$12.99

VIRTUAL REALITY IN HOUSING AND COMMUNITY PLANNING

March, 1996

by

John Thurston, Ph.D.

1994/95 Expert in Residence

Centre for Future Studies in Housing and Living Environments

One of the ways CMHC contributes to the improvement of housing and living conditions in Canada is by communicating the results of its research. Contact CMHC for a list of available information products on a variety of social, economic, environmental and technical housing-related topics.

Phone 1-800-668-2642 or visit us on the World Wide Web: www.cmhc-schl.gc.ca

Cette publication est aussi disponible en français sous le titre *La Réalité virtuelle dans le logement et l'urbanisme, PF 0204.*

This project was funded by Canada Mortgage and Housing Corporation (CMHC) but the views expressed are the personal views of the author(s) and CMHC accepts no responsibility for them.

ISBN # NH15-129/1996E 0-660-16517-1

Printed in Canada
Produced by CMHC

Canada

PURPOSE

"Virtual Reality in Housing and Community Planning" is intended for professionals involved in the provision of built environments or with the issues surrounding them. The report provides a summary of the field of virtual reality (VR) as it relates to housing and community planning. The range of VR applications detailed in the report suggest a close fit between the capabilities of VR and the requirements of housing and community planning professionals.

The mandate of the Centre for Future Studies is to identify and explore new trends and factors likely to impact Canada's housing and living environments into the 21st century. This research was conducted by Dr. John Thurston during his tenure as 1994-95 Expert in Residence at the Centre. The Experts in Residence Program exposes Canada Mortgage and Housing Corporation (CMHC) and the broader housing community to new ideas and perspectives. Experts in Residence are provided with the academic freedom to develop and undertake a research project of their own design that addresses futures-oriented issues related to housing and community planning.

ACKNOWLEDGEMENTS

I appreciate the support given me by the Centre for Future Studies in Housing and Living Environments for this project. It has been a tremendous opportunity for me personally. I trust this report validates the foresight of officials at the Centre in deciding to investigate emerging opportunities in applications of virtual reality to the housing and community planning industries.

I would like particularly to thank Denys Chamberland for his recommendations and advice, and Dick Leong for his help and support. Tom Parker kindly gave me his time and insights from his area of experience and expertise, as did David D'Amour. Sharla Sandrock supplied a look at some CAD files and the files themselves.

Many companies and research groups provided video footage and other useful material. These organizations include Superscape, Division, Worldesign, the Center for the Electronic Reconstruction of Historic and Archaeological sites, Colt Virtual Reality and In~Form Interactive. I thank them for their support.

EXECUTIVE SUMMARY

Potential

Virtual Reality provides the user the illusion of inhabiting and interacting with a computer-generated environment or world. VR can open the design process to everyone by conveying large amounts of information in an intuitive way. A virtual experience requires **immersion** in and **interaction** with the virtual environment, but the former may be more important than the latter for architectural applications.

Categories

The categories of VR, corresponding to different display techniques, include **desktop, projection, cab** and **immersive VR**. These different techniques involve tradeoffs between development expenses and various performance measures, including graphics resolution and complexity, system reaction speeds and levels of interactivity. Many of these tradeoffs affect specific applications, and so must be considered early in the development process.

Applications

Current VR research and development on architectural applications is extensive. VR applications are being explored for **education and training** to improve the quality of life of people with disabilities, reconstruct lost sites of cultural significance for educational purposes, and simulate emergency situations for training and testing.

In the area of **design and testing**, VR is used to test, evaluate and modify designs. For example, architects can simulate ventilation, lighting, temperature and acoustics of a building to determine how their designs interact with these variables. Moreover, architects, builders and developers can construct conceptual designs in virtual reality to identify design flaws and resolve these flaws prior to actual construction. One major application of virtual reality technology in this context is testing barrier-free living spaces interactively.

In the **marketing** field, research is ongoing on the potential of VR to illustrate conceptual designs of homes and communities. The computer images generated in VR and its interactive nature make it a powerful and, possibly, cost effective marketing tool to promote unbuilt structures and development concepts. VR also holds the potential as a global marketing tool of Canadian home designs and building expertise.

For **community planning** purposes, VR applications can enhance urban problem solving, and the nature of public interaction. Virtual reality technology enables planners to manage immense amount of information, and recreate complete sites for development, showing new infrastructure and existing buildings and assessing the impact of construction. Perhaps, the greatest contribution of VR technology is its ability to enhance the nature of public participation in the planning process. Proposed changes to current development, as well as new development concepts and plans must undergo a public consultation process prior to approval. VR technology can enhance the public approval process by creating an interactive and instantaneously understandable medium from which the public can evaluate and experience these new designs or proposed changes to current development.

Design

Successful applications depend on the judicious selection of display, tracking and pointing devices, computer platforms, and software. Design decisions must be made on issues of interactivity and immersion, monoscopic and stereoscopic systems, the use of sound, and questions of ergonomics, hygiene and safety. A range of less tangible considerations relate to the concept of "presence," about which a number of hypotheses have been developed.

Future Applications

The technology holds out the promise of true participatory design, to the point eventually of allowing laypeople to change or even generate their own designs. These and many other potential uses of virtual reality are real, but for the technology to fulfill its promise of contributing to the planning, design and implementation of built environments, a high level of computer software and hardware engineering skills must be deployed, along with a commitment of significant research funding.

TABLE OF CONTENTS

CHAPTER 1 - INTRODUCTION

Virtual reality (VR) is the widely-accepted term for a group of computer technologies used to simulate artificial worlds in such a way that those who enter those worlds have the illusion that the worlds actually – virtually – exist and can be inhabited and manipulated from within. Although entertainment and military applications continue to take the lead, VR is being applied in more useful fields like finance, medicine, education, and architectural and industrial design. Indeed, the range of applications with an architectural theme currently under development suggests an especially close fit between the capabilities of VR and the requirements of housing and community planning professionals.

VR in fact can open the design process to those for whom conventional methods of architectural modeling are inaccessible. Successful virtual environments are able to convey a large amounts of information in an intuitive way. The exact dimensions and visual properties of a proposed building or neighbourhood, for instance, can potentially be presented to stakeholders in these projects early in the design process, at the same stage as would blueprints, scale models or computer-aided design (CAD) simulations, but in a way that does not require the interpretive abilities that these other models do.

Architects can use VR as a tool to test their designs for accessibility to those with physical disabilities. Builders can use it to show their houses to prospective buyers before they are built. VR can be used by developers in the approval process to present their proposals to municipal zoning boards. Community planners can explore the features of their neighbourhood designs through VR. These are among the applications currently under development. It should be kept in mind that these applications, when they are realized, will all enjoy the high visibility and aura of the cutting-edge that VR brings with it.

But those wishing to use VR will have to deal with the many misconceptions about it in circulation. The distinctive features of VR are intuitive interactivity and the sense of being inside the virtual world. VR will probably never be able to produce environments that could be mistaken for their real-world counterparts. Photo-realistic graphics or displays stimulating senses other than hearing and sight are not yet possible. For the foreseeable future, virtual worlds will continue to be notably artificial or synthetic. CAD systems, which do not have to meet the requirements of interactivity and immersion, will continue to be able to produce more visually satisfying graphics. Some examples of three-dimensional simulations that do not qualify as VR will be mentioned in the report.

A prominent recent news item on VR concerned the use of it by NASA – long a supporter of VR research and developer of the first head-mounted displays – to train astronauts for the Hubble repair mission. Attracting less media attention but signifying that an industry is solidifying are the frequent reports of alliances between established names in computing and start-ups in the fields of VR, 3D graphics, interactive media and real-time simulation. IBM, Microsoft, Intel, Digital Equipment, Hewlett-Packard and Sun Microsystems are all investing in these fields. The commitment to the future of VR revealed by this business activity suggests that the technologies it involves may become accepted features of mainstream computing, either in stand-alone applications or through components spun off from VR research.

Objectives

The objective of the report is to provide a summary and analysis of the diverse and expanding field of VR, especially for professionals involved in housing and community planning. Chapter 2, "What Are Virtual Environments?," will introduce VR, generally and in its various forms. Chapter 3, "Applications of VR to Architectural Problems," will discuss applications being developed in the fields of architecture and the built environment generally. Chapter 4, "Tools and Issues Specific to VR," will provide a basic grounding in the components of VR systems and in some of the issues to be considered in designing virtual worlds. Chapter 5, "Future Applications of VR in Housing and Community Planning," will speculate on the uses of VR in the provision of barrier-free housing and the areas of urban planning and neighbourhood design.

Audience

The intended audience of "Virtual Reality in Housing and Community Planning" is anyone professionally involved in the provision of built environments or in the issues surrounding those environments, or anyone for whom the built environment is itself an issue. Housing professionals – architects, builders, engineers, planners, developers – anyone who has ever used architectural modeling of any sort, whether blueprints, cardboard or computer graphics, should find something of use in this report. Medical, public safety, regulatory and emergency response professionals will find examples of how VR has been used to help ensure that their concerns about features of the built environment are met. This report may also be of interest to active housing consumers, especially those for whom such matters as wheelchair clearance of a hall or door, lighting on a footpath in an urban park or line-of-sight at a busy intersection are issues.

Information for this report was gathered from hands-on evaluations of software and hardware, as well as from many contacts with researchers and developers, producers and suppliers. A good deal of material was collected by researching the growing literature – periodical and book – on virtual reality. The Internet, a natural source for finding the cutting edge of VR research, has also been resorted to extensively. The bulk of research was completed by March 1995. While some projects that have surfaced since then are discussed, no attempt has been made to update the body of research.

CHAPTER 2 - WHAT ARE VIRTUAL ENVIRONMENTS?

Public attention to virtual reality has concentrated on its entertainment potential, either as content in movies like Lawnmower Man and television series like VR5 and Tekwars, or as the next generation video game. There are, however, many projects to develop serious uses for the technology in areas like training, medicine, education, design and architecture. These projects highlight VR's ability to allow us to explore information physically. This chapter will discuss the features of virtual environments technologies that enable this capability.

Definitions

Scientists and researchers prefer alternatives to the common term, VR, which they tend to associate with games only. Participants at a American National Science Foundation Invitational Workshop on the subject in 1992 decided on the term "virtual environments for accuracy of description and truth in advertising" (Bishop et al 1992, 156). Robert Jacobson, a leading developer of the technology, "never refer[s] to 'virtual reality,' a dubious term, but prefers the use of the scientific term ... 'virtual worlds'" (Jacobson 1994d 68). This report will exploit the nuances in the range of terms.

The most general definition of virtual reality is that it provides the user the illusion of inhabiting and interacting with a computer-generated environment or world. The participant in a virtual environment (VE) experiences a sense of **immersion** and has a range of **interaction** with the VE open to him or her. While other types of computer interfaces provide one or the other of these qualities, only VE technologies offer them both – at least in theory – and in **real time**, that is, with no delay between action and reaction.

The requirements for real time interaction and for complex, three-dimensional graphics place an enormous demand for rapid processing power on all parts of the VE system. Many computer-aided design (CAD) packages allow for some types of movement and interaction with the designs they produce, but the results of these actions can take hours or days to render. Delays even of milliseconds between action and appropriate response, while no system is without them, can dramatically limit the success of a VE application.

At the Center for Landscape Research, School of Architecture and Landscape Architecture, University of Toronto, software developed for providing an intuitive design environment is considered to be very fast when it can render complex environments at 0.5 seconds per frame on

Definition of VR from the America On-Line VR Centre Frequently Asked Questions (FAQ) file:

"Virtual Reality is a combination of hardware and software that allows you to see, move around in and manipulate computer graphics. ... There are two basic components that a TRUE virtual reality program MUST contain: 1) A first-person viewpoint that has complete movement at will in real time; 2) The ability to manipulate and/or change the virtual environment in real time."

"VR can also be defined as a computing environment where the computer screen disappears and you are manipulating computer objects directly. You are experiencing and interacting with a 'simulated Virtual World'. This world is not pre-recorded, it is generated on-the-fly by the computer."

high-end dedicated graphics processing computers. The acceptable rate of rendering for VR systems is 15 frames per second.

Users enter virtual environments through a range of interface devices and imaging technologies. Sub-categories of virtual reality have developed that correspond to different display techniques.

Desktop VR

Desktop VR uses standard computer monitors to display what are sometimes called 2 1/2 D worlds, because they use perspective to suggest a third dimension on a two-dimensional screen. This method is occasionally referred to as "window on the world VR."

Desktop VR can be made more fully three dimensional with **shutter glasses** – looking like bulky, box-like sunglasses – that rapidly occlude the vision of either eye in synchronization with a display alternately showing left and right eye views. The brain then synthesizes these alternating views into a 3D picture.

Head-Mounted Displays

The next level VEs use a head-mounted display (**HMD**) to fill the user's field of view with the display, while blocking out all other views (see figure 1). Small liquid crystal display (LCD) screens are mounted directly in front of the eyes or in more expensive versions side-mounted cathode ray tubes (CRT) are reflected into the user's eyes. The use of HMDs is sometimes equated with "immersive VR," but immersion is not restricted to this technique.

Figure 1
Head-Mounted Display

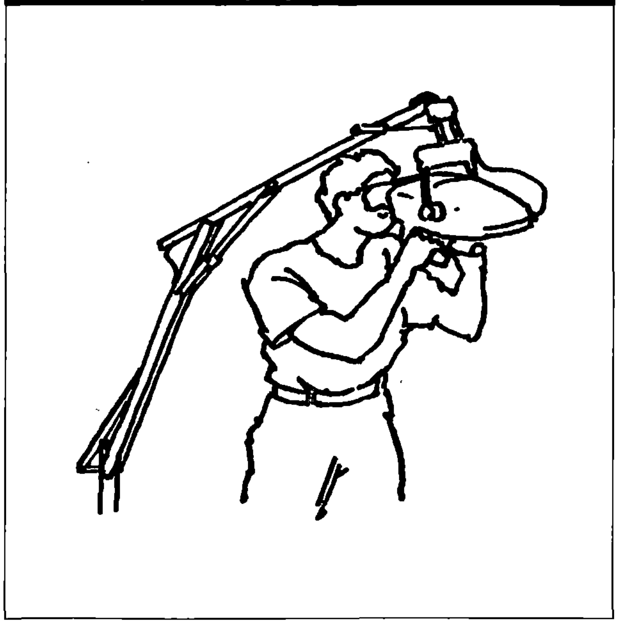
A **head-coupled display** is like an HMDs that is not attached to the head, but suspended on an articulated arm (see figure 2). The user pulls the display to his or her face like a submarine periscope. These displays are particularly suited to professional environments, but only two companies currently supply them and they are more expensive than HMDs, costing over US $10,000. Head-coupled displays that are mounted on desktop pedestals have recently been developed.

