DEVELOPING ARCHITECTURAL VISUALIZATION USING VIRTUAL ENVIRONMENTS

by

ALLISON M. STAMIDES, R.A.
B.Arch. University of Miami
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Signature or Author: ______________________

Allison M. Stamides
Department of Architecture
May 10, 1996

Certified by: ______________________

William J. Mitchell
Dean, School of Architecture and Planning
Thesis Advisor

Accepted by: ______________________

Roy Strickland
Associate Professor of Architecture
Chairman, Department Committee on Graduate Studies

Committee Readers

William L. Porter
Professor of Architecture

Julie Dorsey
Assistant Professor of Design and Computation and Building Technology.

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ABSTRACT

This thesis anticipates the emergence of virtual reality (VR) technology as an economical alternative to architectural presentation. As professionals, designers are trained to interpret two dimensional media spatially. Experience has shown that client (or user) interpretation of traditional media (two dimensional drawings and physical models) has led to discrepancy. Controlled two dimensional media may also serve as a seduction, often portraying unrealistic views. In the case of highly technical spaces, participatory design is a necessity. Successful communication of need and intent are critical to the overall success of the project in concept and in detailed design. The smallest error in communication may result in costly penalties, often at the expense of an architectural amenity or in material quality.

This investigation attempts to eliminate the need for client translation by providing a more intuitive design environment via VR. The goal is to examine several types of environments/scenarios and to design an experiential/interactive environment, three-dimensionally linking the user to the designer's solution and thought processes. Shared models will be posted over a network using VRML (Virtual Reality Modeling Language). The client will be able to use the model as a reference "book" by hyperlinked information attached to model geometry. Projects (not yet built) would be viewed at full scale (some in total immersion), from the same perspectives of their future reality i.e., allowing the client and designer to interact within the space during the design process.

The intent is not to entirely recreate reality or to automate what is now performed manually, but to immediately express thought in a three dimensional world, enhancing collaboration and critique. The pursuit of this thesis is based on a theory which alters the conventional design-communication process to dynamically and positively impact the final product. Final data analysis will examine the process of creating and employing simulated environments for architecture, the pros/cons of implementing such a system, and the feasibility. The conclusion will recommend improving processes, systems, and the techniques employed for future "world building" of architectural space.

As operating systems become more economical and simultaneously more powerful, computer modeling will enhance visualization. The design process approach will then turn from the "bird's eye/plan view" to the eye level perspective view. The model itself will evolve with the design as experiential scenes to ultimately be used as a design tool, as a communication tool, and perhaps finally as a resource --as cad and database information are linked today.--to be accessed throughout the project life cycle.

Thesis Advisor: William J. Mitchell
Title: Dean, School of Architecture and Planning

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For my parents,

Mary Ann N. and Theodore G. Stamides,
to whom I owe all things.

....and in memory of my little brother George, who I love and miss.

My sincere thanks to my advisor William J. Mitchell, to Owen D. Johnson without whom this study would have never been completed, to The MIT Research Lab for Electronics, to Jeffrey C. Krause for unselfishly sharing his time and knowledge, to the staff of the U.S. Army Health Facility Planning Agency, and especially to Colonel CEM Maxwell for his support in helping to make this dream a reality.

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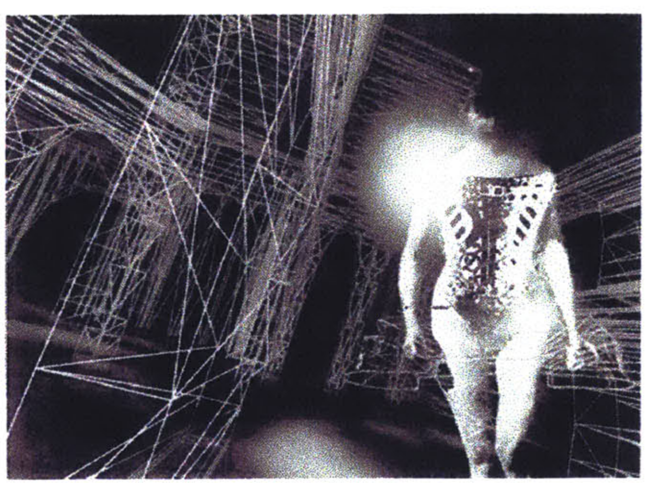
PREFACE

This thesis is an exploration of current and developing computational (virtual) environments and technologies for the purpose of communicating and designing architectural form and space. It offers a series of case studies (using a variety of technological methods) to investigate the impact on visualization and communication in search of how existing tools may be combined for use in a professional setting today.

The projection into an imagined space or a sketched space is common place to design professionals but rarely to those who are *presented to*. The architectural "model" as a representation of built form, no matter how abstract, serves as a communicator of thought. As architects we employ the physical model to confirm the expectations of an original sketch and to solidify thought for a presentation to others. The intriguing aspect of using simulated models or those built with vectors and points, is that they are unlimited to change. Change is the catalyst of design thinking and should therefore embrace the basis of the technology. Once built, a physical model must be dismantled, preprogrammed for very limited change (i.e. plug in sections), or completely discarded to be built again, making it resistant to change. The computational model has increased in value since it is now possible to accurately simulate the affects of lighting and materials, as well as physically link it to other forms of data.

Returning to the revered sketch, some of the most provocative and informative sketches are those which are extremely minimal ["less is more"]. Certainly there are many cases when two dimensional media are more appropriate to explain a concept especially when that concept is linear. Dynamic form and space however, are rarely linear. Since technology has developed to allow more varied and vivid options in representing ideas, perhaps we should reexamine our traditional processes to ensure we are not overlooking a more effective method in favor of habit alone. In doing so, we may incorporate lessons learned from the sketch to communicate what is necessary, perhaps minimally.

Fig. a1.
Archeology of a Mother Tongue (1993)
By Toni Dove and Michael Mackenzie
(Moser, 1996)



1. Introduction to the Problem

The issues and cases being addressed are aimed at 1) helping clients better understand architectural work during the design process, and 2) improving the design process itself by employing new methods of visualization using developing technology. During my employment I have witnessed several clients (users) request change in design during the construction phase or inquire why design decisions were made during the construction phase. Most often, these same clients were the individuals approving and/or requesting those decisions originally. It is only after the *actual* is constructed that the design is realized at an appropriate level by the client, in most cases. The reason for this discrepancy points towards the media used to communicate design to clients, which are most often plans, elevations, and occasionally a perspective view or a physical model. It is common knowledge that clients are often intimidated by the technical aspect of construction documents, have difficulty visualizing with two dimensional media in general, and also have difficulty orienting themselves to a physical model.

The primary reason for pursuing this study is that the mental annotation of the architectural design process (sketch, drawing, model) has also become the way in which we teach and present three dimensional thought. With recent developments in technology however, traditional methods are in flux and should be reconsidered. Architecture: a three dimensional experiential craft, is more often developed and depicted with two dimensional media. This exploration suggests an emphasis on the perspective rather than the domination of the plan.

Based on personal experience, the ideas of designers rarely come to life in the clients view until a model is presented. With this, the view is also limited since the observer is expected to project and orient themselves into the space along with a certain level of abstraction. Models which are less abstract are usually presented after the design is complete or as a final effort to display the product before construction. Regardless of the quality of the model, the issue that cannot be communicated in a physical model is the <u>direct</u> sense of scale and perspective in relation to the human body. Since designers can visualize and project, this is not a problem, but what is the impact on the user who is unfamiliar with the task?

Aside from the user view we should also begin to address the problem of improving the integration of computation and design. Most often, the issues regarding computation and design are associated with CAD technologies. Although Computer Aided Design has not revolutionized the way in which we *design* it has greatly impacted the way in which we conduct business. With the combined newly developed visualization tools which complement it, perhaps CAD is about to make its first dramatic impact in the design process, rather than in only automating drawing and in presenting final products. During the past 10 years we have seen a dramatic change in the improvement of computer generated images for architecture. During the past two years we have seen a much more dramatic popularization and development of graphic media communicated over the Internet. The focus of computation and design should now be on how those issues could and should be integrated as well as the future of architecture as digital space (to establish "place") which is rapidly developing.

Traditionally, communication of design has been through a series of two dimensional media and three dimensional physical models. The use of the physical model as a descriptive tool has been more prevalent in education than in practice. Physical models are mainly used as either; a) mass models describing the exterior form and relationship of the building shape to adjacent structures , b) after final design as a detailed miniature of the space (usually for display rather than study), and c) in some rare cases as a mock up for special circumstances. This study proposes that the "architectural model" be propelled forward for more effective use during the design process by incorporating computation. As architects we should address this topic in order to become involved in the development of the next generation of design/visualization tools.

Recently, several other information technologies have advanced into academia and the workplace. These range from visual structural analysis tools to visual databases. The key issue here is "visual". Information that was only once available numerically, with line diagrams, and with text can now be viewed interactively and translated into a more visually effective (and sometimes spatial) form, making the impact and importance of the information more intuitive and therefore more useful. The result is a creation of a new information "type" in itself.