The only differences between fully immersive and desktop systems are in the display and level of tracking of the user. Many software packages can be used in either type of system, and applications developed for the desktop can often be ported to an immersive system.

Projection VR

Computer Automated Virtual Environments (**CAVE**), pioneered at the National Center for Supercomputer Applications, University of Illinois, achieve the illusion of immersion by

Figure 2
Head-Coupled Display



projecting portions of a VE on to at least three but as many as all six of the inside surfaces of a cube-shaped room (see figure 3). Shutter glasses can also be used with this technique, which is often called "projection VR."

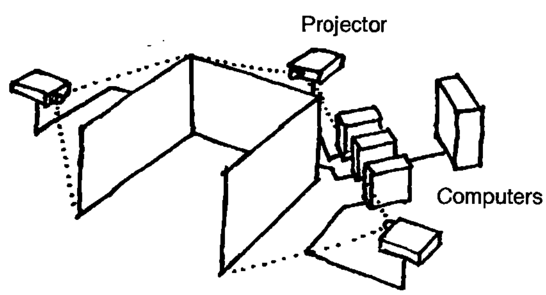
The CAVE method of projecting virtual worlds on surrounding screens is one of the most expensive and specialized types of VR, although it has the most exciting potential for architectural simulations that would benefit from the shared experience of participants in a social environment (see Rourke 1994).

Another kind of projection display method uses the windows of a vehicle cabin. **Cab VR** is particularly suited to location-based entertainment (LBE) installations, but could also be used to train emergency vehicle drivers or to test street plans for the safe passage of emergency vehicles.

Artificial and Augmented Reality

Artificial reality is closely associated with the work and writing of Myron Kreuger on video image capture techniques that place a representation of the user in an environment, providing a form of second-person interaction. This type of system has been successfully marketed by the Vivid Group of Toronto.

Figure 3
Computer Operated Virtual Environment (CAVE)



In some training applications it is useful to allow the user to see through the computer display to the actual world. **Augmented reality**, as it is called, is achieved by projecting the display on half-silvered mirrors situated directly before the user's eyes.

Expense and Performance

Expense is one of the main determinants in decisions about what type of virtual environment to develop. As degrees of immersion and interactivity increase, costs – mainly for processing and graphics rendering power, but also for display equipment – increase exponentially. But **consideration must also be given to the specific demands of the application in mind.** The level of interactivity in an architectural simulation, for example, does not need to be as high as for an adventure game.

Immersion and interactivity, to whatever degree they are obtained, define the VE interface. The sense of immersion is achieved through a range of hardware and software techniques. Display techniques have been mentioned, but the content of the display has to be as three-dimensional, detailed and smoothly flowing as is possible. Three-dimensional sound is also very important for enhancing the illusion of immersion.

The lowest level of interactivity is user control of a simple walkthrough. The next level allows objects in the world to be manipulated. The ideal level of interactivity – yet to be achieved – will allow a user to manipulate all of the features of the world and have changes made to them while he or she is still in the environment. This level of interactivity is especially important for design and architectural applications, and holds out the possibility of the real-time design of products or structures from within simulations of them.

VR and Architectural Data

VR is in effect the visual representation of data. This data can be numeric, abstract, conceptual or representational. The specifications for a house, for example, are only data, but they can be presented in various ways, from blueprints to scale models. A VR presentation of the database of a house would be in 3-D computer graphic form, with analogues for physical attributes like mass, volume and lighting, and would thus be a close approximation in strictly visual terms of what the house would be when transformed from plan or data into matter or actual building.

It is generally easier to process data that can be represented by straight lines and angles, so architectural environments are a natural fit with virtual environments. Architecture is usually one of the first areas listed for commercial applications of VEs, since it is a profession where "inherently spatial and environmental information has been represented in abstract 2-D drawings" (Good and Tan 1993 59). Thomas Furness, who has been researching VEs for over a decade at the University of North Carolina, writes that few applications are "as obvious as the simulation of architectural spaces" (Henry and Furness 1993 33).

The media have been largely responsible for a number of misconceptions about VR. At this point, **the graphics produced by all but the most expensive systems are cartoon-like.** One research group has concluded that "any mapping with 'reality' in current desktop VR is not so much in the quality and accurate representation in the graphics, ... as in the sense that the user is moving in, through or around the world" and is able "to manipulate and interact with the world in real time" (Cobb et al 1994 402).

Researchers recognize that they will have to convince industrial users that VEs can do things that conventional CAD models cannot and that those things are worth doing. Enhanced interactivity may not always outweigh the disadvantage of lower quality graphics. Recognizing that CAD will be a major catalyst to the VR industry, one commentator predicts that "VR will cause the CAD industry to grow in a myriad of other directions" (Pate 1995 67). Another optimistically writes that "software developers expect this technology to replace traditional two-dimensional CAD software" (Barker 1994 58).

Nonetheless, 3-D CAD applications developed in such institutions as the Centre for Landscape Research at the University of Toronto, the School of Architecture at the University of British Columbia and the Department of Urban and Rural Planning at the Technical University of Nova Scotia are impressive in themselves, while pursuing other goals than those associated with VR.

The Search for a New Paradigm

Researchers involved with these technologies are searching for a new paradigm that can produce an accurate conceptual framework for them. Conceptual models borrowed from CAD, 3-D graphics, computer games or graphical user interfaces (GUIs) cannot fully account for the features of virtual environments.

"We must look for the new paradigm and put aside our old conceptions of what computers are and what they do. ... The computer is a communications medium. Virtual reality provides new, better ways to communicate," writes Ben Delaney (1993a 17). William Bricken, an educator and one of the chief researchers at the University of Washington's Human Interface Technology Lab, has complained that "designers are bringing the assumptive baggage of the world of mass into the digital world ... Information is not mass; meaning is constructed in the cognitive domain. Psychology is the Physics of VR" (Liang 1993 392), he asserts.

A recognized "philosopher of cyberspace," Michael Heim suggests that "VR may be signaling a new relationship we have to technology in general" (1993 142). This new relationship points to a growing physical intimacy with technology, which could lead to our ability to explore information physically, with our bodies. While a theoretical tangent, this discussion intersects with practical research now proceeding on interface designs for assistive devices for people with disabilities, designs intended to allow people with limited co-ordination or mobility to interact with computer technology. (See Vol. 3, No. 3 of Presence, collecting papers from the 1993 Virtual Reality and Persons with Disabilities conference.)

The ability to transform our physical being into a virtual being, the characteristics of which we are free to choose, has led some researchers to assert that "virtual reality is inherently barrier free" (Barry et al 1994 208). Among all the convergences this technology heralds, the most significant may be the convergence of research on virtual environments and on the built environment with research on the needs of people with disabilities in both.

An Architectural Paradigm for VR

One attempt to conceptualize the essential features of this technology uses an architectural metaphor: "A new paradigm for developing applications in the 3-D environment must be defined in order to open the VE wilderness for development. ... Virtual architecture uses the principles of physical architecture to define virtual worlds." (Frerichs 1994 50). Researchers on the virtual architecture project tried to capitalize on "the user's natural sense of 'space' and 'place'" to "develop worlds that generate instant recognition of their purpose in the user" (51). The developer's interface for this project consists of an architectural simulation in which rooms, doors, windows and other features represent different ways of interacting with the application.

Summary

VR by definition, then, requires immersion and interactivity. Varying degrees of these qualities can be obtained using different display techniques, the main ones being desktop monitor, head-mounted displays, projection techniques and artificial reality. The greater the degree of immersion and interactivity, the greater the expense, but architectural applications could do without a high level of interactivity. Architectural applications would seem especially suited to VR, but VR will have to surpass CAD systems in key ways if it is going to gain widespread acceptance. One of the most crucial ways it may surpass CAD is by enabling the physical exploration of data.

CHAPTER 3 - APPLICATIONS OF VIRTUAL REALITY TECHNOLOGY TO ARCHITECTURAL PROBLEMS

As a relatively new and hot field, there are many companies claiming to be able to do wonderful things with virtual reality or trying to associate their more conventional offerings with this technology. This chapter will present projects and applications with an architectural or built environment theme that from a critical standpoint seem likely to deliver on their promise. For the most part, these projects set out to provide immersive environments with which users can interact in real time. Some of the projects discussed have already borne fruit and many of them are related to the applications speculated upon in Chapter 5.

Many of the companies or research institutions included in this discussion are working with substantial resources and often have not yet passed the research stage, but most have a mandate to make their products or services more widely available and readily useful. The technology will need to achieve broad market penetration if it is to have the impact its developers believe it should, and commercial VR enterprises are to survive.

VR businesses do already exist, although largely as consulting firms supplying custom applications on demand. A number of multinational manufacturers are developing VR design facilities. These projects bridge the divide between research and development, while projects exploring the uses of VR for education and medicine are more thoroughly research-based. Other applications of VR technologies for marketing, training and scientific visualization are being explored.

This chapter will focus on current research on applications of virtual reality technologies to architecture, the field that may lead in the adaptation of these technologies for practical, professional purposes. The discussion of these applications will be organized under the headings of **Safety and Training, Building Design and Testing, Marketing and Development** and **Neighbourhood Planning and Urban Regeneration.** More detail will be provided on companies and research institutions that are working in areas especially pertinent to housing and living environments. Key issues will arise out of the discussion of these applications.

Safety and Training

Industrial Operations

Telepresence, or the control of robots through a virtual reality interface, holds out great promise for **research or industrial operations in remote, hazardous or low visibility sites.** In 1992, Fujita, Japan's largest construction company, contracted two California VR firms to work on a telepresence project to compensate for a shortage of human inspectors to cover the company's construction projects around the world (Churbuck 1992 486, Emmett 1992 48). Bechtel Corporation, a huge San Francisco construction and engineering firm, redesigned a crane for remote operation with VR technology. Engineering managers at Bechtel foresee the day when VEs will supply an intuitive interface for the remote control of a fleet of machines operating at the construction site (Jacobson 1994a 50).

Emergency Simulations

Virtual environments are also being used **to present simulations of emergency situations for education and training.** A Toronto company, 3Space, in collaboration with the North York Fire Department, is creating a low-cost simulation of a burning apartment building for public safety education. 3Space has also presented tutorials on the potential of VR for the North York Board of Education. Colt Virtual Reality Ltd., part of the Colt Group of England, has developed a package to simulate the reactions of crowds to emergency scenarios in built environments and determine the affects of changes in, for example, door width or location. The Colt software, VEGAS (Virtual EGress Analysis and Simulation), takes into account both physical variables, including the

Some existing applications of Virtual Reality

Entertainment and marketing

Straylight, New Jersey: built 26-seat VR theatre for CableTron, touring simulation for Cutty Sark

CyberMind, California: built entertainment installation for CN Tower, VR attractions for Blockbuster Video

Virtuality, England: built installations and sold turnkey entertainment systems world-wide

Disney Corporation: hired engineers from several VR companies to develop multi-million dollar Aladdin simulation

Design and manufacturing

Chrysler, Michigan: began developing a system with IBM in 1991 that could become a routine part of design process

Boeing, Washington: has been using VE technology for design since early 1990s and is developing systems for training

British Virtual Reality and Simulations Initiative: demonstrated simulations for Vickers Shipbuilding and Rolls-Royce Ford, GM, Volvo, Gulfstream, McDonnell Douglas, AT&T and Sharp are among others trying out virtual design technologies

Education and medicine

The Shepherd School, England: exploring use of VR to educate children with severe learning difficulties

The Computer Museum, Massachusetts: sponsored study comparing teaching in VEs vs. non-immersive, passive environments

High Techsplanations, Maryland: developing simulators for medical training, especially for laparoscopic surgery

Greenleaf Medical Systems, California: using VE tracking devices for stroke-injury rehabilitation, sports medicine

fluid dynamics of the flow of smoke and toxins, and psychological variables, including those linked to mobility.

VEGAS runs on a standard personal computer. Not all possible variables can be considered with these limits on processing power and there are questions about how accurate the simulation can be. Colt is continuing to consult with clients and develop validation techniques to improve the accuracy of the software. One of their main clients, CrossRail, is using VEGAS in the development of designs for railway stations that will be built in central London starting in 1996 (see Brister 1994). For higher quality visualization of building interiors, Colt is developing software that will be able to represent ventilation design using computational fluid dynamics and illumination systems using advanced radiosity techniques.

Fluid Dynamics

Similar to this work at Colt, but further developed and using custom-configured high-end machines, the Living Environment Systems Laboratory is a joint project of Division Ltd., based in England,

and Matsushita Electric Works, based in Japan. Their goal is to integrate computational fluid dynamics and immersive virtual environments **to provide building designers with an accurate simulation of air conditioning and ventilation, lighting, temperature and acoustical characteristics**. There are plans to provide a system in which customers can experience their own home or office, with proposed modifications virtually in place.

Archaeological Sites

The Center for the Electronic Reconstruction of Historical and Archaeological Sites (CERHAS), a computer imaging laboratory at the University of Cincinnati, is **reconstructing lost architectural sites of cultural significance for educational purposes**. They have produced walkthroughs of archaeological sites in Greece and the interior spaces of early American houses. Benjamin Britton, assistant professor of fine arts, has directed the one fully immersive and interactive VE project at CERHAS, a reconstruction of the caverns and prehistoric paintings of Lascaux, France (see video). He has also collaborated with programmers to assemble a Virtualized Architecture Design Engineering Resource, an authoring system for non-programmers.

Initially developed on PCs, Britton has created a museum installation of the Lascaux Caves project using donations of high-end hardware. One user enters and interacts with the virtual world through a head-mounted display. A second room is set up with a monitor upon which an audience can passively and non-immersively follow the movement and actions of the immersed participant (Baggs 1994). The walls of the caves are texture mapped for increased realism and the sense of an interior architectural space is convincing. Britton appreciates the sense of the VE's presence that the fully immersive interface enhances, an affect interactivity also has. When the visitor focuses on one of the cave images, the image dissolves and a full motion video of the animal depicted plays.

The Lascaux Caves project again demonstrates the close mesh that can be obtained between built environments and virtual environments. Since the real caves are closed to the public, the technology provides people a facsimile of an experience otherwise denied to them. While it is unlikely that virtual environments are going to get much share of the tourism market in the near future, they could be used **to provide experiences of distant or inaccessible sites to seniors and people with disabilities.** This application is particularly significant for the way it gives new meaning to the concept of VR by finding a hitherto unimagined but nonetheless compelling use for it.

People with Disabilities

Judged by the number of projects in this area, another compelling use for VR is **to train people with disabilities in the use of wheelchairs**. At the Oregon Research Center, Dr. Dean Inman has since 1993 been researching such applications. Inman's VEs provide mobility training for children with cerebral palsy. While they need to develop the upper body control necessary to operate motorized wheelchairs, these children have to learn to operate them safely before they can be insured. In many cases they must first acquire the basic motivation to do anything for themselves, since their disability may have made them completely passive and unwilling even to attempt to move.

The Center has completed three virtual training scenarios. One contains a black and white tile floor and nothing else, and is intended to get the children simply to move. The second world contains obstacles and stations with interesting things happening, and its purpose is to encourage exploration. The final scenario, a simulation of a marked pedestrian street crossing, will train disabled children to cross the street on their own.

The Center's system uses a wheelchair mounted on a treadmill, designed on-site, and a head-mounted display. Although the graphics in the simulations are primitive, Inman suggests this need not harm the effectiveness of the training. He nonetheless identifies low frame-rate, system lag and resolution as problems. He remains convinced that "VR is a technology that can assist children who are born with problems, who never enjoy independent mobility ... It will give them a chance to experience more, learn more, and be more productive" (Buckert-Donelson 1995 26).

Virtual Therapy

Scientists at the Ohio State University Supercomputer Center have also created a system that allows power wheelchair users to drive through simulated architectural environments. Through the Virtual Wheelchair Project, architects will test their designs for accessibility, people with disabilities will be trained in the use of power wheelchairs and health care professionals will assess their proficiency. The University of Daytona, in co-operation with the regional transit authority, is similarly working on a project to train students with disabilities to use public transit, substituting VR bus rides for the real thing.

Some recent studies suggest that **certain psychological disabilities may be amenable to treatment using virtual environments.** At Delft Technical University, the Netherlands, Rob Kooper documented the affect of virtual reality Graded Exposure therapy for people with acrophobia. Subjects were treated using three different virtual environments of increasing challenge, including an operating glass elevator. Kooper observed reduced fear of heights in his test group, some of whom later exposed themselves to real height situations. He believes all phobias treated using Graded Exposure can be treated in VEs.

Dr. Ralph Lamson of the Kaiser-Permanente Medical Group, California, in 1994 also demonstrated that virtual environments may be useful in treating acrophobia (Morkes 1994, Latham 1994). Subscribers to Kaiser-Permanente health insurance volunteered for this study. As in Kooper's study, readings of physiological signs during "virtual therapy" showed that the participants experienced the stress and acute anxiety associated with actual encounters with heights. "A part of you knows it's not real," Lamson has said, "but another part doesn't, because it's so immersing ... It's real enough to scare them but not so real that it overwhelms them" (Hamilton 1994 19). The virtual therapy appeared to allow participants to confront their phobias safely, yet successfully. After their therapy, 90% of the volunteers met self-assigned, real-world goals ranging from cleaning leaves from a rooftop gutter to ascending in a glass elevator.

Although preliminary, the results from Lamson's and Kooper's studies have far-reaching implications for attempts to establish the reality of virtual reality. That these experiments in virtual therapy used virtual architecture to establish the sense of height once more points to an inevitability in the linkage of virtual environments and built environments. More practically, they forecast the use of VR **to improve the quality of life of people whose mobility is impaired due to psychological as well as physical factors.**

Transfer of Learning

The potential of the technology for such tasks as training emergency personnel for crisis situations, teaching people with disabilities to operate power wheelchairs or providing virtual therapy for acrophobics relies upon positive answers to questions about **the transfer of learning achieved in virtual environments to real environments.** The Institute for Simulation and Training at Central Florida University in Orlando, in co-operation with the Army Research Institute, has set up a Virtual Environments Test Bed to seek empirical, verifiable answers to questions about the use of virtual environments as training tools.

Researchers at the Institute are attempting to measure human cognitive abilities in computer-generated environments, ranging from basic perceptual abilities to more complex skills like navigating through a labyrinthine office building. One phase of their experiments uses an architectural simulation. Having built a virtual model of their office building, researchers are trying to determine whether experience gained from navigating through the virtual building can be translated into real-world knowledge. Can the knowledge of routes gained in the VE be transferred to navigation of the real building? Can the mental image the user acquires of the virtual labyrinth be mapped onto the corridors of the real building?

Preliminary results gathered at the VE Test Bed are promising, but further testing is proceeding. One future project will model an extensive outdoor environment and incorporate advanced dynamic terrain features. Applications developed for that project will also test the suitability of virtual environments for such large-scale applications as neighbourhood design.

Building Design and Testing

Testing Barrier-free Buildings

The various projects to train wheelchair users in virtual environments demonstrate the potential of the technology to enhance the lives of people with limited mobility. This potential is also manifest at the design stage, where systems have been used to ensure the compliance of building designs with the Americans with Disabilities Act (ADA). Building design and testing is one of the main areas where VR applications are being developed.

Prairie Virtual Systems, Chicago, markets Wheelchair VR, a system for **the interactive design and testing of barrier-free living and work areas**, co-developed by Dr. John Trimble in 1992 while he was research director at the Hines Rehabilitation Research and Development Center. Users enter fully immersive virtual environments by moving their wheelchair onto rollers. They are able to assess the accessibility of various design configurations and make adjustments as they see fit. CAD files are used to construct the virtual buildings and alterations made by users to the buildings can be copied back to the CAD files in a form architects can use, complete with specification sheets listing necessary components.

The system was initially tested in conjunction with an architectural firm building a complex to enable people with limited mobility to live independently. An evaluation team of wheelchair users tested the virtual apartment and then the real one. Upon experiencing the real apartment, users are reported to have said they felt as if they had been there before. Designers and architects can use Wheelchair VR **to improve their understanding of the needs of wheelchair users by experiencing the problems they encounter in everyday environments.**

The architectural firm of O'Donnell, Wicklund, Pigozzi and Peterson, specialists in institutional health care design, used the Wheelchair VR system to test their original plans for the 140-room Copley Memorial Hospital in Aurora, Illinois, in the summer of 1993. They discovered that the sinks jutted out too far and would prevent someone in a wheelchair from reaching the faucet handles. Fixing all of the sinks after construction would have cost $56,000, while running the model cost only $10,000.

Another product from Prairie, the Virtual Workstation is a tool for designing work environments. Users can try out dozens of office layouts to assist them in space planning and interior design. Prairie does not offer turnkey systems, but configures them to customer specifications, and with added consultancy expenses their services can easily cost in the six figures. The company does, however, establish the commercial viability of VR for architectural applications to provide for the needs of people with limited mobility.

Building Design

As with the Copley Hospital, **the ability to test virtual buildings, identify design problems, resolve them prior to actual construction and save money** is one of the greatest attractions of applications of VR to architecture. In 1992 computer scientists at the University of North Carolina, Chapel Hill, "built" their new building in a VE, found a wall out of place and changed it before physical construction began. Researchers at UNC are also looking at techniques for designing directly in three-dimensional space, as is the Virtual Environments Group at the Georgia Institute of Technology, Atlanta. Students in the College of Architecture will create conceptual buildings, and inspect and modify their designs while immersed in the virtual world. The Group has created or refined a large number of tools and interface elements intended to make design in their virtual environments interactive, intuitive and direct.

Designers at Hastings College, England, have also proven the usefulness of VR in the redesign of the College's library to provide improved access for more students. Running on an integrated system from Division Ltd., the virtual walkthrough of the library revealed congestion problems, missed by conventional space and capacity planning, and allowed the design to be modified and re-tested to confirm that the problems had been eliminated. The simulation also provided **a means of presenting a range of design possibilities to senior management and of quickly accommodating and representing modification requests.**

Douglas MacLeod, an architect by training and director of virtual environment programs at the Banff School of Art, sees in "cyberspace ... a tremendous new design opportunity for architects." He tends not to credit the "experts" who "feel that architects will never really be players in this field because they lack the necessary capital to purchase even the most basic equipment" (MacLeod 1994 32). In a recent program at Banff, Lawrence Paul, a Salish native artist, produced a virtual sweat lodge that has been exhibited at the National Gallery and internationally. This simulation of a ceremonial structure was created and run on "basic equipment," suggesting that architects may not need high-end hardware to use VR for design.

The Virtual Reality Demonstration Centre of Germany's Fraunhofer Institutes has modelled a number of public buildings (Segura 1994 32). Work on the Presidential Office of the European parliament was done with a furniture manufacturer and users can select and customize items in a graphical database of the manufacturer's products (Kloss 1994 29). Art+Com, another German group, has developed a VE application to design virtual buildings and visualize art exhibitions that have yet to take place. It enables city planners and architects to walk through realistic virtual rooms, interact with them and evaluate light sources. Researchers with Art+Com are trying to determine whether feelings about virtual rooms are confirmed in the real room when it's built (Emmett 1992 46). The intention in developing such systems is **to support an iterative planning process carried out interactively with the user**.

The Human Interface Technology Laboratory (HIT Lab) at the University of Washington was established in 1989 to transform VE concepts and early research into practical, market-driven products and processes. With funds from various public and private sources, including over 25 companies in a Virtual Worlds Consortium, the HIT Lab performs basic research and develops applications for transfer to industry. Since building Virtual Seattle in 1990, the lab has continued to develop and evaluate architectural and urban planning applications of VE technology.

Early in 1995, as part of the intercollegiate Virtual Design Studio project, architecture students at the HIT Lab connected to their peers at the University of British Columbia and held **a joint design simulation session, proving the possibility of remote co-operative work in a VE**. A high-end graphics workstation was used to manipulate 3-D models over the Internet by students 300 miles apart. Students at the HIT Lab transferred 3-D files from UBC, simulated the design proposals in real-time and then broadcast flythroughs back to the studio at UBC for their evaluation.

The Virtual Design Studio at UBC grew out of the Electronic Design Studio, the vision of which is to integrate new technology into the design culture and extend traditional CAD through the use of the latest communications developments. Another Canadian school of architecture, at the University of Toronto, is exploring cutting-edge CAD to integrate the necessary areas of knowledge and landscape representation in one computational system. The Centre for Landscape Research (CLR) at UofT has developed PolyTRIM, a toolkit combining a range of data types, including VR, and made it available to researchers over the Internet. Their fundamental premise is that **spatial language must be supported in a computational medium accessible to everyone in order for intelligent environmental decisions to be made**. Visualizations produced at CLR can be viewed at their Internet site using CLRMosaic, a 3-D browser. But the browser and PolyTRIM are as yet only accessible to users with Silicon Graphics UNIX workstations.

The HIT Lab at the University of Washington co-ordinates the Community and Environmental Design Simulation Laboratory (CEDeS) with the College of Architecture and Urban Planning. The CEDeS Lab will utilize immersive technologies like virtual reality for design and simulation of real and virtual worlds. Hardware and software has been purchased and a simulation of the Seattle Commons created and made available on the Internet as an MPEG video file. When fully operational, the CEDeS Lab will use design facilities at the College of Architecture and simulation facilities at the HIT Lab, the two connected by fibre-optic cable that will enable real-time simulation during the design process. The CEDeS Lab will be open for research and education to public and private organizations involved in the design of communities and environments. It is intended to encourage **the ongoing integration of VR with the design and planning professions.**

At North Carolina State University's School of Design a Virtual Environments Laboratory has been set up that will similarly encourage this integration by developing software **to support the focus on design of architects.** The lab is under the direction of Rick Zobel who has collaborated with Robert Jacobson, formerly a director at the HIT Lab, on a proposal for a Virtual Design Environment to provide regional planners with tools to model and understand the evolution of urban spaces. This ambitious proposal has yet to get acted upon.

Zobel's graduate work compared the various media through which viewers could experience representations of architectural spaces. He assessed static perspectives, physical models, non-interactive video, interactive screen-based walkthroughs and immersive environments as to their success in providing the illusion of moving through an architectural form. He found that virtual reality compares favourably with traditional media. He predicts that as hardware price / performance ratios improve, VE technologies will break into architecture, driven by the demand of clients to gain a spatial understanding of architectural projects. "We need to understand more about how space is perceived and what it means to design at full scale and in three dimensions instead of two," he has said (Novitski 1994 125).

Through the School of Design's VE lab, Zobel has shifted his focus to the design process. Design-based VR will be driven by **the architect's need to manage and refine the immense amount of information that goes into a structure that meets today's codes, costs and client demands**. The technology will allow designer and client to communicate in a shared visual language, so to understand for themselves and to help others understand exactly what they are trying to say with their design. Zobel hopes that through the integration of a variety of information and intelligence augmenting technologies with VR, "the design process will become a greater portion of the overall project, and thus bring the art back into architecture as the primary goal of the architect" (email to author, October 1994).

Marketing and Development

If virtual environments can be used to design and test built environments before construction, a logical extension of this capability would be **to market and promote unbuilt structures and developments through virtual environments**. Not surprisingly, there has been and continues to be a great deal of activity in applications of VR in this area.