Figures 1.1 and 1.2 are simulations using the "Lightscape Visualization System" Software. A computer mock up of a room and proposed luminare were defined within a computer model. Using sophisticated parameters, the materials of the space were replicated along with the settings for the luminare in question. After processing, the simulation creates a rendering of the scene and also allows a *visual* of the technical data, Figure 1.2 attaches color to illuminance values in footcandles. The manner in which the information is presented allows a more comprehensive view of the data. Here, a great deal of information is transmitted accurately and subtly. Exposure to this type of representation, replacing (or enhancing) numerical data with color, provides the user with information while educating, making future predictions of (in this case light reaction) more intuitive. The next step toward advancing this visual analysis would be to reverse the process. In the future, a designer might interact with the illuminance number/color coding directly to alter the light which would ultimately result in automated luminare alteration. An example related to this (originally conceived at the M.I.T. Media Lab and now found in other forms on the Internet) is visual stock data, where numerical information is once again presented visually and in a third dimension. This reduces the amount of time needed to absorb the information and therefore allows more data to be analyzed.

Fig. 1.1 (detailed description in appendix d)

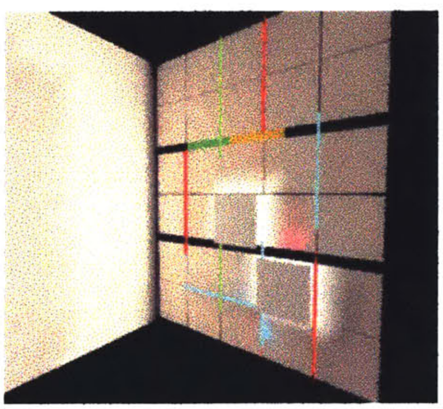
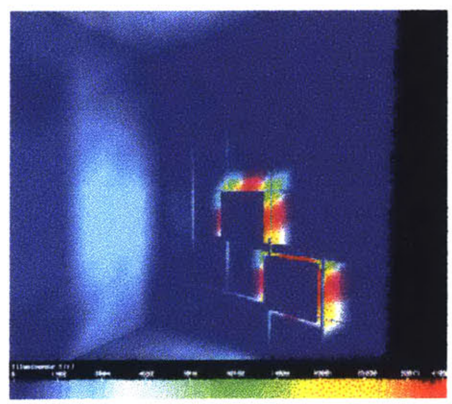


Fig 1.2



Another data environment recently established and popularized is the creation of the World Wide Web. The "Web" as it is referred to was created by the European Laboratory for Particle Physics (on a protocol proposal by Tim Berners-Lee) and has increased in popularity "faster than any other communication media in the history of the United States" (Matsuba, 1996). According to one visionary "if the web were to expand at its current rate it would overtake the population of the planet within the next 5 years"(Negroponte, 1995). If this is true, then we must expect that the Web will arrive at its peak exposure within the next 5 years and continue to grow not only with the population but expand by transforming into other products even more so that it has already. During the past year alone an overwhelming number of businesses have employed, been created, or have supported the World Wide Web. Advertising of a Universal Resource Locator (URL) has become commonplace wherever advertising exists, including personal calling cards. [*The combination of these two new interfaces (visual data structures and global networks) warrants reinvestigation of current practice in visualization and design communication.*] Reconforming the traditional bombardment of project information is the crux of improving visualization within virtual worlds. If the visual data structure could be captured in an interactive intuitive view and utilized as the design environment, more accurate information could be accessed and employed with far greater impact.

1.1. Problem Solving Proposals

Through *case study* exploration, a number of environments will be tested which combine these technologies and others to communicate space from both the user and designer points of view. The cases incrementally search for lessons learned within a specific area to ultimately determine key points for building "worlds" and visualization methods. The main research tool of this study is one which has historically suffered from underdeveloped and limited debate with regard to architecture and is commonly known as "Virtual Reality". The term "Virtual Reality" is used (and over used) to describe many systems and types of synthetic environments. Its use here will be further defined in section 1.2. "*Clarification of Terms*".

The theory: is that since the model is a necessary tool for learning design, it should be more integrated into the traditional design (professional practice and learning) process. **[*the word model here is used to define an object which represents architectural form/space and which is or appears three dimensional and can be manipulated physically or in real time*]** Also, since computational models are more adaptable to change (in geometry, materials, light, etc) and can be viewed from the actual perspectives in question (and in combination with the conceptual "bird's eye view"), that they be ultimately used as the <u>environment</u> for the design process. By doing so, the designer and client are continuously experiencing the solution from the perspective view (as space is actually perceived), rather than the plan view. This would allow immediate witness to the effects of changes in plan and section while in perspective. Virtual environments provide an excellent research method for this theory by visually placing the observer within a computational model and allowing the observer to interact with the environment intuitively. Figures 1.3 through 1.5 diagrammatically depict a basic outline of 1) the traditional approach to the design process, 2) the proposed approach by this study, and 3) the ultimate goal that this study points toward.

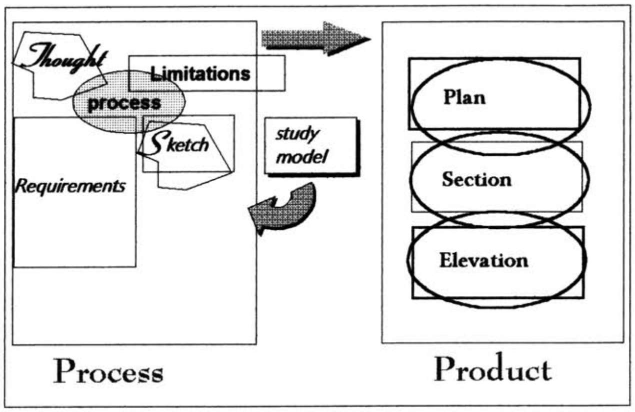


Fig. 1.3 Traditional Process

The model is secondary to the process (if employed at all). The product is largely represented by two dimensional media.

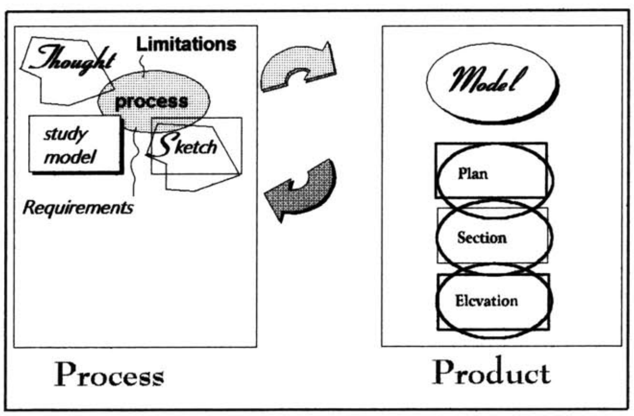


Fig 1.4 Proposed Process

The model becomes more integrated in the process, therefore including experiential design. The model becomes a necessary part of the product.

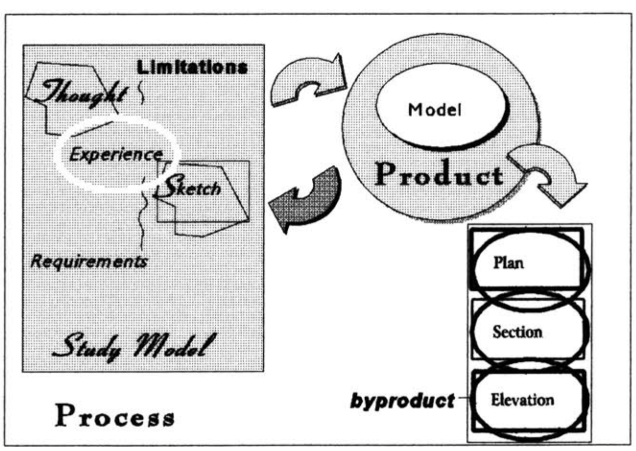


Fig 1.5. Ultimate Process Goal-

-The model is the design environment with all parameters visible within the environment while the process is ongoing.
-The product becomes three dimensional.
-The plans become the creation (byproduct) of the three dimensional experience.

The theory contends: that creating form from different viewpoints will yield improved results. A student work developed *only in plan* will seem flat in experience once extruded in the third dimension. If however, we begin to enhance (or continue the process) from the actual perspective view (rather than the predominant plan view), the results are likely to be more dynamic. If we further enhance the experience with not one, but several moving perspective views (i.e. via an interactive environment at full scale) then the results are likely to be more developed spatially and more sensitive to issues of access, view, lighting, etc. The suggestion is one that directly links plan (or section, elevation) to the actual perspective views as experienced at eye level interactively during the design process.

To explore this we may turn to existing electronic media, specifically synthetic environments, by showing:

- the similarities between virtual space and actual space as perceived by the non-designer
- how economical low level programs may be incorporated into actual projects to explore and communicate design today
- how architects' perceptions are changed/enhanced from simulated experiences

1.2. Clarification of Terms

Before beginning it is important to define the use of the term Virtual Reality and the equipment/apparatus that will be employed. "Virtual Reality" is a term used to describe several synthetic environments. Most commonly it is "that which does not exists physically" but which is believed. In this study, Virtual Reality will be used to describe immersive environments. Immersive environments are those which encompass all views of the spectator with the synthetic or simulated environment. Therefore all head movement and views are focused on the synthetic environment with all views of the real world excluded, the individual then becomes immersed.