Matsushita Electric Works began as early as 1992 to use VE simulations to market kitchen appliances. British Gas is currently using desktop VR to allow customers to visualize kitchen designs and experiment with layouts, units and colours, while exploring the ergonomics of their designs. Even though they are using high-end machines, the company developing this application does not believe that immersive technology can yet deliver high enough image quality. They hope to create a portable visualiser that can be taken to customers' homes.

Matsushita, a multi-national conglomerate with a wide range of activity and an extensive research budget, has gone on to collaborate with Division on more ambitious projects, including the Living Environment Systems Laboratory discussed above. They have also produced a demonstration model of a complete two-story Japanese house, with fully detailed interior. The virtual house is furnished from a graphics library of Matsushita products. This immersive walkthrough also simulates lighting and acoustics, and allows the user to view design choices, open closets and drawers, move furniture and turn on taps. Matsushita intends to use the simulation in showrooms.

VR is being used to market more specialized products as well, including those requiring **layout of special features and equipment within buildings**. Amsco International is using it to sell hospital decontamination and surgical equipment. Interactive custom layouts of its equipment are designed and documented by Amsco's system designers, then sent to outside sales staff on diskette. Presentations typically allow customers to visualize better the design and so shorten the decision-making process. From a library of pre-programmed equipment, Amsco's designers and sales staff create interactive presentations without having to become VR specialists (O'Connor 1994 27).

In a similar vein, In~Form, a Toronto company, in 1994 debuted a virtual reality simulation of an automated clinical laboratory for Autolab Systems, a division of MDS Health Group, Canada's largest medical laboratory. The simulation is used to familiarize prospective customers with Autolab's expertise in laboratory automation. It has been shown at trade shows and conventions, and can be taken to customer sites less expensively than bringing customers to the MDS laboratory.

Procos Architecture and Planning of Halifax has exploited software related to VR to present performance simulations of its passive solar energy project. The company used QuickTime VR (QTVR), an offshoot of Apple's QuickTime video standard and software, which does not offer immersion and interactivity but is an effective way to present CAD designs. Atelier d'Architecture Imagine in Montreal has also done QTVR presentations, in its case of 3-D computer models of Montreal as part of its Virtual Cities Repository. Imagine has done 3-D presentations for new projects, bylaws visualizations and promotional purposes. Design Vision in Toronto has done similar work to bring proposals for changing public spaces to the public through 3-D simulations that are output as video to be shown on information kiosks. Design Vision has used videos to focus interactive design review sessions and move them forward to final design concepts.

VR is being used to fund-raise for reconstruction of public buildings. Scientists at Research Triangle Institute, North Carolina, have built a VE model as part of a project to rebuild Dresden's Frauenkirche, destroyed during World War Two. The model is intended to help generate enthusiasm for the church, which will be reconstructed largely with private funding. First displayed at a German trade show in March 1994, more than 14,000 people 'visited' the church, voted the best exhibit of the show. In order for so many people to see the model, groups of 40 at once were accommodated. Only one spectator was immersed in an HMD, while the others wore stereoglasses and watched on a large projection monitor (Keppler 1994 49).

Opportunities

Apart from architectural firms like Procos of Halifax and Imagine of Montreal that are using technologies coming out of VR research, there are a growing number of VR consulting firms trying to cash-in on the natural fit of VR and architecture by designing tools for the visualization and marketing of unbuilt structures. These include Interactive Business Computers Inc. and Synthetic Environments Inc., both of Ottawa, FIVE (Full Immersion Virtual Environments) Inc. of San Antonio, Texas, and Xtensory Inc., with offices in California, Massachusetts and Minnesota. Xtensory specializes in participatory design consulting, involving end-users of their VR systems from the beginning of the design process. They have produced **a mass and spacing simulation of Milwaulkee for a real-estate developer trying to obtain city approval for a mall.**

AVR (Applied Virtual Reality) Corporation, Toronto, founded in 1994 as a Canadian resource for information, education, research and technology acquisition, lists architecture, urban planning and realty development as industries they can serve. AVR is currently seeking collaborators on a project to develop a marketing tool for a realty company selling Canadian condominiums to Hong Kong buyers. AVR is facilitating this project, hoping to acquire the necessary software and hardware expertise and equipment through its collaborators. The project points to the potential of VR as **a global marketing tool, perhaps using a database of Canadian home designs and building expertise.** The experiments at the School of Architecture, University of British Columbia, and the Centre for the Landscape Research, University of Toronto, among other places, suggest that the tool could someday use the Internet as a delivery medium.

At least one architectural firm is itself getting into true VR development, for itself and other industry partners. Mike Rosen and Associates, Philadelphia, plans to put VR to work as a tool for builders, home-buyers, real-estate agents and architects. A Pennsylvania developer is expecting **to use a desktop system from the company to**

walk customers through homes in its next subdivision. Rosen's preliminary demonstration space features a furnished kitchen and conference room. "We can create a model of a complete house this way," Rosen claims. "You'll be able ... to see what it looks like from the street or in the context of the neighborhood" (Austin 1994 C3). He recognizes, however, that the expense of virtual reality at present is prohibitive for small companies. His company may organize a demonstration space, to be set up in a mall or other public place, where a number of builders could pool their resources and be represented.

Dutch builders have used a similar solution on a larger scale to exploit the marketing potential of VR. The Computer Applications Laboratory in Building Research and Education Institute at the University of Eindhoven, the Netherlands, developed a project for a Dutch association of 300 companies in the building trades. The Institute **constructed virtual models of a number of unbuilt houses – interiors and exteriors – to show prospective buyers at a new housing development.** This marketing tool could be further enhanced to let customers design parts of the houses they are interested in. Collaborative arrangements, with other architects or with VR developers, is one way in which Canadian architectural firms could become involved in VR. Collaboration in VR and related technologies is already occurring among some Canadian institutions like the Centre for Landscape Research and the Canadian Centre for Architecture, Montreal Research Group.

Neighbourhood Planning and Urban Regeneration

Far from being limited to promotional and marketing stages, virtual environments can be used at all stages of the development process. With the municipal approval of urban and suburban developments so often a lengthy, complex and involved quest requiring public consultation and communication with a broad range of constituents, any tool that could facilitate the process would likely be welcome. Once again, neighbourhood planning and urban regeneration projects have been under development almost since the very inception of virtual reality.

Virtual environments technologies have the potential **to present in immediately comprehensible terms immense amounts of information necessary to the urban and neighbourhood planning process on such things as zoning, valuation, ownership and licensing.** Planners, residents and officials used a virtual reconstruction of riot-torn south-central Los Angeles, created by urban planners at the University of California, Los Angeles, to help cope with a whole range of issues involved in the actual reconstruction (Aukstakalnis 1993 195-96). Such simulations do have heavy computational requirements. The UCLA environment was run on high-end graphics machines but was nonetheless neither immersive nor interactive in real time.

Virtual reality is being used in the regeneration as well as reconstruction of inner cities. The Tyne and Wear Development Corporation is working on the City of Newcastle's massive Quayside redevelopment and rehabilitation project. VR is expected to help manage the scale and complexity of the Quayside, and to contribute to the promotion of the various components of the project to interested parties. The developers are aiming **to recreate the complete 25-acre site in a virtual world, showing the new infrastructure of roads and public utilities, a number of existing buildings and more general blocks to indicate planned construction.** As plans for the various sites are submitted, they will be incorporated into the virtual world to provide detailed visual information and walkthroughs for architects, engineers, planners, members of the Development Corporation and the general public.

Intelligent Systems Solutions Ltd., England, co-ordinates a British Virtual Reality and Simulation consortium, providing industry members a VR laboratory and team of researchers. ISS has worked with the Cooperative Wholesale Society to prototype a new retail checkout and with the regional British Water Authorities to reconstruct urban areas. The aim of the latter project is **to provide a tool to aid the planning of drainage and sewerage networks, and to assess the impact of construction work on the local population.** The Water Authorities hope also to use VR to consult with local shop-owners and residents and to involve them fully in the planning process. For a model of roadwork in Wrexham, they have augmented the area flythrough with digitized photographs of the actual pipe condition under a given portion of the pavement (Stone and Connell 1994 54-56).

Worldesign Inc., Seattle, was founded in 1992 by Dr. Robert Jacobson, co-founder of the HIT Lab, **to develop technologies to enable architects and planners to communicate their ideas about complex urban sites to a lay audience**. Jacobson, educated in urban planning, has focused the company on simulations of large architectural sites and begun developing virtual worlds to display data from geographic information systems (GIS).

In Worldesign's Virtual Environment Theater (VET), images are projected on three sides of a small chamber that can accommodate up to a dozen people at a time. One person, assigned as navigator, takes the remainder of the participants through the world using a 3-D controller. While the VET is a less expensive version of the CAVE system first developed at the University of Illinois' Center for Supercomputer Applications, the smallest model – "the Mini-VET" – lists at $75,000.

Worldesign has developed models of the Port of Seattle's proposed waterfront expansion. Five alternative designs have been constructed **to translate the Port Authority's voluminous environmental impact statement into a form that is instantly understandable to citizen reviewers.** The Port of Seattle models were first show in June 1994 to over 2,000 building-industry professionals at the A/E/C Systems conference in Washington. Worldesign plans continually to enhance the system, adding such factors as economic growth, traffic patterns, water runoff and noise pollution. Jacobson has in mind a self-sustaining database that incorporates further levels of detail as they become available or the hardware is developed to process them. Further development hinges, however, on the continuance of substantial outside funding.

Worldesign has also teamed with Tellus, the software subsidiary of the Puget Sound Power and Light Company, to create a 3-D visualizer for electric power systems and similar above- and underground constructions. The visualizer converts output from Tellus's utility management software into representations of subdivisions with their power and utility networks in place. This system would enable planners **to see the underground electric power grid in place in visualizations of residential neighbourhoods.** Dispatchers could have recourse to these visualizations prior to assigning repair crews.

Worldesign is developing RealityWorks, a software package to let non-programmers assemble, test and modify virtual worlds. This package will allow real-time modifications of the environment, something not possible with Worldesign's current system. Development expenses and hardware costs put Worldesign's services out of reach of all but the largest firms, but the company's goal is to make urban and geospatial information more accessible to public and private decision makers.

Summary

This chapter, while far from comprehensive, helps to substantiate a statement made a few years ago by a member of the Chrysler/IBM VR project: "We are past the hype and pursuing real applications" (Hamilton 1992 97). The range and number of ongoing virtual environments projects in the area of architecture alone suggests that a great many professionals have seen within it the potential to enhance their practice.

CHAPTER 4 - TOOLS AND ISSUES SPECIFIC TO VR

Virtual environments by definition differ from other types of computer environments by the specific interface devices they use to present data and allow users to manipulate that data. **Display, tracking** and **pointing** interface devices distinguish VEs, but ultimately rely for their performance on the processing power of the **computer platform.** The whole system is inert machinery without **software** with which to create applications and run them.

Issues of **design** must also be considered, usually in direct connection with the applications for which a system is intended. These issues include decisions about what levels of **interactivity** and **immersion** are desirable, the trade-offs between **monoscopic** and **stereoscopic** systems, the use of **sound**, questions of **ergonomics, hygiene** and **safety**, and a range of less tangible considerations grouped under the topic of **presence.** All of these issues will be touched on after a brief survey of the components of a VR system. (For more information on the latter, see Appendix A – Technical Considerations.)

Computer

For three-dimensional, interactive graphics to be rendered in real time the **processing speeds** of the computer platform upon which they are run must be very fast. The difference between displaying the canned graphics of multimedia and CAD programs that may have taken hours to render and displaying interactive, immersive graphics are like the differences between showing someone an already complete painting and producing that painting before their eyes. CAD systems typically take hours to render individual scenes. The PolyTRIM CAD software developed by the Centre for Landscape Research at the University of Toronto optimizes all processes but can achieve rendering rates only of 2 frames per second, from short of the 15 frames per second minimum necessary for convincing movement within a VE.

The minimum platform for professional VEs at the present time would seem to be a high-end, **Pentium-based** PC. PC systems performance is improving daily and prices continue to fall. A spokesperson for a systems integrator claims that "it is possible to achieve a high degree of visual realism in an immersive environment with some degree of natural interaction with only a $20,000 budget. In another year or two that will be $10,000 or less" (Du Pont 1995b 54).

It must be pointed out, however, that most of the applications discussed in Chapter 3 operate on mid-range graphics workstations with symmetrical multiprocessing units (SMU) using UNIX-based operating systems. Although competition in this market is heating up, these computers cost US $100,000 and up. The technology in SMU workstations will undoubtedly become more affordable and their market may broaden, but the UNIX operating system required to maximize these resources does require a different skill set from that used in a PC environment. While "experts" may now feel that "architects will never really be players in this field because they lack the necessary capital to purchase even the most basic equipment" (MacLeod 1994 32), this state should change.

Display

Head-mounted displays (HMDs), once commonly like motorcycle helmets with huge scuba goggles attached, are now available in less cumbersome designs and have become the public icon for VR. They are not the only accepted display option for virtual environments, but much of the equipment needed for HMD-based immersive systems is the same as for other types of display. A **graphics subsystem** of as high a performance as is feasible is also required to assist in processing output for the display device.

There are a number of recent articles discussing the issues involved in choosing an HMD from among the increasing number of makes now available (see Delaney 1993b and Zwern 1994). While improved products continue to appear, the range of unique optical and ergonomic requirements, and physical, mechanical and electrical specifications that these articles identify still need to be kept in mind, as well as more traditional considerations like cost and the reliability of the manufacturer. Although suppliers make detailed specifications available, there is no escaping the need for extensive, hands-on testing to determine the suitability of a particular make of HMD to a given set of applications.

There are also applications-dependent questions to be answered and they usually require trade-offs. Does the device need to be rugged for multiple users or more comfortable for extended wear? Is ease of getting the headset on and off more important than getting it fitted properly? Is stereoscopic display more important than cost? Is a broad field of view more important than resolution? These questions need to be addressed for each application that is to be developed.

Tracking

For the immersion of the user within the VE to be convincing, the system must be able to track the user unobtrusively. When the user moves his or her head, either in location or orientation, the system must receive and interpret input to update the display and provide a representation of the environment from the new perspective. To gather data specifying user movements, a position and orientation tracking system with a transmitter attached to the user (head, hand or both – even full body, in the most sophisticated systems) and a receiver connected to the main processor are necessary.

These trackers usually gather data on three degrees of both **position and orientation.** Position describes location relative to the 3-D space – up, down, forward, backwards, left, right – and orientation describes the yaw, pitch and roll settings of the user's perspective. Hence these trackers are called **six degrees of freedom** (6DOF) devices (see figure 4). Some low-end trackers cover the orientation half of this spectrum, requiring another means, usually a pointing device, for establishing user position.

Pointing

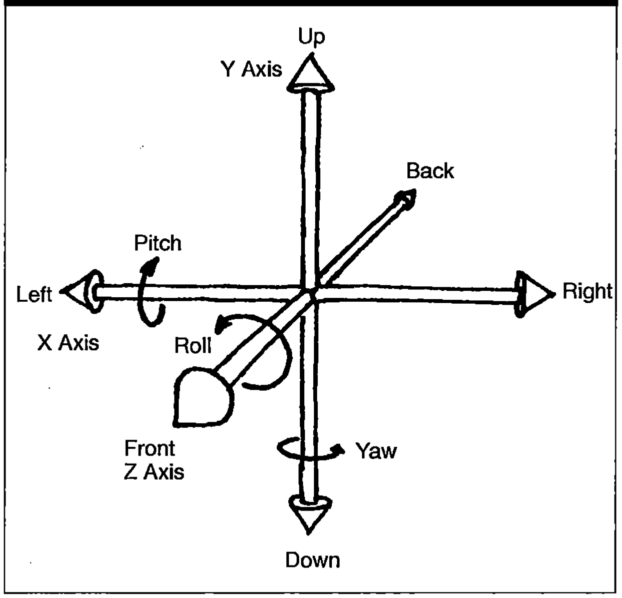
The pointing devices for VEs are really extensions of keyboard and mouse inputs, but suited to 3-D space and intuitive operation. These devices are used to input position data (often even when a full 6DOF tracker is used) and to enable user interaction with the VE. As a mouse will move the cursor over the surface of a two-dimensional screen, so a 3-D pointing device will move the user's point of access to the environment through three-dimensional space. Once the user's point of access is in the desired location, buttons on the pointing device are used to perform whatever manipulations of the VE or objects in it that the system allows and the user desires.

Software

Because VR technologies are so new and still largely the domain of computer programmers and engineers, the software available is not often easy to use. (For discussions of commercial software, see Brill 1994b, 1994c, Hamit 1994, Linda and Eric Von Schweber 1995). Neither is it always clear whether a given package is complete in itself and has all of the desired functions and features. Once again, as with head-mounted displays, hands-on experience may be the only way to arrive at answers to many software questions. People within the field recognize the imperative to improve software design and a great deal of work is being devoted to this end.

Virtual reality software can be divided into the complete and the incomplete, and into

Figure 4
Six Degrees of Freedom (6DOF)



programmer's and non-programmer's products. Some software has been optimized for specific applications. Some software is difficult to learn, while other packages require a long development time, even after they have been learned. Using C-language programs means that "you have to build the worlds stick by stick," says Dean Inman at the Oregon Research Institute: "You have to have a programmer and a designer who are quite versatile with 3D programming and input/output devices" (Buckert-Donelson 1995 25). According to Rick Zobel, "the most important quality for software ... is that it be immediate and intuitive; otherwise design will be a struggle. ... It is vital," he believes, "that architects get involved in this research and join the teams working to refine the next generation of design tools" (Novitski 1994 125).

Questions of the learning curve to be confronted, of ease of use and of development time do not apply only to programming. Because the nascent VR industry is so far lacking in accepted standards, anyone putting together a system must ensure that all components are compatible with each other. Inman has described the process of integrating the necessary components into a system that will perform well within the allocated budget as "a nightmare." Systems integration may be the most challenging task for any attempt to develop a VR system for professional applications.

Design

Decision concerning design and implementation of a virtual environment system and of applications for it usually take the form of trade-offs between different performance measures or between performance and expense. Many of these decisions will be made differently for different applications.

For example, the higher the level of **interactivity** for a VR system, the higher the cost for both the system and the development of applications for it. If a system is being used to show pre-established designs of unbuilt houses, the level of interactivity can remain low, at the walkthrough level. If a system is intended to help consumers make choices about the furnishing of a room or appliances in a kitchen, users should at least be able to choose from a variety of objects, move them around and change their colours, all in real time. If a system is to help make decisions about the design of a house or a neighbourhood, a very high level of interactivity will be needed.

Different levels of **immersion** will also be suitable to different applications, and again, the greater the immersion, the higher the cost. An architect using a VE to design a structure may not want to be immersed in it at all, and may want to be able to enter and exit the virtual structure with ease, so as to refer to other forms of data concerning it. A desktop system provides this ease. Systems using head-coupled displays mounted on articulated arms provide a similar ease of entry, with a greater sense of immersion. A desktop system can be used to show structures to end-users, but if a full sense of the development or structure is required and if less tangible qualities like "feel" or "atmosphere" are to be measured, immersion is necessary.

There is also a question as to whether full **stereopsis** or stereoscopic vision, with separate displays providing binocular parallax (doubling the price of key components) is necessary for architectural applications. For larger-scale activities that draw on gross motor skills for interaction, other depth cues, like disparity, object occlusion, perspective, level of detail and motion parallax, are sufficient. Architectural applications will not usually deal with the small, detailed or ambiguous objects that are more easily comprehended if presented in stereo. For surgical simulators, on the other hand, stereo is crucial. In architectural settings, other cues enable depth judgments (see Cochran 1994 33-34, Wann et al 1993 2).

A **monoscopic** system not only saves money but allows for improvements in other performance measures. For example, without stereopsis, a wider **field of view** can be obtained, thus enhancing both the sense of immersion and the ability to make accurate spatial judgments. A wide field of view, however, generally requires heavier optical systems that can lead to the distortion of images at the periphery. It is also more difficult to present fine detail within a wide field of view. (Aukstakalnis 1992 41-100 is a good source on all issues of vision and VR.)

A great deal of emphasis has recently been placed on 3-D sound or **auditory display** as a way of enhancing the user's sense of immersion in a VE and of improving applications overall (see Begault

1994). Researchers have found that 3-D sound, presented through a combination of hardware and software techniques developed specifically for VR, can compensate for many shortcomings, such as lack of realism and slow refresh rate.

The thorough integration of sound in architectural applications will require some ingenuity. Within a structure, doors, windows, cupboards, faucets, switches and other features should have the appropriate sounds associated with them. Perhaps music or the sound of a television, localized in appropriate appliances that can be turned on and off, could be used. In a virtual neighbourhood simulation, the sounds of vehicles, airplanes and various outdoor activities, plus natural sounds like the wind and bird song would be essential to exploit the auditory sense. Since hearing and sight are the only senses that can as yet be feasibly played upon in VR, they should both be stimulated to the fullest extent possible.

Ergonomics and **hygiene** are hardware-specific design issues to which attention must be paid. The sturdier head-mounted displays tend to be heavy and uncomfortable. They are more suitable for multiple users who wear them only a short time each. This type of HMD would be the choice for a VE intended as a sales tool. If traffic is to be very high, it should be possible to clean and sterilize or replace parts of the headset making contact with users. Lighter, more ergonomically correct HMDs also tend to be more expensive and of higher performance. This type of HMD would be suited to design tasks performed by professionals within an architectural or urban planning office.

Safety issues must also be addressed. A fully immersive system leaves the user totally blind to the real world, and precautions such as installing a railing or using a guide need to be taken. Alternatively, an augmented reality system that allows the user to see the outside world through the virtual one might be preferable. Some HMDs, while immersive, leave space at the bottom between the display and the user's face that allow the user to see at least where his or her feet are.

There have been reports of nausea in users of VR systems. While articles based on outdated, incomplete and poorly understood information have sensationalized the phenomenon of **simulator sickness** (see Strauss 1995), prolonged immersion in VEs must be undertaken with caution. Sim sickness seems related to motion sickness, but there are factors specific to VR. One cause of sim sickness is the discrepancies between visual and haptic or kinetic sensory arrays, that is, between what the user sees and what the user feels through his or her body. Delays in frame refresh rate increase these discrepancies, although they can also be due to means of locomotion in the VE, such as pointing and flying, that do not correspond to the way people usually get around.

Dr. Erik Viirre, a London, Ontario neurologist has studied sim sickness and done work in the Neurology Department at the University of California at Los Angeles and in the HIT Lab. He has also studied the problem of eye strain, which is only an issue with stereoscopic displays. A recent study recommends that "those using HMDs should carefully consider the duration and repetition of their use and restricting their use by those with visual disorders" or the young (Wann et al 1993 2).

Presence

Compelling and successful virtual environments are said to give their inhabitants a convincing sense of **presence**. Presence is used to describe the feeling that one is truly inside a real space, and will remain a relative measure until an unforeseeable future when VR can replace natural reality. Presence is also hard to measure since it is subjective. Nonetheless, some discussion of it is useful in this report because the transferability of anything experienced in a VE depends upon the sense of presence that VE can convey. If what is experienced in a virtual barrier-free house cannot be transferred to the experience of a real barrier-free house, and vice versa, then the simulation will have achieved nothing.

A recent experiment set out to test the "assumption that the basic characteristics of spaces, that is to say, their shapes, their relative location, and their 'feel' are perceived the same way in both virtual and real environments" (Henry and Furness 1993 34). The experiment compared the sense of space achieved by subjects in three different levels of computer simulation of an art gallery with that achieved by subjects who toured the real gallery. The study found that those who toured the virtual gallery underestimated spatial dimensions. The greatest underestimates came from those who had used the most immersive system, but those subjects also reported a better sense of the "feel" of space than did users of the other simulations.

There is anecdotal evidence to suggest that virtual experience is transferable to the real world. Participants in Dr. John Trimble's development work (see Chapter 3) said that when they entered the real versions of apartments they had entered in their virtual state, they felt like they had already been there. Preliminary results in some studies tend to confirm this evidence. One study has attempted to answer the questions, Can people learn to work in VEs? and Does learning in VEs transfer to real-world performance? They have found that subjects are able to learn how to operate virtual control panels, and they can take that ability with them back into the physical world (Regian and Shebilske 1992). Researchers at the Institute for Simulation and Training, Central Florida University (see Chapter 3), have come to the same preliminary conclusions.

The studies of Ralph Lamson and Rob Kooper on treating acrophobia suggest that the confrontation with the fear of heights in the virtual world enabled subjects to confront that fear in the real world (see Chapter 3). In observing his subjects being confronted with virtual heights, Kooper watched them grip the railings in a mock-up of an elevator as it rose, suggesting that the subjects felt present in the environment. Objective measurements of the physiological reactions of the subjects in both Lamson's and Kooper's experiments confirm this conclusion.

Kooper supplements his conclusions about virtual therapy by formulating a number of hypotheses about presence that need further testing. He believes that the experience of equivalence between virtual and real-world environments does not rely upon accurate or complete representations of the real-world situation. He also asserts that prolonged exposure to a virtual environment does not necessarily increase the participant's sense of presence (Kooper 1994). Other studies have found that the unrealistic behaviour of objects in the virtual world (walls that can be walked through, balls that do not bounce) can compromise the illusion of presence (Slater and Usoh 1993).

Summary

The strongest sense of presence in virtual structures will probably correspond with the highest combination of values for field of view, frame refresh rate, realistic object behaviour, immersion and interactivity, and when 3-D sound is used in conjunction with these. How well a system convinces a user that he or she is inhabiting a virtual world and how well it satisfies pertinent design criteria only determine the performance of the tool. The success of a VR project depends upon the successful conception and planning of an application both that is worth doing and that can be uniquely well done with VR techniques.

CHAPTER 5 - FUTURE APPLICATIONS OF VR IN HOUSING AND COMMUNITY PLANNING

The greatest overall benefit that virtual environment technologies hold out to the architectural and urban planning communities is the potential to involve all stakeholders actively in the design process. The technology holds out **the promise of true participatory design,** to the point eventually of allowing laypeople to change or even generate their own designs through trial and error. Chapter 3 discussed examples of VE projects intended to reap this benefit for various constituencies. This chapter will identify applications that might be developed to provide services for people with disabilities and to assist in the urban planning process.

Applications for People with Disabilities

The technologies reported on by this study have the potential **to assist in the goal of providing a variety of barrier-free accommodations for people with disabilities.** They may do so in a cost-effective manner consistent with the need to provide these accommodations at no greater cost than regular units. Virtual environments can achieve these benefits by providing architects, builders, doctors, physiotherapists and other professionals the sensory experience of what it is like to have a disability, and by providing those with disabilities direct access to architectural plans before they become finalized in actual structures.

Architectural blueprints can be exactly duplicated in three dimensions through CAD software and then ported into VE software. The latter transforms the CAD files into structures through which a user can manoeuvre and that will have set properties for interaction. Surfaces representing solids in the real world, for instance, are equipped with collision detection in the virtual world so that users cannot go through them. Objects in the VE consist wholly of numerical data rendered into graphical form. Measurements can thus be precise. The interaction of the user with these objects is based upon the mathematical co-ordinates assigned to the user, again, wholly a matter of numbers.

Measurements that have been established for clearances in corridors and doorways, elevators and washrooms to allow access for wheelchair users can be readily tested in a VE. As a first stage, it may be possible using available CAD packages to model a given building and then run the building's dimensions through a set of standard algorithms that would test whether the dimensions met those established for accessible structures.