Immersion is currently achieved through a variety of apparatus. One of the most common pieces of optical display equipment associated (and faulted) with virtual environments is the HMD (Head Mounted Display) shown Fig. 1.6, 1.7. This is a visor like apparatus that presents automated views to each eye. The movement of the wearer's head is monitored by a tracking device. The tracker communicates the movement and position of the wearer's head to the computer processor(s) allowing the appropriate view of the simulated world to be rendered inside of the HMD and to each eye. There are primarily two types of HMD's commonly available on the market, the biocular monoscopic viewer and the steroscopic viewer. Both provide two lenses however the first presents the same view to each eye while the latter presents a different view to each eye.

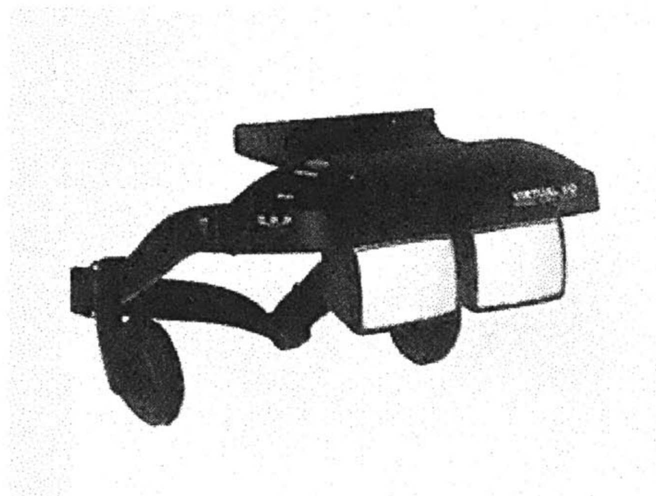


Fig. 1.6. Recent development by "Virtual IO", Light weight HMD with some external view to lessen simulator sickness

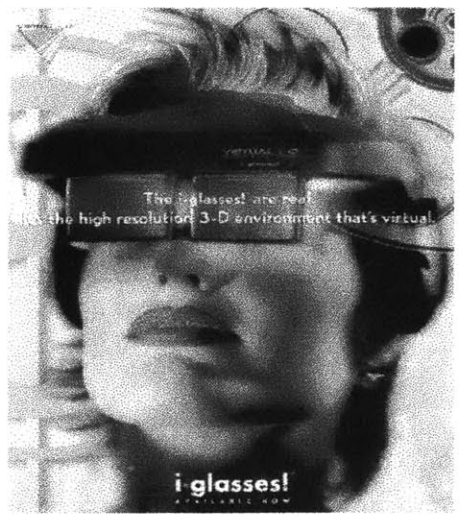


Fig. 1.7. Commercial Advertisement, by "Virtual IO".

It is reported that steroscopic viewers better represent reality since each eye view is actually different (eye parallax). The stereoscopic viewer is known to provide greater depth perception for this reason and is most effective in comprehending objects within close proximity. The HMD used throughout this study is a biocular monoscopic viewer manufactured by "VR4".

In early development the HMD was a very heavy cumbersome piece of equipment. The technology has now progressed to be very small and light weight, comparable to a visor and quickly approaching the stature of glasses. The price has also decreased tremendously and several models are now designed for the Personal Computer market, primarily aimed at computer game players and geared towards being affordable. The cost begins to increase with the quality of the resolution. The HMD has been one of the largest inhibitors of the technology. Many wearers suffer from vertigo while only in the apparatus for a short time. The nature of the simulation also limits the experience to one person. Although piped views from the HMD maybe directed to another monitor, the immersed experience is lost to external observers. Limitations aside, the HMD is excellent for research purposes since it is economical, often high resolution, adaptable in configuration, and even portable. This study places its limitations aside since there are several other display device solutions available and currently in development. Other display devices include virtual projection, the CAVE, and the BOOM.

Virtual projection is similar to a holographic view. The viewer observes the object naturally in actual space while the object is projected into reality and appears to be three dimensional. The CAVE is a multi-sided projection room which has a reputation for being comfortable and well suited for collaboration. The BOOM is a heavy high resolution display device that is counterbalanced for weightlessness. A recent development has been shown in the creation of a desk top version of this device. The observer peers into the optics (like a biocular microscope) and moves it in the direction of the desired view. Of these, the most promising is the CAVE or an adaptation of it. The U.S. Military currently uses an adaptation of the CAVE for pilot training. This incorporates three projection screens simulating the windows of a cockpit. The results are increased comfort with realism while providing a shared view.

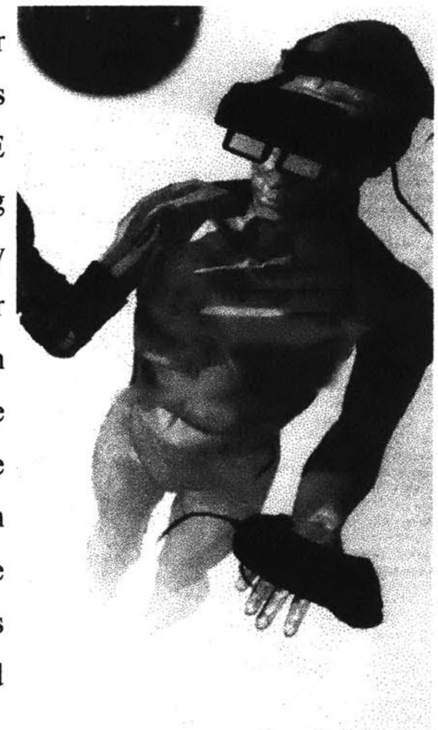


Fig. 1.8. Image from *PC Magazine*, 14 MAR 95

Interaction devices:

Interaction devices include peripherals such as the traditional mouse, the 3D mouse (one which tracks its position in space similar to the head tracker), joystick, space ball, data glove (and data suit), and voice recognition system. The data glove (Fig. 1.9) has also advanced technologically and has decreased in cost.

Fig. 1.9.
Advertisement for "The Pinch" Data glove.

To summarize, the technologies used in immersive environments (Virtual Reality) are :

- display
- tracking
- graphics processing
- interaction/navigation interface device

1.3. Introduction to VRML

On the other end of the spectrum, a system which emphasizes economy is the newly created Virtual Reality Modeling Language. This language and many of its development and viewing tools are available for free over the Internet's World Wide Web. It's creation was intended to "bring VR to the masses"(Pesce,1995). It is a lower form of environment that maybe run on a 486 processor. The result is a low to medium resolution product with varying speed in maneuverability. VRML was based on Silicon Graphics Inventor file format. It can be combined with HTML (hypertext mark up language) to link pieces of the model geometry to any other information that the Web will allow, which at the time of this writing is practically unlimited.

In terms of an immersive environment, VRML was not developed for the use although it can be adapted. VRML parsers (otherwise known as browsers or viewers) are now offered with joystick and HMD configuration allowing them to become immersive. Even in its lowest form, it is an excellent way to share models over bandwidth. Experiment 2 [Chapter 6] in this study will demonstrate an actual building modeled in its entirety and reduced to less than a megabyte. Currently, several Schools of Architecture have developed (and are developing) student work in this format for distribution over the WWW, they include UCLA, Columbia, and the University of Washington to name a few.

The language itself, is actually a series of instructions. These instructions communicate with the browsing software, to direct how the geometry should be drawn and rendered as well as the placement, positioning, and type of lighting and cameras within the scene. The script or instructions is in this case the VRML code which lists a set of Cartesian coordinates forming the geometry, vertex ordering instructions, and viewer scene information. The parser, interprets those instructions to the rendering engine within the browsing program. The original language was meant to create simple scenes and objects by hand coding the language.

A rule of thumb given by its creators for the maximum world size is around 10,000 polygons for ease of movement within the model (Pesce, 1995). The 10,000 polygon estimate is aimed at desktop personal computing. This may obviously be increased significantly for use with an SGI, depending upon the processing power and RAM.

Other extensions of this language promise the addition of "behaviors". An organization called "Moving Worlds" was recently formed to create the next version of the specification. The goal was to improve the first specification by allowing a more object oriented world in place of an entire scene which essentially becomes one object. Some introductions to these behaviors are now available. The results allow each object within a scene to be manipulated individually in real-time. Aside from being able to navigate through an area, the observer may also become a participant by interacting with the object directly. One may interactively change color/texture of an object, move objects, change the lights within a scene interactively, or preprogram objects to include certain ranges of motion (i.e. animated objects) and the attributes of gravity.

Although the majority of this software is currently in beta, one can easily imagine its potential for use in architectural applications. Being able to interactively change a modeled scene which appears rendered adds value to the computational model over the physical model. In a future critique the reviewer (or client) might be able to see the impact of their suggested changes immediately [is this dangerous?]. If this were combined with the existing capability of immersive VRML, then we would have a very economical solution for designing within an environment from the perspective view.

In addition, the cost of viewing and development tools may be the best convincing point of all (free or under $50.00 for commercial use). This makes it a media which will be accessible to most Internet users and design firms, increasing its communication value. At the time of this writing, several model builders and rendering packages have just begun to support conversion to VRML. However, at this time, a direct conversion (which guarantees a complex geometry will be correctly read by the 3D browser) does not exist. Furthermore, most of the scenes successfully built in this format have been extremely limited in complexity. Architecturally successful scenes have been limited to very simple geometry, some texture mapping, and no detail, i.e., a room within a building, cities consisting of texture mapped blocks.