A full VR simulation, however, might be preferable. The user's presence in the environment would be given the dimensions of someone in a wheelchair. Input on the user's movements would be taken through a treadmill interface for the wheelchair. If the user encountered a doorway too narrow to enter, a corridor too narrow to turn in, a corner to sharp or a threshold too high, the system's collision detection routines would detect the attempt of the user to move into an impossible space and halt his or her movement. Furniture could also be modelled realistically in virtual rooms so that its effect on freedom of movement could be assessed.

Similarly, the tracking mechanism attached to the pointing device through which the user gained access to the virtual space would be set with precise mathematical perimeters matching those known for the average approximate horizontal and vertical reach of a person confined to a wheelchair. The user's hand in the virtual world would be halted when it encountered the limits of that reach. In this way the locations of sinks, cupboards, drawers, shelves, windows and other features could be tested for accessibility.

Systems operating on these very principles have been developed, tested and, in the case of the Wheelchair VR system by Prairie Virtual Systems, brought to market. Many believe that virtual barrier-free design promises to help meet the growing need for universally accessible environments. Factors that influence the primary considerations of personal safety and accessibility to resources vary widely, depending on the nature of an individual's disability. Applications such as the one described should be flexible enough to be customized **to test for a range of mobility impairments and to accept models of a range of housing alternatives.**

Systems running such an application would have many potential uses beyond design. That virtual barrier-free design allows for the participation of end-users in the design process at a very early stage, itself a desideratum, suggests other applications. If people with disabilities can explore virtual dwellings designed for them but not yet built, then they could also explore dwellings already built but from the real versions of which they are barred because of institutional factors. That is, they could start the process of their deinstitutionalization by exploring in an unthreatening, safe way a virtual version of a dwelling outside the institution.

Tom Parker, Project Manager in the Housing People with Disabilities Research Division at CMHC, has suggested **that VR could let people with disabilities try out designs before they chose one.** He notes that the experience of people with disabilities who have been institutionalized all of their lives is severely limited. They may have little sense of the difference between styles of housing and VR could educate them, potentially better than any other medium. Parker describes the hypothetical case of a logger, in the bush all of his life, who was becoming physically unable to work. He might want to move to the city, but would have no experience with housing designs or neighbourhood layouts. A virtual environment could help him test design options he would otherwise have no contact with.

The use of VEs in the design process has been called **"experiential prototyping."** The use of VEs in the process of reintegrating people with disabilities into the community should perhaps be characterized as **"the prototyping of experience."** People who have never been outside an institution could compare simulations of apartments meeting minimum requirements, residential group homes, integrated housing developments and detached housing. Through this prototyping of experience they could make informed choices about where they were to live.

The virtual prototyping of experience could also be used to acquaint people with what they will encounter in the world outside of the institution and equip them with skills to meet it. Risky experiences can be simulated and the user can extract the lessons to be learned without encountering the risk. Dr. Inman's work in wheelchair driver's training for children with cerebral palsy at the Oregon Research Center establishes a "proof of concept" for this application. During its testing, Prairie System's Wheelchair VR was apparently used at a veterans administration hospital to teach paraplegics how to get around in apartments before they actually moved in.

Inman has pointed to the limits of the children he works with "in what they can do, express, enjoy, and such. My area of interest is in overcoming motor dysfunction, and I am interested in using VR as a tool to work toward that goal" (Buckert-Donelson 1995 26). Some of his patients have been so dependent since birth that they have lost all motivation even to try to move on their own. By providing them with the ability to move in ways that they have never experienced, he has helped generate in them the motivation necessary to embark on the arduous task of disciplining their bodies enough to operate a wheelchair.

Jutta Treviranus, while she was at the Hugh MacMillan Rehabilitation Centre in Toronto, set up studies using VE technologies with severely disabled children. She suggests that a lack of certain kinds of physical stimuli when very young may inhibit later psychological and intellectual development: "Exploratory play, independent hypothesis testing, and independent mobility are believed to be necessary precursors to the development of later academic skills" (1994 203). This technology could, by giving children virtual physical experiences they cannot have in the real world, **provide a range of neurological stimuli they would otherwise not get, but that are necessary to development.**

If the able-bodied architect can be confined to the experience of someone in a wheelchair, and if the child with cerebral palsy can, as Inman reports, race across a virtual checkerboard field at the equivalent of 80 miles an hour, then one further application for people with disabilities may one day be possible. When networked VR is fully developed, it should be **possible for differently abled people to meet in virtual worlds as equals.** They could play virtual 3-D Pong and other games of physical activity or explore virtual worlds together and share the experience. What other sorts of activities they could engage in is perhaps best left to the imagination, although it must be kept in mind that virtual reality is never expected to provide a convincing substitute for reality and the experiences it allows will always seem artificial.

Urban Planning and Neighbourhood Design

The potential of virtual environments to involve everyone concerned in the planning and design process could be valuable at an even larger scale when it comes to the design of whole neighbourhoods or city developments. The imperative to involve all members of the community in planning for developments that will effect them has become policy, in the furtherance of which VR could become a powerful tool. It could help **to expose citizens to planning options, let them participate in decisions and get their consent to decisions once they are made.**

VR could help achieve greater community participation in the public review of proposed projects. This participation could in turn give the residents of a community a greater sense of ownership of that community and greater satisfaction with it. Hence, this technology is a potential tool for the further democratization of urban planning.

For in-fill housing and urban regeneration projects, VR could be useful early on in the process as architects and planners try out various options that would have to accommodate existing buildings. Once satisfactory alternatives had been built within a virtual space that could cover whole blocks, citizens could be invited to walk through their virtual neighbourhoods to get a feel for proposed developments. The mix of existing and planned structures in such virtual worlds might provide something of a reality check from one to the other. Once built, such a virtual neighbourhood could become **a database for future developments and be kept up with changes in zoning, the allocation of building permits and even the destruction of properties through fire.**

Changes to standards for street clearances for emergency vehicles are very difficult to make. A project by AGC Simulations for the Milpitas, California, police, to allow them to practice high-speed chases using cab simulators (see video), suggests that **VEs could be used to assess alternative street clearances.** Simulations of emergency vehicles – real drivers at the wheel – could be introduced into virtual neighbourhoods and the ability of the drivers to deal with emergencies tested. These tests could be run through a series of alternatives and even under different climate or traffic conditions. Occurring in real time, they could also be clocked.

The same features of the technology could be exploited to meet other urban planning objectives. VR could be used, for instance, **to assess neighbourhoods for safe places and individual home sites for security.** The existence of virtual worlds as three-dimensional environments that users can explore, checking out obstructions and sight-paths from many different angles, make them very effective for this task. These applications would again rely on the ability of virtual environments to convey more about a given data set – street plans, a building lot – than can statistics or blueprints. The aesthetics of a site plan could be tested through the ability of VEs to communicate subjective qualities like atmosphere and feel.

Virtual environments could also assist in the use of zoning and subdivision controls as instruments to enact planning goals for city growth. Resistance to the trend towards mixed zoning could be met by using VR for educational purposes. Likewise the need to increase densities and reduce lot sizes in traditionally low-density greenfield developments could be promoted by using VEs to prototype an experience of neighbourhoods built under these planning imperatives, surely more effective than statistics and drawings. This technology could be used **to counter the general resistance to change among urbanites and suburbanites anxious at the prospect of higher densities in their area.**

These technologies could also become **essential tools for developers who have to sell their proposals to a variety of different participants in the development review process.** Much of the very design of developments may in the future be created virtually as well as on blueprints and with scale models. Among architects, planners and developers who share a common language of blueprints and street plans, VEs may communicate ideas more quickly and immediately, and with greater impact.

Once a virtual shopping centre or office complex is designed, it must be taken to city councillors who may have varying degrees of expertise. A virtual model would ensure that, despite the variety of backgrounds, each councilor is communicated the same thing. As a proposal is refined or changed to meet various demands and then altered in its virtual state, it could be taken on to the next set of constituents in the approval process.

VEs could also be used in the process of both generating and communicating environmental impact assessments for large projects. The technology could eventually become **a research tool able, given the proper algorithms and data, to project development patterns through time.** It could help to refine predictions and work out the implications of alternative scenarios. These possibilities require the ability of VE technology to absorb, synthesize, process and display a variety of data, including information on pollution, weather patterns, demographic trends and materials decay. One firm, Worldesign, has plans to develop their systems to be able to handle such data. In work for the Port of Seattle, Worldesign has shown how a virtual world can communicate a six-volume impact assessment in a comprehensible and engaging way to both lay and professional audiences.

Other Potential Applications

The Division project for Matsushita that combines computational fluid dynamics and virtual environments has already been discussed (see Chapter 3). This high-end system shows the potential of virtual reality to aid in the study and representation of air, heat and gas flow – indoor air quality generally. The Division work suggests that **VEs could soon be used in the development, testing and promotion of energy-efficient housing.** These systems would show their strong suit in being able to represent a variety of options in materials, design, insulation, heating systems and other crucial factors. Individual factors could be changed in real time and the effects of changes immediately shown. Heat dispersion outside of the home could be represented graphically. Various environmental factors including exposure to sun and wind, and seasonal variations could be explored. The Procos architectural firm in Halifax has shown the potential to use VR-related technologies to present performance simulations of its passive solar house project.

These technologies are already being used in the design process by architectural firms. Some believe that the ability to create and modify designs in real-time, immersive environments will allow for greater experimentation on the part of designers and architects and lead to a better understanding of architectural space. There is **a potential for exploring architectural designs in new ways.** Experiments in scaling, massing, contrasts, rhythms and the symbology of the space could be done more rapidly and effectively in virtual environments than in CAD or more traditional means. The use of the latter techniques by such firms as Imagine in Montreal and Design Vision in Toronto could lead to explorations of VR in its more strictly defined sense.

VEs are also already being used as sales and promotional tools. Any architect or developer that acquired a system for any of the purposes already explored in this chapter would find they had acquired the added value of a very effective marketing tool. As a communications medium VEs can also readily function in educational applications. They could be used **to promote sustainable cities and energy-efficient homes.** It would certainly be much cheaper to transport the virtual model of an energy-efficient home to shows across the country than to transport a full-scale mockup of such a home.

One final application to be mentioned is the potential of these technologies **to provide a user-friendly front-end for building management control systems.** Atelier d'Architecture Imagine of Montreal on its Web site lists property and facilities management as one of the services it can offer through 3-D visualization software. The details of computer control systems could be conveniently hidden behind a 3-D graphical interface that allowed intuitive access to those systems. A facilities manager who wanted to alter a maintenance schedule would step into the virtual control room and jot the change down in a virtual log book. Such a virtual world could allow managers to enter a simulation of the physical plant room and simply click on the equipment they wanted to operate.

Summary

This chapter has discussed a range of applications of virtual environments of interest to the housing and community planning industries, particularly in the fields of barrier-free living and urban planning. Some of these applications have been developed or are currently being researched, others are farther away and will depend on technological advances to make them possible. This survey should spark ideas for other applications. The potential of virtual reality for architecture and urban planning is vast, and no one can know what applications will really be developed. For any applications to be developed, however, speculative exercises such as the preceding and those it may lead to must first take place.

CONCLUSION

For virtual environments to aid in the planning, design and implementation of built environments, a high level of computer software and hardware engineering skills must be deployed along with a commitment of ongoing and long-term research. Turnkey systems are available, but not yet in affordable and flexible configurations. A range of technologies must be integrated in custom, applications-specific systems. Each successful application of VR has come from a system configured for that application.

Virtual reality may in fact go the way of artificial intelligence, another recent buzz phrase that came out of computer research and was distorted and amplified by the media. Some may assume that artificial intelligence has been a dead end, but the results of research in AI are being put to use in such things as expert systems and neural networks, they are just not appearing as AI. Many of the individual technologies that go into virtual environments are also being explored separately, and may find uses far from any association with VR.

The human-computer interface technologies of VR are an exciting and active area of research with broad application. VR systems and applications are even now migrating from the laboratory into the office. Architecture and urban planning will remain one of the main professional areas for this migration.

BIBLIOGRAPHY

Anon. 1993a. "Virtual Reality Gets Real." The Economist Fe 20, 61-2.

Anon. 1993b. "Firm Takes Virtual Reality to Work." Calgary Herald, 9 July: C6.

Anon. 1993c. "British Gas Unveils Virtual Kitchen." Virtual Reality Report Vol. 3, No. 7 (Se 1993): 6-7.

Anon. 1994a. "Howdy Hubble" CyberEdge Journal. Vol. 4, No. 1 (Ja/Fe): 1, 3-4.

Anon. 1994b. "Developing Virtual Reality as a Tool for the Disabled." New York Times 13 Ap: C1, C6.

Anon. 1994c. "Disabled Find Freedom with Virtual Reality." Toronto Sun, 20 May.

Anon. 1994d. "Disabled People Use Virtual Reality." New for You Vol. 42, No. 23 (June 15): 3.

Anon. 1994e. "Colt Virtual Reality Ltd. Using VR to Make Buildings Safer." VR World Vol. 2, No. 4 (Ju/Au): 4.

Anon. 1994f. "Architect 'Walks' Clients Through Virtual Creations." The Computer Paper Vol. 7, No. 11 (November): 24.

Antonoff, Michael. 1993. "Living in a Virtual World." Popular Science Ju, 83-6, 124-5

Aukstakalnis, Steve and David Blatner. 1992. Silicon Mirage: The Art and Science of Virtual Reality. Berkeley: Peachpit Press.

Austin, Gene. 1994. "Real Estate, Virtual Reality." The Montreal Gazette De 29. C3.

Baggs, Tom. 1994. "Virtual Reality at Work - The Cave of Lascaux." PC Graphics & Video (Mar/Apr): 7-8.

Bailey, J. H. and Witmer, B. G. 1994. "Learning and Transfer of Spatial Knowledge in a Virtual Environment." Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting. Santa Monica, CA: Human Factors and Ergonomics Society. 1158-62.

Barker, Quint. 1994. "Virtual Reality Market Analysis." VR World Vol. 2, No. 2 (Ma/Ap): 55-64.

Barry, Philip, John Dockery, David Littman and Melanie Barry. 1994. "Intelligent Assistive Technologies." Presence: Teleoperators and Virtual Environments Vol. 3, No. 3 (Summer): 208-15.