1.4. Existing Technologies Pro/Con

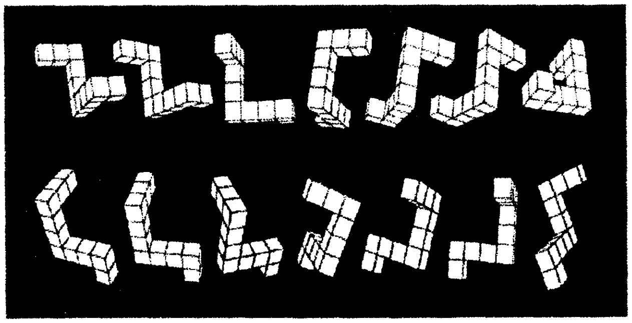
For research purposes this study will focus on the potential of virtual environments and the experiential concepts rather than be stifled by a critique of the current apparatus. Like its components, (i.e. processing power), the apparatus is most likely to develop in quality and decrease in cost . In terms of software, most will be obsolete prior to the completion of this writing however, it is their contribution to the theory that is the focus. Most critics of VR refuse to have any vision in the potential, and continue to dwell on the present limitations, further inhibiting its development. Virtual Reality has been used to describe systems that were once too costly and limited in use. Most believed that it may develop as a tool far in the future but that it certainly would not be affordable by architects. These misconceptions were born out of its early development stages (during the 1960's). When we revisit the technology today, we see a clear advancement to the extent of turn key marketable systems, i.e., VRML and PC based peripherals and software.

2. Translating 2D Media to 3D Objects

We cannot recreate all of the nuances of an actual environment at this time and perhaps we should not attempt to. The ambiguity of the two dimensional sketch can be translated into another forms language three dimensionally, (albeit with very different connotations) within a synthetic environment. By capturing this at progressive levels of design development, the imagination (or creative process) is supported and reenforced with visual information at an early stage rather than fully relying on two dimensional media, memory, and assumed mental rotation.

2.1. Perspective and Perception for Learning

One of the classical examples in cognitive research study was completed by Shepard and Cooper (1986) on the subject of two dimension to three dimension representation and mental rotation (Finke, 1992). The study presented a series of sketches which represented three dimensional objects. The objects were then rotated and the test subjects were asked to choose the resulting object (sketch) once rotated. The results showed the complexity of the object to be proportional to the time needed to solve the puzzle. This indicated that the method for solving the task was associated with a visualization of mentally rotating the objects. The subjects first created the objects within their minds, rotated it and then chose the result of their final vision.



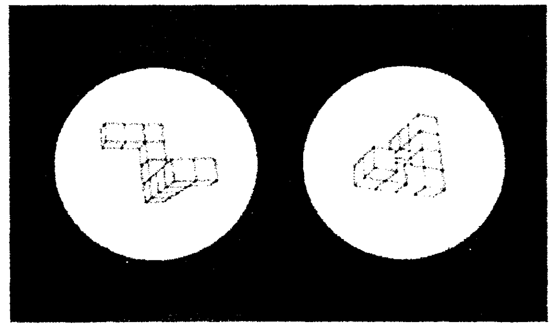


Fig. 2.1. Two sets of computer generated perspective views from the Shepard/Metzler study (Shepard/Cooper 1986)

Fig. 2.2. A Pair of perspective views used in the the Shepard study - views differ by 80 degrees rotation in depth (Shepard/Cooper, 1986)

While creating space, these same principles apply. The 'vision' of the designer is projected by a series of mental rotations, an understanding of the site, and future expectations (requirements). Thought is then recorded in sketch, taking on the form of parti, perspective view, plan, section, and elevation. What if these images could be captured and placed within context, on the site, while designing? The "images" would not be limited to sketch but would include desired architectural precedents, photographs, sound, objects, and anything else the imagination desired to evoke a sense of place. The combination would then become a new form of "sketch". We now have the capacity to exploit this proposal. Will it ultimately change the way we traditionally perceive or create space?

This is also an opportunity to bring others into the thought process of the designer. Accomplished successfully, (if only in part) it would make a significant contribution to the understanding of the process. This is not to suggest that the sketch be replaced in any way, it does call for the enhancement of the tools that are available. As various other graphic media evoke different qualities of style and understanding of concept, the virtual environment as a perspective design tool will also be refined to suit the message.

Other studies have shown evidence in how mental images are constructed and understood. The experiments prove that mental images are constructed "piece by piece in a structurally coherent way"(Neisser 1967; Pylyshyn 1973)(Finke, 1992). Once a mental image is formed, experiments also indicate that they are "scanned for information" similarly to how actual objects are observed and understood (Finke and Pinker, 1982). Perhaps this is why computer animations of objects being constructed (element by element) are so effective in communication. Why not use their principles to create a design environment which enhances mental imagery during the process? Visualization of space through virtual environments logically connects these principles and will be shown effective throughout this exploration. The next critical step will surely be the manipulation of those objects to visually construct what the mind projects, in order to share with others. Although there are currently other forms of VR which are more realistic in portrayal, (such as "Quick-Time VR"), the systems chosen for this exploration were due to the presence of object rather than image. In the systems chosen, the actual geometry is present as much as possible in anticipation of more object oriented worlds.

2.2. Representation Media and the Benefits of Total Immersion

Immersive environments present a view that is very unlike that of an animation or video. The immersed viewer projects their body into the space by associating with it visually, intuitively, and while baring all views of the actual environment. Animation, or screen viewed scenes, are alternatives to 2D representation since they are projected on a two dimensional plane. The sense of scale and intuitive viewing is obviously lost in the screen view. The animation or video also differs from the interactive model since all of the views are well choreographed and controlled by the designer or renderer. In the case of the interactive environment, views are determined by the observer, closely linking the experience with a more actual presence in the space. The interactive viewer is a participant.

2.3. Altering the Conventional Design Process -Client Communication

Regarding client communication, there is almost a conflict of interest where some designers are concerned about involving the client to a great degree. In participatory design scenarios (of highly technical spaces for instance), client input is paramount. If we revert back to lessons learned from cognition theory we might form an opinion as to why some so called "great works" were never built. Architects continue to argue that people in the majority prefer traditional *banal* construction over "*good design*" due to a number of reasons, two of which are: familiarity with " the traditional" and lack of architectural understanding. Apart from aesthetic preference however, if a truly superior(but more complex) design solution is chosen over one that is lacking (but minimal in form) during design, perhaps it is because the client is indicating a threshold in understanding 2D media. Better communication of modern and/or complex forms may ultimately change what is commonly built.

3. System Implementation

To begin a basic investigation we must first understand the tools available today and their limitations. All of the computational goals I have mentioned earlier exist in one form or another but most often are limited in use since the functions are isolated within one software package or platform. This exploration as a whole, has been conducted using a variety of file structures with increasing levels of polygon intensity. This was done to expose the testers to worlds of varying speed and rendering, to finally determine how available formats will be matched with specific communication tasks.

The experiments were either conducted remotely (over the Internet, supplemented by chat sessions, conference calling, or video teleconferencing) or were completed in a laboratory using equipment with limited access. For these reasons the cases remain a series of *explorations* and not controlled scientific experiments.

3.1. File Formats

One of the largest problems with data sharing is the fact that systems and file formats are not likely to be compatible. This leads to the need for file conversion. Error in compatibility may occur within an upgrade of one software package alone, even though the file structure was intended to be of the same type. An example of this is the upgrade within the popular CAD program Autocad (versions 12 to 13). Here, a technological advance in the method of modeling has reduced functionality in backwards compatibility. However, it is possible to use other programs as file converters if a direct translation is not performing. At the time of this writing, file conversion is a large case of trial and error especially among computational models since the database structures vary from program to program. Several programs have proved that although one file extension may be "supported", it could very well not be read by another program which may claim to support the same so called structure. The end result may be in a partial (or complete) loss of data. At this time the only way to combat this is with experimentation unless the vendor specifically states compliance with a specific package. This reenforces the need for more universal file structures.

One of the unifying aspects of the world wide web is that it provides a universal language among browsers (HTML). Other languages which boast cross platform compatibility are quickly becoming popular although they have not seen their potential (to date), these languages include JAVA, CGI (is a hybrid -actually a protocol more than a language), and PERL. The event that makes HTML so successful is that it (the original script) may be read by a variety of browsers which exist on any number of systems all over the world increasing potential exposure and data sharing, and therefore, value. Similarly we have seen an increase in the number of translators available within software packages. The more options available for export, the more valuable the tool.