Begault, Durand R. 1994. 3-D Sound for Virtual Reality and Multimedia (New York: Academic Press).

Berg, Tor. 1994. "Immersive Internet." Virtual Reality Special Report Vol. 1, No. 4 (Winter): 50.

Bishop, Gary et al. 1992. "Research Directions in Virtual Environments." Report of an NSF Invitational Workshop. 23-24 March 1992, Univ of North Carolina at Chapel Hill. Computer Graphics Vol 26, No 3 (Au 1992): 153-77.

Blau, Brian and Kevin Yurica. 1994. "Designing VR Applications for the Desktop." VR World Vol. 2, No. 5 (Se/Oc): 17-21.

Bletter, Nathaniel. 1993. "The Virtues and Vices of Virtual Reality." Design Quarterly No. 159 (Spring): 38-44.

Boras, Alan. 1993. "Calgary Entrepreneur Designing Virtual Reality Computer Link for Groups." Citizen, 3 Oct.

Brecker, Lora. 1993. "Interactive Virtual Environment -'Trying Out' Accessibility." Advance for Occupational Therapists (Ja 13): 10-11.

Brill, Louis. 1992. "Facing Interface Issues." Computer Graphics World Ap, 48-50, 52, 55, 57.

——. 1993. "Kicking the Tires of VR Software." Computer Graphics World Vol. 16, No. 6, June, 40-2, 44-6, 48, 53.

——. 1994a. "Virtual Reality: Designing, Authoring, and Toolkit Cyber Software." Pt I. VR World Vol. 2, No. 3 (May/June): 22-29.

——. 1994b. "Virtual Reality: Designing, Authoring, and Toolkit Cyber Software." Pt II. VR World Vol. 2, No. 4 (July/Au): 41-47.

——. 1994c. "Museum-VR: Opening the Gateway. Part 1." VR World Vol. 2, No. 6 (No/De): 33-40.

——. 1995a. "Museum-VR: Part II." VR World Vol. 3, No. 1 (Ja/Fe): 36-43.

——. 1995b. "Somewhere Over the Rainbow: Creating Virtual Realities." Digital Video Magazine Vol. 3, No. 3 (Mar): 32-36, 38, 40, 42.

Brister, Andrew. 1994. "Vegas or Bust." Building Services (Feb): 35-36.

Buckert-Donelson, Angela. 1993. "Business News." Virtual Reality Report Vol. 3, No. 7 (Se 1993): 2-5.

——. 1994a. "Scared of Heights? Virtual Therapy May Be on the Way." VR World Vol. 2 No. 6 (No/De): 7.

——. 1994b. "Drafting Boards and Blueprints Give Way to Interactive Design." VR World Vol. 2, No. 6 (No/De): 7-8.

——. 1995a. "VR Trumps CAD: Engineers Choose Superscape for Equipment Planning." VR World Vol. 3, No. 1 (Ja/Fe): 4.

——. 1995b. "VR People: Dean Inman." VR World Vol. 3, No. 1 (Ja/Fe): 23-26.

Chapnick, Philip and Sean Vikoren. 1994. "Books: Virtual Reality becomes Actual Reality." Virtual Reality Special Report. Premier Issue (Spring): 27-32.

Cochran, Wil. 1994. "How Do I See Thee? Let Me Count the Ways." Virtual Reality Special Report. (Fall): 33-37.

Churbuck, David C. 1992. "Applied Reality." Forbes Se 14, 486-8, 490.

Cobb, Sue, Mirabelle D'Cruz, Jeremy Robson, Richard Eastgate, David Brown, Nick Cope and John Wilson. 1994. "Evaluating VR as a Practical Tool for Industrial Applications: Individual and Organisational Usability." Proceedings of the 12th Triennial Congress of the International Ergonomics Association. Vol. 4. Ergonomics and Design. Ed. Sharon McFadden, Les Innes, Maury Hill. Mississauga: Human Factors Association of Canada. 400-02.

Conway, Matthew, Laura Vogtle and Randy Pausch. 1994. "One-Dimensional Motion Tailoring for the Disabled: A User Study." Presence: Teleoperators and Virtual Environments Vol. 3, No. 3 (Summer): 244-51.

Cook, Rick. 1992. "Serious Entertainment." Computer Graphics World Ma, 40-1, 43, 45-8.

Deering, Michael. 07 1992. "High Resolution Virtual Reality." Computer Graphics Vol 26, No 2 (July 1992): 195-201.

Delaney, Ben. 1993a. "The Perfect VR Application." Virtual Reality Special Report Premier Issue (Spring): 15-17.

——. 1993b. "A Survey of Head Mounted Displays." Virtual Reality Special Report (Fall): 21-4.

——. 1994a. "1993 Conference Rankings." CyberEdge Journal. Vol. 4, No.1 (Ja/Fe): 12-5.

——. 1994b. "Getting Into Head-Mounted Displays." CyberEdge Journal's Virtual Reality Products Vol. 1, No.1 (No/De): 5-8.

Dittmar, M. L. and Hale, J. P. 1994. "Virtual Reality as a Human Factors Design Analysis Tool for Architectural Spaces: Control Rooms to Space Stations II: Subjective Measures." Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting. Santa Monica, CA: Human Factors and Ergonomics Society. 280-84.

Duncan, Dan. 1993. "VRAIS Conference." Virtual Reality Report Vol. 3, No. 9 (No 1993): 10-12.

Du Pont, Pierre. 1995a. "What's a High-End System?" VR World Vol. 3, No. 1 (Ja/Fe): 54.

Du Pont, Pierre. 1995b. "CAVEs." VR World Vol. 3, No. 2 (Mar/Apr): 63.

Dysart, Joe. 1995. "Madison Avenue Discovers VR." VR World Vol. 3, No. 1 (Ja/Fe): 28-29.

Emmett, Arielle. 1992. "Down to Earth: Practical Applications of Virtual Reality find Commercial Uses." Computer Graphics World Mr, 46-8, 50-1, 53-4.

Enrado, Patty. 1994. "VR in Escrow." Virtual Reality Special Report. Premier Issue (Spring): 56.

Fisher, Scott S. and Jane Morrill Tazelaar. 1990. "Living in a Virtual World." Byte July, 215-6, 218, 220-1.

Frerichs, David. 1994. "Bringing Real Applications to the Virtual Environment." VR World Vol. 2, No. 4 (July/Au): 50-4.

Gantz, John. 1992. "A Virtual Market." Computer Graphics World Ma, 27-8.

Gay, Eben. 1994. "Is Virtual Reality a Good Teaching Tool?" Virtual Reality Special Report Vol. 1, No. 4 (Winter): 51-59.

Gildea, J. P. and Bailey, J. H. 1994. "Correlates of Route Traversal Performance in a Virtual Environment." Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting. Santa Monica, CA: Human Factors and Ergonomics Society. 966

Glovsky, Patricia. 1995. "VR's Commercial Advance." VR World Vol. 3, No. 1 (Ja/Fe): 13.

Good, Michael and Linn Tan. 1993. "VR in Architecture: Today's Use and Tomorrow's Promise." VR World Vol. 2, No. 6 (No/De): 58-64.

Gooderman, Mary. 1994. "The Next Best Thing to Being." The Globe and Mail 23 Ap. C1, C5.

Gossweiler, R., Laferriere, R. J., Keller, M. L. and Pausch, R. 1994. "An Introductory Tutorial for Developing Multiuser Virtual Environments." Presence: Teleoperators and Virtual Environments Vol. 3, No. 4. 255-264.

Gradecki, Joe. 1994. The Virtual Reality Construction Kit. John Wiley and Sons. (need city)

Greenleaf, Walter. 1995. "Rehabilitation, Ergonomics, and Disability Solutions Using Virtual Reality Technology." Proceedings of the Interactive Technology and the New Paradigm for Healthcare. Amsterdam: IOS Press. 415-22.

M.H. 1993. "Virtual Reality on a PC." Popular Science Ja, 44-5.

Hamilton, Garry. 1994. "Taking a Dose of Virtual Horror.' Equinox No. 78 (De): 19.

Hamilton, Joan O'C. 1992. "Virtual Reality: How a Computer-Generated World Could Change the Real World." Business Week Oc 5, 97-100, 102, 104-5.

Hamit, Francis. 1993. Virtual Reality and the Exploration of Cyberspace. (Carmel, IN: SAMS).

Hamit, Francis. 1994. "Is It Real, Or Is It Superscape?" Information Week (Dec 5): 68, 72.

Hamit, Francis, Kenny Meyer, Ben Delaney. 1993. "Mickey Meets Mini Mouse, SIGGRAPH '93." CyberEdge Journal Vol. 3, No. 5 (Se/Oc): 1, 3-7.

Hedberg, Sara. 1994. "Desktop-based VR: Requirements and Costs." Virtual Reality Special Report Vol. 1, No. 3 (Fall): 17-25.

Heim, Michael. 1993. The Metaphysics of Virtual Reality (New York: Oxford University Press).

Helsel, Sandra K. 1993. "Editorial." Virtual Reality Report Vol. 3, No. 7 (Se 1993): 1-2.

Henry, Daniel and Tom Furness. 1993. "Spatial Perception in Virtual Environments: Evaluating an Architectural Application." IEEE Virtual Reality Applications International Symposium (Seattle: IEEE): 33-40.

Hollands, Robin. 1994. "The 'Garage' VR Solution." VR World Vol. 2, No. 4 (July/Au): 21-4, 26-7.

Horn, Miriam. 1991. "Seeing the Invisible." US News and World Report Ja 28, 56-8.

House, Geoffrey. 1994. "Going to the Shopping Mall Via VR." VR World Vol. 2, No. 6 (No/De): 41-3.

Hsu, Jeffrey. 1993. "Virtual Reality: Reality-What a Concept!" Compute Fe, 100, 102, 104.

Jacobson, Linda. 1994. Garage Virtual Reality. (Carmel, IN: SAMS).

Jacobson, Robert. 1993a. "CAD Off the Screen: The Virtual World as a More Natural Design Environment for Architects." Presentation to ACS 93, Weisbaden, Germany, 26-27 Nov 1993. Printed in VR World Vol. 2, No. 3 (May/June 1994): 46-52.

——. 1993b. "Unrequited Desire and Virtual Worlds: Transforming the Pursuit of the Ineffable." Keynote address, VR Users Conference, London, England, 1 De 1993.

——. 1994a. "Virtual Worlds: A New Type of Design Environment." VR World Vol. 2, No. 3 (May/June): 46-52.

——. 1994b. "Applying the Virtual Worlds Paradigm to Mapping and Surveying Data." VR World Vol. 2, No. 5 (Se/Oc): 60-2, 64-9.

——. 1994c. "What's This VR Stuff, Anyway." VR World Vol. 2, No. 6 (No/De): 68.

——. 1994d. "Virtual Worlds Capture Spatial Reality." GIS World Vol. 7, No. 12 (De): 36-39.

——. 1995. "Hard Copy." VR World Vol. 3, No. 2 (Mar/Apr): 62.

Johnston, Stuart. 1994. "Virtual Reality Takes Architectural Leap." Computerworld (June 20): 72.

Kameyama, Ken-ichi and Koichi Ohtomi. 1993. "A Shape Modeling System with a Volume Scanning Display and Multisensory Input Device." Presence: Teleoperators and Virtual Environments Vol. 2, No. 2 (Spring): 104-11.

Keck, Jon. 1994. "A Virtual Diploma." Pix-Elation No. 11, 12-14.

Kelly, Richard. 1994. "Getting Started in Virtual Reality." Virtual Reality Special Report Summer, 17-9, 21-4.

Keppler, Kay. 1994. "Time for Church." Virtual Reality Special Report Summer, 49.

Kloss, Joerg. 1994. "Fraunhofer Frolic." Pix-Elation No. 10, 29-30.

Rob Kooper. 1994. "Virtually Present: Treatment of Acrophobia by Using Virtual Reality Graded Exposure." MSc Thesis, Delft University of Technology, the Netherlands.

Kreuger, Myron. 1993. "The Experience Society." Presence: Teleoperators and Virtual Environments Vol. 2, No. 2 (Spring 1993): 162-68.

Latham, Roy. 1994a. "'Virtual Therapy' Used to Treat Phobias." Real Time Graphics Vol. 3, No. 1 (July): 10.

——. 1994b. "Head Mounted Display Survey - A Comprehensive Round-Up of Products." Real Time Graphics Vol. 3, No. 2 (Au): 8-12.

——. 1994c. "HMD Products Edging Towards Mass Markets." Real Time Graphics Vol. 3, No. 2 (Au): 1-2.

——. 1994d. "Kaiser Electro-Optics President Comments on HMD Business." Real Time Graphics Vol. 3, No. 2 (Au): 3, 13.

Laurel, Brenda. 1992. "Artistic Frontiers in Virtual Reality." Computer Graphics Special Issue, Proceedings of SIGGRAPH 92 (July): 58-63.

Levine, Joshua Z. 05 1991. "Reality Testing." Planning Vol. 57, No. 5 (May): 22-23.

Liang, Bob. Chair. 1993. "Virtual Reality and Computer Graphics Programming." Computer Graphics Proc. SIGGRAPH 93 (Au): 392-93.

Lipsky, Daniel. 1994. "Falling In Glove Again." Pix-Elation No. 10, 28.

Livingston, Jim. 1994. "Almost Like Being There." Urban Land Vol. 53, No. 11 (No): 44-45.

Louderback, Jim. 1993. "Emerging Technology to Look at But Not to Touch." PC Week Vol. 10, No. 34 (30 Au): 67.

Lowe, Robert. 1994a. "Three Case Studies in VR Systems." Virtual Reality Special Report Premier Issue: 77-9.

——. 1994b. "Three UK Case Studies in VR Systems." VR World Vol. 2, No. 2 (Mar/Ap): 51-4.

McElroy, Duncan. 1993. "Deep Footprints." Pix-Elation Vol. 2, No. 4 (Fall): 5-6.