3.2. Building Cyberspace -VRML and its Extensions

E-mail, chat rooms, MUD's (multi-user dungeons), the World Wide Web; these were the buzz words of 1995 which began a series of debates on the future of space and inception of electronic place. The creation of negotiable objects/geometry has launched a new phrase for 1996, "Multi-user Environment". Suddenly, communication through electronic and digital means has taken on spatial character and the ability to occupy it with others. "Cyberspace" is now inhabitable through a number of services and software packages which use landscapes, structures, buildings, and mock public space as a means for socializing, as an alternate method of searching the web, as a place to build, and is now pointing towards being a location to conduct business. Multi-user worlds have truly become the new "melting pot" as people of all cultures not only chat on line, they project themselves in space with the persona of their choice. In most worlds is common to find a "regular group" of people who occupy the space socially. Within these worlds most of the projections of geometry and structure strangely resemble those of the real world to a large degree. This is in no doubt a response to the way in which humans ambulate naturally. Here, people project themselves in the form of avatars. *[An avatar is a geometric form meant to be a caricature of the person it represents, but not limited in shape or context.]*

Within the gravity-free realm of Cyberspace some architects have already claimed a preference for designing virtual space over built space. In this alternate reality, freedom of expression is unlimited by construction budget, building codes, site constraints, and the physics of the real world. In addition, the project is more likely to be built (and on time). Suddenly, a vast expanse of unchartered territory has been created for unlimited development, ironically, it does not physically exist.

(Case 6.2 examines an actual space communicated as a Multi-user environment.)

Users log into the world and are presented with their own view of the experience as well as a view of others (who are logged into the space). Participants within the space communicate in avatar form. Chat sessions between other users "present" within the space are also supported as well as additional browsers such as Netscape, Mosaic, etc. In essence, the total environment allows the viewer to project themselves within the space they are navigating through while communicating with other users regardless of their position in space. Curiously, most people chatting do "face" each other in virtual space. Since users have "bodies" which occupy virtual space, the activity of searching for interesting sites and being on-line is no longer a solitary activity. Two people who are located on opposite sides of the world might meet at a favorite location in Cyberspace (perhaps a cafe or a virtual pavilion) to begin their exploration (or conversation) together.

It is possible for a person sitting at home alone to attend a crowded international event. Increased resolution of the world in turn, increases the "immersion" of the participant. In this sense, the concept of immersion is not complete but does have some value due to the nature of the interaction with "others" within "space". Even with very limited expression (or no facial/gestural expression), the amount of body language communicated by avatars can be very effective in showing social cues. The medium has perhaps taken on a new definition of "avatar body language". Just as the symbols =) have come to express a smile or approval over electronic text communications, they too have expanded in gesture ;) wink, :D laugh, =0 distress, =(frown, =P~~~~ slobber. It is no surprise that avatars are also moving toward more intimate communication by incorporating hand gestures and facial expressions. In response there will no doubt be new definitions and criteria for designing appropriate virtual space.

Regardless of the challenge, most of these new places curiously appear untouched by architects. One environment called "Alpha World" is focused on encouraging the literal "building" of Cyberspace. It presents fields of green surrounded by texture mapped mountains and comes complete with world building instructions. Its creators encourage visitors to claim a piece of land and "build". Although the software is free for download, the resolution is very pixilated and the overall "Alpha World Universe" seems inhabited by some unskilled or unwilling builders. Another environment called "Cybergate" also encourages world building by supporting external VRML files. Their requirements are more in line with traditional building codes, as the user's world must meet company approval.

Resolution and movement throughout is much improved over many other worlds. The linking of their approved worlds has come to be a coherent series of places with many professional points of interest, some host 3D sites of well known companies.

Fig 3.1. Cybergate browser multi-user environment Two avatars are currently facing the screen owner and are having a chat session in the lower left frame.

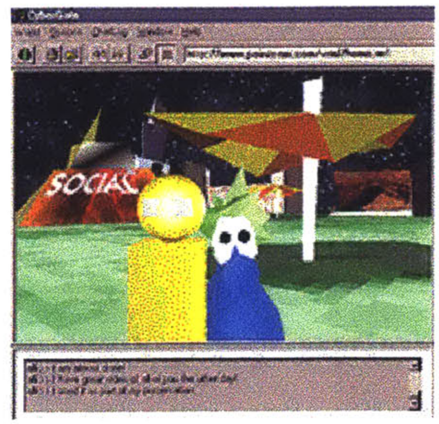


Fig 3.2. Two Avatars posing for a picture in the digital landscape.

(More detailed descriptions of figures found in appendix d.)

3.3. The Future of Networked Simulations

Case 6.1. will show how current tools available over the Internet may be placed together to form a practical application for VRML in creating an acceptable communication of building experience. In light of this in comparison to multi-user worlds, we might take the best of both to predict future developments of communicating three dimensionally over a network. There are many other issues that come into play when considering using "multi-worlds" in a professional setting. Interestingly, different sets of social etiquette and interaction apply from the real world. Since gender is actually "unknown" unless specifically revealed, a certain amount of fantasy is accepted and often expected. All are eager to interact without knowledge of gender, color, race, or religion. Manners are expected and observed and risque conversation is usually taken onto a private chat line. If this concept were used in a professional setting to communicate three dimensional form, there is no doubt that employee "interaction" would take on new meaning since identity is so easily concealed. The major point is that, this is another form of data sharing in real-time. The format allows a low level of "belief in place" (immersion) while sharing common space and objects simulated three dimensionally. It is easy to envision those digital spaces becoming more convincing and simultaneously more immersive in the near future.

4. The Balance Between Realism and Economy

The following sections list technical notes on the methods used throughout the subsequent cases in terms of the compromise between quality of view and accuracy in movement for the systems used in this study. The three keys to believing in an environment are 1) immersion, 2) accuracy in lighting, and 3) and the economy of the file in polygons which allows more responsive head tracking. These points will be made throughout the subsequent cases.

4.1. High-end vs. Desk-top

It is unrealistic that high-end immersive research could be accomplished by an architect *for* architecture anywhere other than academia since it is cost prohibitive. Desk-top systems are quickly making immersive technologies more of a reality in the work place however, with increasing computer processing power and memory capability, and the decreasing cost per megabyte. Several immersive systems released in 1995 were also designed to run on a system as low as a 486 processor ("WorldToolKit", and a turn-key system by "d-Vise"). In addition, most of the VRML desktop viewers now available offer maneuverability with 6DOF (6 degrees of freedom: **forward-backward, left-right, up-down, rotate** left-right, **pitch** up-down, **angle** left-right) through mouse navigation. With these developments, desktop VR is slowly emerging. This investigation takes advantage of the high-end processing power of SGI in anticipation of that power being available in more common personal computing tools. Therefore, all of the following explorations present different viewpoints with various file formats and programs, in search of clues to design, build, and implement synthetic environments, whether they be immersive or screen based.

4.2. Notes on Complexity/Maneuverability - Material/Lighting

Regardless of which system is being used there is always a compromise between the geometric complexity of the scene and the ease of maneuverability. It is now common practice to substitute texture mapping for complex geometry although, some high resolution textures might be more memory intensive. The following studies have taken cues from their specific subjects, the information being exchanged, and the purpose of view, to determine which side the compromise leans. Proximity and the environment scale also help to make that determination. Smaller environments which represent closer quarters and which may be more focused on ergonomics might demand a higher quality of diffuse lighting and rendering to fully understand the distance of the planes, while more urban scaled environments may depend upon texture and ambient light to communicate space at a minimal level. With regard to the representation of more constrained environments, the simulated camera lens used to determine FOV (field of view) becomes very important. In immersed environments, a limited FOV exists within the hardware of the HMD and therefore must be altered within the communicating software if possible.

The FOV and scale are in turn closely linked to the acceptable simulation of movement throughout a space. The units of the model must be translated to a navigation device which correlates to the human scale. An environment may have to be scaled up or down depending upon the geometry translator which communicates with the processor. Once converted, a model built to scale in one software is likely to be proportional in another package but not necessarily in the same units even if units are specified.

Some of the cases will show that a simulation of low-level directional lighting with some shadows more closely represents that which most people consider to be "accurate", rather than overall ambient lighting. This may in some instances provide an additional level of abstraction. Generally abstract form with neutral material simulations and more representative lighting is preferred and understood over poor attempts of texture emulation. Since textures can be used to provide spatial cues in depth (converging lines to the horizon) they are more effective in larger scenes.

Lightscape is one system that was used throughout the cases to more accurately simulate lighting conditions. As the simulations progress in numbers of iterations the mesh also increases in complexity however. Once calculated the files were then translated to inventor format to be viewed immersively within Performer. During the conversion, the file might increase to more than double its original size. It was found that with the current VR configuration used (outlined in -experiment 1, chapter 5) files in excess of 10 MB will cause an unacceptable delay in head tracking. In order to successfully use radiosity models with our immersive environment configuration the following techniques were employed for Lightscape version 1.3s:

- minimize geometry to include the visible polygons only
- specify a coarse mesh within Lightscape - although not sustainable for final professional renderings, emulation of shadows and diffuse lighting provide substantial impact in an interactive environment.
- process radiosity solution to less than 40% of light distribution (this depends up the file size but is a good rule of thumb)further precessing is likely to overextend the file size for tracking.
- compensate for light distribution by adjusting brightness/contrast/ambient values
- convert to inventor for immersive viewing

The file may then be converted from inventor to VRML. This will once again increase the files size. Once converted to VRML, "Level of Detail" nodes may be employed to reduce size and increase efficiency. High precision modelers are also to blame for unnecessary computation. By reducing the accuracy of the Cartesian coordinate values (to two decimal points for example) which specify polygon locations, it is possible to reduce file size by 50%. A freeware script called the "datafat munger" is available on-line and will complete this calculation without any visible differences of the geometry.

4.3. Managing Levels of Detail

One current method of increasing performance in maneuverability while retaining complexity and texture is by incorporating 'level of detail" instructions. In VRML, LOD's are employed with a node specification. This eliminates unnecessary geometry from memory by using a set of instructions which will render the required field of view. Geometry is turned on or off by specifying a maximum distance (usually a circumference) from the center of the element. Once the maximum distance is exceeded by the viewer the geometry is switched off. Instead of completely switching off all the geometry, a replica of the object (built at a lower level of detail) may be simultaneously switched on. Since the action is executed at a distance, the details are not needed, and the processor is free to render objects of higher complexity which are close in proximity. Larger scenes may be broken down into these successive levels of detail, making the experience appear as one seamless environment while providing quick rendering and movement throughout.

5. Experiment 1. (Perception of the synthetic)

Perception of space in total immersion

The first experiment is an expansion of a pilot study initiated in the Spring of 1995 by myself and Owen D. Johnson for Professor Sandra Howell. The focus was a comparison of non-designers perceptions of virtual space to that of an actual space the former was meant to represent. The purpose was to identify spatial perception differences and similarities with regard to orientation (cognitive mapping), visual processing of abstraction, and the ability to adapt synthetic spatial cues for actual.

5.1. Goals

In order to propose a "virtual" environment as a location for future design communication of space we must first demonstrate that the environment is translatable (to the actual space proposed) by the average person. Here we will gather information on how subjects judge space and distance individually within the real world and directly compare the response to those judgements in replica virtual world. By direct comparison of specific points within actual and virtual areas, we hope to understand how accurate the space is being represented (in abstraction and total immersion). By conducting this comparison we also hope to gain insight on how we might improve future virtual world representation. In light of the previous sections, we have shown that some "sacrifice" may need to be made depending upon the system used and the message being communicated. Here we strive to extract information on which (virtual) environmental aspects are effective, and economical.

5.2. Process

The experiment uses immersion to communicate the simulated space. The test subjects were individuals between the ages of 18 and 26. All subjects were familiar with the space being simulated although, none were informed on the actual place. This brought each individual into a synthetic representation of a building they frequent on a daily basis. After being tested in three variations of the simulated space, they were then immediately reintroduced to the actual built space and reviewed the same series of tests.

Fig. 5.1 A participant in the apparatus while, the monitor in the foreground captures a glimpse of his view.

Interviewing, observation, and problem solving were used to gather perception data in each area in order to form a comparison.

The subject was a highly trafficked well known space on the M.I.T. campus; the M.I.T. Student Center. The extent of the model included: the building's first floor (in detail) but without furniture, the exterior plaza (to the edge of the pavement), and an overall exterior abstract representation of the building. The experiment was limited to visual stimuli and its affects on mobility and/or the simulation of mobility within a space. Testing consisted of three phases using three versions of the model. Model 1 was considered an "accurate" representation, Model 2 was the same model with a variation in lighting, Model 3 distorted the original geometry by moving the locations of partitions, columns, and by removing geometry.

The System

The system used was comprised of a Silicon Graphics Onyx Reality Engine II (with two processors), a Silicon Graphics Indy, a Polyhemus tracking system, and a VR4 Head Mounted Display. Navigation was via a voice recognition software system known as HARK. The subject is visually immersed in the environment by using the HMD. The method of navigation is by looking in the desired direction of travel and simply stating the movement commands which were in this case "walk, stop, faster, backup, and reset". At a later date, additional elevation instructions were added to the command list (Johnson, 1995). The central graphics program used was "Performer" by Silicon Graphics. The composite system is one that was originally created for U.S. Naval research for the purpose of instructing officers to guide submarines into harbor. *Further detailed specifications of the system are referenced in appendix a.*

Conditions

The total experiment consisted of three phases; the simulated space, after simulation interview, and testing/interview within the actual space. The use of three variations of the model allowed data gathering on perception changes within the simulation alone.

Through a series of questions and routes within the space (directed and free) the following areas were tested:

- Site/landmark/object identification
- navigation, orientation and memory
- depth perception and distance estimation
- affects of simulated lighting
- affects of simulated materials (texture mapping)

Model 1: employed a fairly precise geometric representation of the actual building with dimensions taken from plans and details modeled from photographs. Testing began by bringing the subjects into the virtual space to allow time for familiarization, and navigation technique. Light and color were used with some texture on the floor. A low form of lighting adjustment within the model editing program allowed each object in the simulation to be lit ambiently. Due to incompatible conversion between software packages, the original color information programmed was interpreted differently by the viewing software. For this reason, the colors within the final simulation are exaggerated.

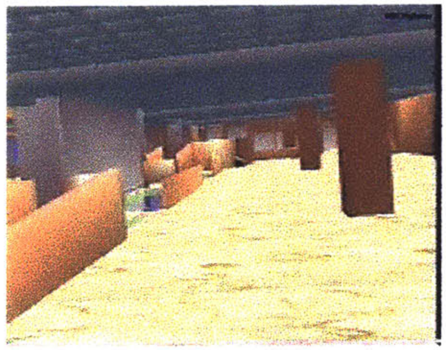
Model 2: contained the same structure as Model 1 with lighting, color, and texture being the only variables. Lighting was severely decreased on the interior presenting a much more flat appearance to surfaces. All textures were removed and the colors were reduced to gray overall with the exception of the ceiling plane. Using these variables in a comparison established and reenforced theories on how they (light, color, texture, in combination) affect depth perception and distance estimation.

Model 3: contained an altered structure. The ceiling plane and entire top of the building had been removed, all of the column locations were shifted, and objects were added/removed. The variables of lighting, color and texture were reverted back to those similar to the initial conditions.

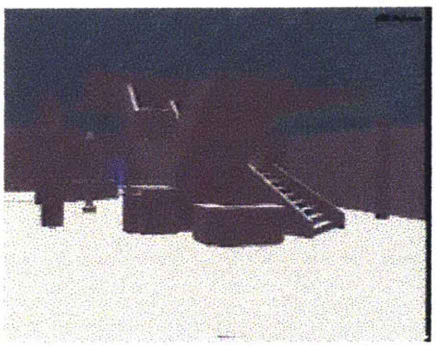
In the second phase, the subjects were brought out of the simulation and allowed time to relax. They were then interviewed to gather information on:

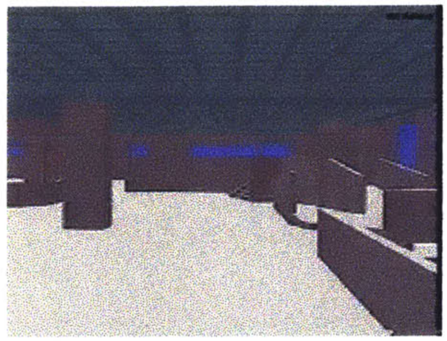
- comparing their simulation experience with the two dimensional plan
- impressions of the overall simulation experience
- personal data - *which confirmed area of expertise (as being non-design/architectural) contact with the space on a weekly basis (familiarity), computer experience, and physical effects if any.*

Detailed description on the following figures found in appendix d.

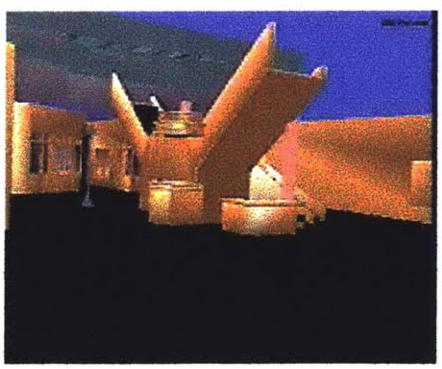


Figures 5.2., 5.3.
(respectively)
screen capture of Model 1 views within HMD.





Figures 5.4., 5.5.
(respectively)
screen capture of Model 2 views within HMD.



Figures 5.6., 5.7.
(respectively)
screen capture of Model 3 views within HMD.

During the third phase the subjects were brought to the actual built space for further interview and comparison of perception. The intent was to reiterate some of the questions on distance estimation to establish a baseline for how they perceived distance and size in reality. General impressions of the space after experiencing the simulation were also gathered as well as suggestions on how to improve the experience.

Data Collection Methods

Field notes were collected in parallel with video of a) what was viewed within the HMD, b) the external view and voice of the subject, while in the apparatus, c) final interview at the actual built site. *The questionnaires and methods used are provided in appendix b.*

5.3. Findings

Table 5.1.

Site Recognition	Immediate Interior	Interior	Exterior
Number of Subjects	2	1 + pretest	4

All subjects recognized the synthetic space as the Student Center First floor, although at different time intervals. Two of the subjects recognized the space almost immediately , two recognized it from the interior, and the remainder from the exterior.

Table 5.2.

Striking Differences	Color	Furniture/objects	Lack of people
Number of Subjects	4	2	2

Most striking difference between the model and the actual space.

Table 5.3.

Model 2 Changes	Change in structure	Color	Lighting
Number of Subjects	5	2	0

When the scene changed to the dimly lit (more abstract) model, the majority of subjects commented on a change in structure, even though no change in structure occurred. None commented about the lighting.

Table 5.4.

Model 3 Changes	Change in structure	Color	Lighting
Number of Subjects	6	1	0

All subjects responded to the structural changes which did take place in this case. Little comment was made on light and color.