McLellan, Hillary. 1993. "Virtual Reality and Persons with Disabilities Conference." Virtual Reality Report Vol. 3, No. 7 (Se 1993): 10-14.

——. 1994. "Beam Me Up to My Avatar." VR World Vol. 2, No. 2 (Mar/Ap): 33-39.

MacLeod, Douglas. 1994. "Flirting With Cyberspace." The Canadian Architect Fe: 31-2.

Montefusco, Diego. 1995. "Looking in on the Netherlands." VR World Vol. 3, No. 2 (Mar/Apr): 12-13.

Morkes, John. 1994. "Vertigo Reality." Wired (xx): 48.

Moshell, J. Michael and Richard Dunn-Roberts. 1994. "A Survey of Virtual Environments: Research in North America." VR World Vol. 2, No. 1 (Ja/Fe): 24-36.

Nemire, Kenneth, Adam Burke and Richard Jacoby. 1994. "Human Factors Engineering of a Virtual Laboratory for Students with Physical Disabilities." Presence: Teleoperators and Virtual Environments Vol. 3, No. 3 (Summer): 216-26.

Newby, Gregory. 1994. "Gesture Recognition Based upon Statistical Similarity." Presence: Teleoperators and Virtual Environments Vol. 3, No. 3 (Summer): 236-43.

Noakes, Susan. 1994. "The Uncertain Reality of Virtual Reality." The Financial Post. Oc 15. C3.

Novitski, B.J. 1994."Virtual Reality for Architects." Architecture. Oc 1994. 121-5.

O'Connor, Gerald. 1994. "Use Your Illusion: A Superscape Showcase." Pix-Elation No. 11 (Nov): 26-27.

Orr, Joel. 1994. "A Way Out, A Way In: VR and Disabilities." Virtual Reality Special Report Summer: 35-8.

Oyama, Eimei and Naoki Tsunemoto. 1993. "Experimental Study on Remote Manipulation Using Virtual Reality." Presence Vol. 2, No. 2 (Spring): 112-24.

Pancucci, Dom. 1993. "Industry Uses Virtual Reality." Byte Se, 38.

Pate, Angela. 1995. "Paperback VR/CAD Worlds." VR World Vol. 3, No. 2 (Mar/Apr): 67.

Peterson, Ivars. 1992. "Looking-Glass Worlds." Science News Vol 141, 4 Ja, 8-10, 15.

Regian, J. Wesley and Wayne Shebilske. 1992. "Virtual Reality: An Instructional Medium for Visual-Spatial Tasks." Journal of Communication Vol. 42, No. 4 (Autumn): 136-149.

Regush, Nicholas and Heather Pringle. 01 1993. "Machines of Illusion." Equinox 12.1 Ja/Fe, 59-64, 66.

Reimer, Janet. 1994. "Design Validation." Iris Universe No. 29 (Fall): 32-35.

Richards, Bill. 1994. "Test of Virtual Reality Spans the Pacific." Wall Street Journal. 16 No. B1, B8.

Roehl, Bernie. 1994a. Playing God. (Corte Madera, CA: Waite Group).

——. 1994b. "The CyberMaxx HMD: Good Value for the Dollar." VR World Vol. 2, No. 6 (No/De): 66-7.

——. 1995. "The Logitech Cyberman." VR World Vol. 3, No. 1 (Ja/Fe): 58-59.

Rourke, John. 1994. "SIGGRAPH: A Computer Geek's Memoirs." Pix-Elation No. 11 (Nov): 20-21, 28.

Roy, David, Marilyn Panayi, Richard Foulds, Roman Erenshteyn, William Harwin and Robert Fawcus. 1994. "The Enhancement of Interaction for People with Severe Speech and Physical Impairment through the Computer Recognition of Gesture and Manipulation." Presence: Teleoperators and Virtual Environments Vol. 3, No. 3 (Summer): 227-35.

Segura, Jean. 1994. "VR Project at Germany's Fraunhofer Institutes." VR World Vol. 2, No. 6 (No/De): 30-2.

Slater, M. and M. Usoh. 1993. "Virtual Environments for Architectural Walkthrough: the Issue of Presence." Abstract in Ophthal. Physiol. Opt. Vol. 13, No. 4 (Oc): 438.

Smets, G., P. J. Stappers and C. Overbeeke. 1993. "Virtual Reality and Design." Abstract in Ophthal. Physiol. Opt. Vol. 13, No. 4 (Oc): 438.

Stampe, Dave, Bernie Roehl and John Eagan. 1993. Virtual Reality Creations. (Corte Madera, CA: Waite Group).

Stanfel, Julie. 1993. "Virtual Cities - A Regional Discovery Project." Educational Media International Vol. 30, No. 1 (Mar): 42-45

Stone, Bob and Andy Connell. 1994. "The UK's Virtual Reality and Simulation Initiative: One Year Later." VR World Vol. 2, No. 5 (Se/Oc): 50-8.

Strauss, Stephen. 1995. "Virtual Reality Too Real for Many." The Globe and Mail Sat. 4 Mar: A1, A7

Suding, Robert. 1993. "Low-Cost VR for the Virtual Hacker." Virtual Reality Special Report Fall: 25-30.

Tarr, Tom. 1994. "Washington: Prone to Synthetic Environments?" Pix-Elation No. 11 (Nov): 22-23.

Testa, Bridget Mintz. 1994. "Virtually Walking in Space." Virtual Reality Special Report Vol. 1, No. 4 (Winter): 67-74.

Treviranus, Jutta. 1994. "Virtual Reality Technologies and People with Disabilities." Presence: Teleoperators and Virtual Environments Vol. 3, No. 3 (Summer): 201-07.

Vacca, John. 1995. "NASA Projects; Part I." VR World Vol. 3, No. 2 (Mar/Apr): 48-51.

Vance, Judy. 1993. "Virtual Reality 101: SIGGRAPH's 'Applied Virtual Reality' Course." Pix-Elation Vol. 2, No. 4 (Fall): 25-26.

Vanderheiden, Gregg and John Mendenhall. 1994. "Use of a Two-Class Model to Analyze Applications and Barriers to the Use of Virtual Reality by People with Disabilities." Presence: Teleoperators and Virtual Environments Vol. 3, No. 3 (Summer): 193-200.

Von Schweber, Linda and Eric. 1995. "Virtual Reality: Virtually Here." PC Magazine Vol. 14, No. 5 (Mar 14): 168-72, 179-80, 183, 186-87, 190, 196-98.

Wann, J.P., S.K. Rushton and M. Mon-Williams. 10 1993. "What's Wrong with your Head Mounted Display?" CyberEdge Journal. Supplement. Vol. 3, No. 5 (Se/Oc). 1-2.

Whitbeck, Caroline. 1993. "Virtual Environments: Ethical Issues and Significant Confusions." Presence: Teleoperators and Virtual Environments Vol. 2, No. 2 (Spring 1993): 147-52.

Wilder, Clinton. 1992. "Virtual Reality Seeks Practicality." Computerworld Vol. 26, No. 17 (Ap): 26.

Zwern, Arthur. 1994. "How to Select the Right HMD." VR World Vol. 3, No. 2 (Mar/Apr): 20-22, 24-27.

Zyda, M. J., David Pratt, John Falby, Chuck Lombardo and Kristen Kelleher. 1993. "The Software Required for the Computer Generation of Virtual Environments." Presence: Teleoperators and Virtual Environments Vol. 2, No. 2 (Spring 1993): 130-40.

APPENDIX A

TECHNICAL CONSIDERATIONS

This appendix provides information supplementary to that contained in the first part of Chapter 4.

For the peripheral interface devices associated with VR to operate effectively, certain minimum processing requirements in the **computer platform** must be met. Because the graphic objects are three dimensional, any of the single mathematical points that define those objects can be anywhere within Cartesian space. The computer has mere milliseconds to compute – and re-compute – the location of all those points as they move.

Only a few years ago, technical limitations made it impossible to produce virtual environments on personal computers. Advances in processing power, systems architecture and software design have brought VEs to higher end PCs. There is much to be said for off-the-shelf PC systems, including integration within the work environment, ease of use and cost, and a growing range of hardware and software VR products are being produced specifically for the PC (see Linda and Eric Von Schweber 1995). The minimum processor for desktop VR is an Intel **486**, with a clock speed of **33 megahertz** (see Holland 1994). The 486-series chips already have the numerical co-processor needed for floating-point mathematical computations. Virtual environments developed on this minimum configuration, however, are hardly suited to professional applications.

While there are ways of optimizing lower-end machines, including making the software algorithms more efficient, the minimum platform for professional VEs at the present time would seem to be a **Pentium-based** PC, with a **90 MHz** clock speed and a **peripheral computer interface** (PCI), 32-bit local bus as the graphics pipeline. The system would also need upwards of 8 megabytes of system memory or RAM (some software requires more), and a large permanent storage capacity.

Speed of refresh rate, expressed as **frames-per-second** (fps), is one of the main measures of performance for VE systems. The minimum speeds cited for convincing simulations are in the range of 15 fps. Lag in the feedback loop or **system latency** is another measure of performance. The ability to render complex scenes, shading and textures are measures having to do more strictly with display performance. The level of interactivity that can be achieved is also dependent on the processing power of the system. All of these factors contribute to how convincing a given virtual environment is, and all of them require money, skill and experience to obtain satisfactory numbers.

There is an ever-increasing variety of off-the-shelf **HMDs** available for systems from the low-end or “garage VR” level to the high-end research lab, so buyers can now actually choose equipment to suit their specific requirements (see Latham 1994a). According to Bernie Roehl, co-developer of the popular VR shareware, REND386, and software developer at the University of Waterloo, until recently “the only ’missing piece’ in low-end VR systems has been an affordable HMD” (1994a 66), but the release in late 1994 and early 1995 of at least four HMDs in the $1,000US range is changing that. Of course the question of whether these pieces of equipment will perform well enough to suit the demands of building professionals will only be answered through testing.

Whatever the end display device, there are other equally important components necessary to drive it. A high-performance **graphics subsystem** is also required. Good quality VGA graphics cards have been used, but more expensive boards with built-in 3-D processors, hardware-assisted rendering and Z-buffering are better. Some graphics accelerator manufacturers have worked with software developers to maximize the components on both sides of the graphics equation. Depending on the end display – LCD, CRT, projection or monitor – a VGA to NTSC signal converter might be needed, although these cost only a few hundred dollars. For stereoscopic display, double these requirements.

For 6DOF position and orientation **trackers**, magnetic, mechanical and ultrasonic techniques are used with attendant strengths and weaknesses for each technique. Magnetic trackers are fast and accurate, but are subject to interference from ferrous metals in the environment and are the most expensive. Mechanical trackers are accurate and when used with head-coupled displays built especially to accommodate them allow the user to exit and re-enter the virtual environment without losing position data, but they do restrict the type of display that can be used and they too are expensive. Ultrasonic trackers are least expensive, and reasonably fast and accurate, but they are subject to line-of-sight and distance limitations.

The range of **pointing devices** includes wands, joysticks, gloves with sensors and transmitters (datagloves), spaceballs and flying or 6DOF mice. The user's point of access is sometimes represented as a cursor arrow, but more often represented as a cartoon-like hand with articulated fingers. Pointing devices and trackers both deliver user input to the system, and the former often incorporate tracking technology. But pointing devices enable a more accurate and more consciously driven user interaction with the environment than do trackers, which sample data from actions that are usually unconscious outside of VEs.

Price appears to have little to do with whether a VR **software** package is complete or modular, a toolkit for programmers or non-programmers products. What seems like an arbitrary price structure often means that price also has little to do with functionality. (The VREAM package, for instance, was initially released at $1,495 US, but fell to $495 in less than a year.)

The cheapest commercial software package is Domark's Virtual Reality Studio for less than $100, and while it is relatively easy to use, it is little more than a toy. It is actually the forerunner of Superscape, one of the more expensive packages. A cheaper package still is REND386, and its derivatives VR386 and AVRIL, produced by Bernie Roehl and Dave Stampe – together and apart – at the Universities of Waterloo and Toronto. They are free for non-commercial uses, and provide complete virtual environments - if one can learn to script in their complex and decidedly unfriendly code. (See Stampe, Egan and Roehl 1993 and Roehl 1994b, for copies of REND386 and guides to using it.)

VEs must first be built and then object behaviour and user interface established, two wholly different tasks. Sense8's WorldToolKit and Autodesk's Cyberspace Development Kit are C programming libraries that provide virtual environments for objects modelled in conventional CAD packages like MultiGen, 3D Studio and AutoCAD, and also provide all of the necessary software drivers to link these environments and their objects to the whole range of VE peripheral devices. The worlds they produce are very impressive when run on systems that can optimize them, but because of their expense (approx. $2,000US, plus licensing fees), difficulty and requirement for additional modelling software, they are most commonly found in well-funded government or business research labs. WorldToolKit is, nonetheless, the software foundation of many of the applications discussed in Chapter. MR Toolkit is a similar package available for free to research institutions through file transfer protocol (ftp) from the University of Alberta.

For non-programmers who do not use CAD, toolkits from Superscape and VREAM hold down the high and the low end. Both have graphical user interfaces (GUIs) and allow for objects to be modelled with them (although they will import objects from CAD programs). Superscape can be used to produce stunning architectural simulations and has been used in many of the applications discussed in Chapter 3, especially those outside of the U.S., but is priced in the $5,000US range. The VREAM package (version 2 soon to be released as VRCreator) seems at this point to offer the best price/performance ratio, but the quality of its graphics are still somewhat primitive, especially for those familiar with CAD graphics. Perhaps with further releases of the package and with greater familiarity with it, VREAM will be able to meet the expectations of architects. Another option is VirtusPro. Its graphics are quite sophisticated but it is not true VE software: the user cannot move through buildings with any ease and cannot interact with objects.

The lack of the standards necessary to ensure that all the hardware and software components of a VR system work well together is one of the primary barriers to the widespread use of the technology. Integrated systems are available, but they are very expensive, usually optimized for one set of applications and require continual technical support (at a cost) from their suppliers. The development of open systems and standards for interoperability will improve the market acceptance of VR.