Table 5.5.

Recognition of light source	do not know	top of walls	from above	windows
Number of Subjects	3	3	1	1

There were no direct light sources within the scene. The editing program "lit" objects individually and ambiently. The correct answer would have been "from above" or from the tops of objects (windows, walls).

Synthetic Space - Distance estimates **Table 5.6.**

Individual#	1	2	3	4	5	6	7
Model 1 col	25'	25'	40'	20'	20'	25'	35'
partition	3.5'	3.5'	3.5'	2'	2'	3'	2.5'
floor to ceiling	10'	10.5'	12-15'	9 or 10	9'	12'	12'
Model 2 column	no change	no change	no change	no change	25-30'	40-50'	60'
partition	4'	3'	3 -3.5'	no change	1.5'	no change	4.5'
floor to ceiling	12'	15'	10-12'	no change	8'	10'	18'
Model 3 column	not available	same distance	have changed	not available	no change from #2	has changed	same as model 2

Actual Built Space - Distance estimates **Table 5.7.**

Individual#	1	2	3	4	5	6	7
col	25'	35'	60-65'	25'	35'	50'	35'
floor/clg	11'	12'	10-12'	10-12'	8-9'	10'	12'
partition	4'	3.5'	3.5	3'	3'	3	3'

Actual Dimensions of the Model:

- distance between columns = 24'
- height of the referenced short partition = 3.5'
- floor to ceiling height = 11'

Figures 5.8. & 5.9. (respectively), showing test subject during HMD phase and later during interview in actual space. *(More detailed description in appendix d)*

5.4. Conclusions and Residual Data

The data, although not a comprehensive study does form identifiable patterns to yield interesting and often surprising results. The approximate time within the HMD per subject was 20 to 30 minutes. All of the subjects made a point following the simulation to report how "enjoyable" the event was even though most of them suffered the short term affects of motion sickness. Even with these symptoms, all encouraged the use of the technology to communicate space. Some also commented that although they frequently occupied the actual site, the experience of the simulated space had changed their views of the space. In fact, the simulation was a more accurate representation then previously thought, this was realized when visiting the actual space immediately after the simulation.

The patterns shown in the findings point toward a successful interaction within the apparatus and the ability of the subjects to understand the forms and to comprehend their own placement within the space. This was effectively shown in the distance estimation comparison. In almost all cases the distance, height and orientation estimates of the simulated space were very close to the actual. We can see that in one case the estimates are exaggerated however, for that individual, they are also exaggerated in real space indicating poor distance estimation in general. In one instance, the distances of the actual space seemed larger to one individual while his estimates of the simulated space were much more exact.

6. Experiment 2. VRML and Practical Applications

6.1. Final Design

This case was a first attempt to apply available Internet applications to an actual design project. All the applications used here were available free of charge via the World Wide Web. Most applications are still being developed and had some current form in beta at the time of investigation. The object was to take an actual building program that had endured the design process and to place it into a simple environment which simulates the model as a three dimensional form for the purposes of :

- transmission/data sharing over the Internet
- communicating space in an interactive environment simulating three dimensional form inexpensively.
- exploring multimedia capabilities through hyperlinks

In this case the design had been completed and construction had not yet begun. The structure of the experiment stresses the design of the environment as a tool while allowing those familiar with the project (A/E, Deisgn Agent, and Client) to test the product before ever experiencing the building in its material form.

VRML was chosen for this task since its future developments are promising in terms of increased interactivity, improved rendering, and as a multimedia information source (through hyperlinking). This case strives to incorporate a 15,000 square foot building in detail. The level of detail will include window frames/mullions, glass, and some millwork. To my knowledge this is one of the first buildings (an actual design project) of this magnitude and detail that has been successfully placed in this format and communicated over the Internet.

Given the limited use of the medium (VRML), it was first necessary to explore how such a conversion would be possible and effective. If the model could be successfully translated to this form, then the next task would be to search for model formats (singularly and with other applications) to design an environment that would allow a coherent connection between other forms of information planned to be hyperlinked. Other forms of information besides the model would potentially be unlimited and may include text, sound, video, actual CAD drawings, additional models (perhaps more detailed), and other still images (such as renderings of the space/model; photographs of the site, building materials and finishes). By combining an interactive three dimensional representation with more traditional two dimensional media the message is clearly enriched. The model provides a direct and immediate translation of the two dimensional data, communicating traditional plans, sections, and elevations into their perspective intent.

Besides being a communicator of form this browsing environment might also be used as an intelligent reference by incorporating search engines and comment programs allowing the tool to be used for information exchange. Comments, on the design for example, might be directly attached to the document (or model itself) while the client is navigating through the simulated space. Additional information on one specific aspect of the design could be "searched" by using database filters and then "found" by using hyperlinks.

The designed browsing environment could be formatted to address several types of audiences. For example, one set of links might appeal to the client while another linking path might be more useful to the design team as a reference, and still another path might be used for either the client's advertising or A/E portfolio of works in progress. Another path might be more oriented towards the coordination of disciplines (architectural/structural/mechanical/electrical/civil) in terms of confirming overlap during the design process, and as a facility management tool after construction has been completed.

6.1.1. Program

The subject project is a new medical facility which will provide a family practice clinic with ancillary support and support services. The site is located in Fort Carson, Colorado Springs, Colorado and is 1/4 mile east of Evans Army Community Hospital. The building will primarily serve the 10th Special Forces Unit and their families. A new complex for the unit has recently completed construction and is also located in close proximity to the site. The character of the terrain combines rolling hills surrounded by mountains. The building will be sited such that the northern wall is cut into the hillside allowing the main entry elevation of the building to have full southern exposure.

The design was completed by Nix, Mann, Perkins, and Will (Atlanta, Georgia) with the U.S. Army Health facility Planning Agency (Office of the Army Surgeon General, the Pentagon) as the design authority and client. The ultimate clients or users in this case are the staff from Evans Community Hospital and the members of the 10th Special Forces Group. ***All parties were used to test the product.***

The main departmental functions within the facility include: Family Practice Clinic, Physical Therapy Clinic, Pharmacy, Pathology, Audiology, Optometry Screening, Reception/ Medical Records, Command Suite/Administration. These departments were later incorporated as camera "points of interests" (like book marks) within the model to allow quick reference and navigation with the capability of animating between chosen views.

6.1.2. Process and Parameters

The VRML browser selected was a product called "Live3D". Although the current rendering capabilities are low, it ensured the least amount of errors in terms of parsing the VRML 1.0 specification and supported all the available nodes within the 1.0 specification. This choice limited the amount of possible errors during the first conversion process. Much time was devoted to experimenting with the various browsers (most in beta). Other products incorporated more advanced features and rendering, but did not support the more fundamental code attributes.

The modeler used for this project was Autocad version 13. Autodesk are the makers of Autocad and 3D Studio (a complementary rendering program) and have recently formed a new part of their company to support more web oriented programs. Currently, these include a VRML add-in for 3D Studio and a Netscape Plug-in that allows vector based drawings to be viewed in detail within Netscape. In this case two methods of conversion were found to be successful with manual adjustment of the basic VRML code. In terms of modeling, surfaces are better employed when possible (rather than solids) to keep the polygon count low. Planning in the modeling stage will speed up the rendering and conversion process. Through experimentation, successful translation was found by addressing the following issues:

**Note - a outline of successful conversion steps are found in appendix c.*

- Geometry - plan to model only the forms that will be visible.
- Block instances
- Rotation /orientation of the navigation plan before and after export.
- Scale (must be scaled up by a factor of 6 to 9 times for architectural modeler and appropriate camera view)
- Layering in terms of materials, and future hyperlinks
- Viewer position at eye level within the VRML world - world position
- LOD nodes and WWWAnchors and Inlines in relation to an architectural scene
- targeting hyperlinks to other frames
- Manual alteration of the translated code framework

6.1.3. Designing and Implementing the Environment

By studying the impact on users in immersed environments we may find an acceptable level of abstraction for use in screen based environments. One of the more important aspects here was in choosing a JAVA capable browser that allows a potential real time connection between the conceptual plan and the interactive perspective view. Also the ability to target frames within the same screen opens access to attached information without expelling the viewer from the interactive model.

At this time there are two ways to accomplish this, one (also shown in example, Fig. 6.1.) is by using an embeddable application. In this case there were two, the VRML viewer and the vector drawing viewer. The other method is to use a stand alone program and to allow the 3D browser to generate another HTML browser when accessing additional information.

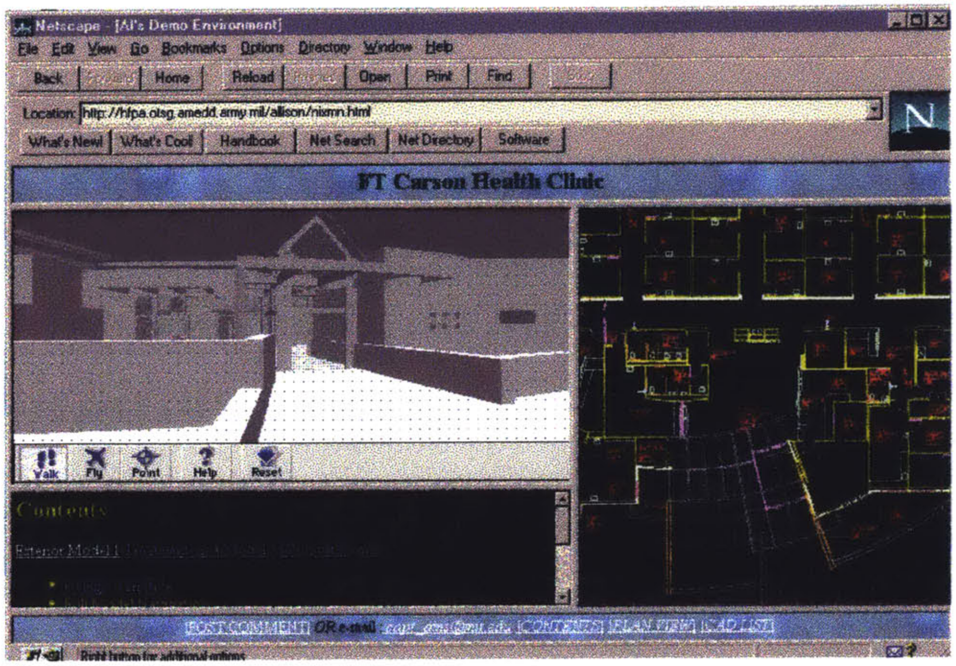


Fig 6.1.
One possible view within the designed environment.
The upper left displays the VRML browsing window - -with a maneuverable model loaded- -right window with manipulatable cad drawing, lower left window displaying table of contents to hyperlinked information.

(More detailed description on the following figures found in appendix d.)

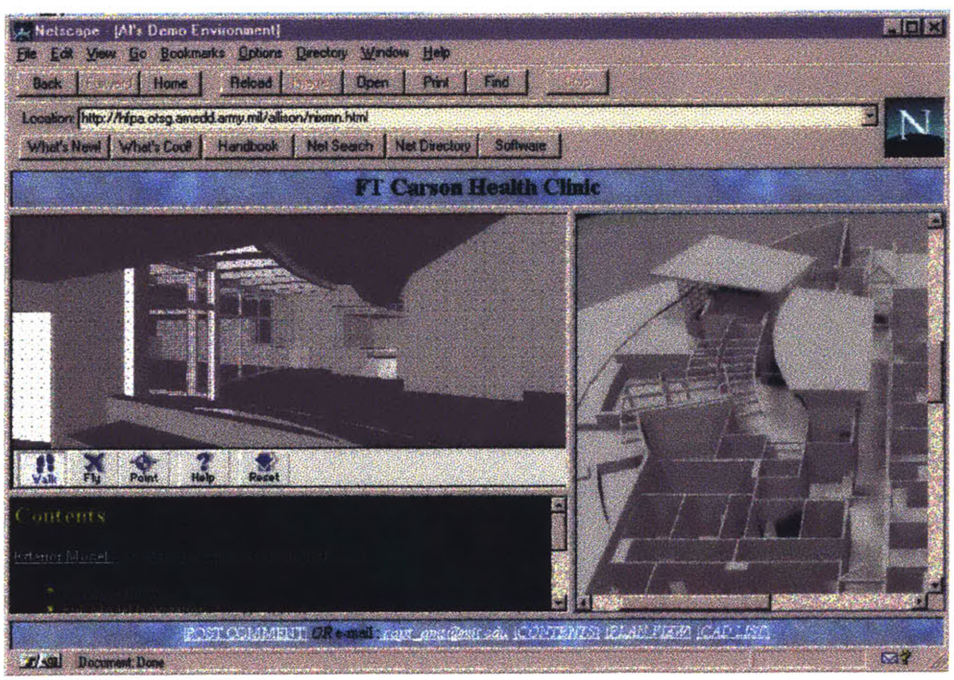
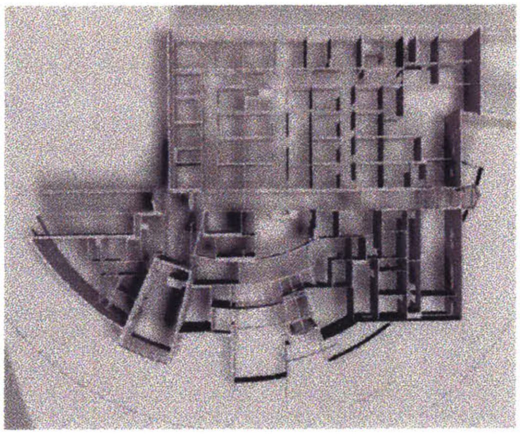


Fig 6.2.
Another view within the designed environment. The upper left displays the VRML browsing window - -with a maneuverable model loaded- -right window a with a conceptual still simulation, lower left window displaying table of contents to hyperlinked information.



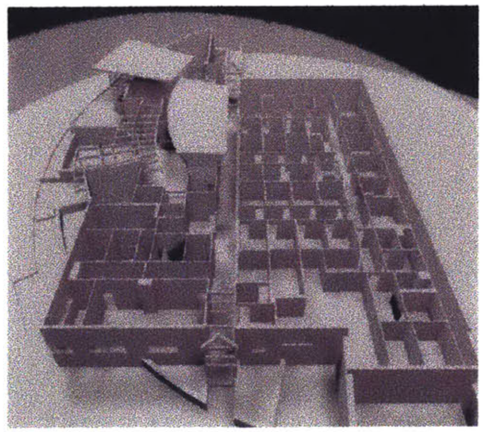


Fig. 6.3. **Fig. 6.4.**
Conceptual simulation stills used in combination with real-time simulation

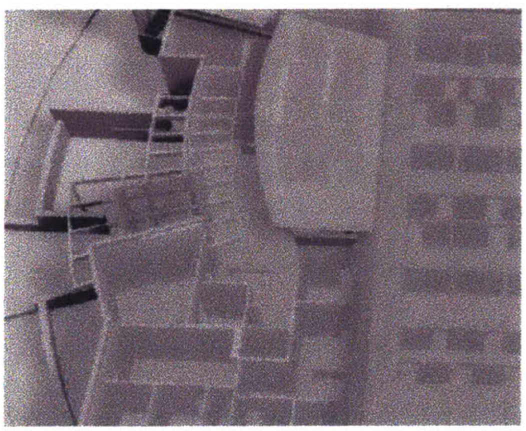


Fig. 6.5. *Conceptual simulation* still

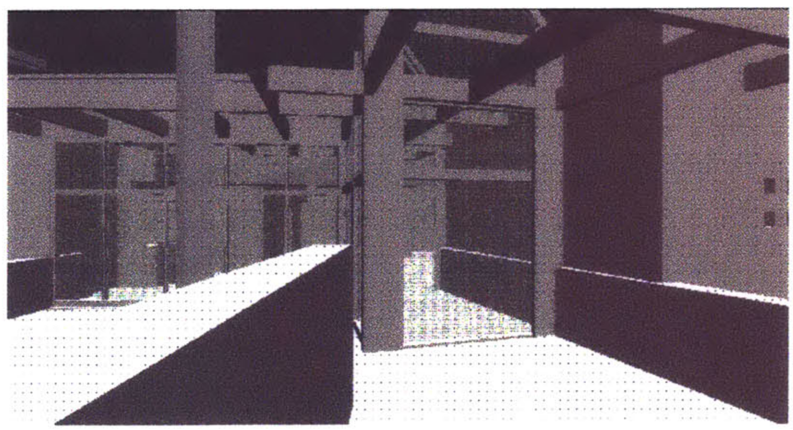


Fig. 6.6. Screen capture of real-time simulation (Front entry)

The combination of images chosen to form the environment are detached from imitations of texture. The combination of images are abstract to prevent confusion (of the client) by simulated colors since these cannot be represented in a photorealistic manner within the VRML model at this time. Photographs of the actual finishes were hyperlinked to respective elements within the model to be viewed with any combination of information. Here, a list of data "types" have been hyperlinked to the model elements and appear in the lower left frame. Items (such as finishes for example) are in turn linked and targeted to the right frame making the original "loop" of information visible and accessible at all times. Even though the model was left in an abstract form for this experiment, it appeared to successfully communicate design intent. By using other more highly rendered raytraced stills in combination (with similar abstract material), a conceptual overview acts as another frame of reference during navigation. Furthermore, since hyperrealistic stills can be accurately produced, they may become a hyperlinked extension of the real-time model. An abstract/hyperreal comparison could be used as a reference by specifying a camera view within the VRML model, specifying a hyperlink to the rendering, and then using the same camera view for the detailed rendering.

At any time during the experience, a viewer may access a database hotlink (which is always visible regardless of browsing) to add a comment about the design. The comments may be later filtered and viewed by key word or subject. A more advanced goal, would be to reverse the database search by not only finding and organizing comments, but also to view the relevant frames of information to include; perspective view, cad drawings, text, photographs, etc.

6.1.4. Data Collection

Aside from the process, interaction with the environments has taken place with the A/E firm, the client, users, designers and non-designers. The program was also presented to Major General Cuddy. *[General Cuddy is an Oral Surgeon and the Deputy Army Surgeon General.]* Overall, reactions to the environment were extremely positive. Although each group experienced a demonstration separately, and had different concerns, some of their requested needs overlapped. While building the model and working with the architects, some discrepancies in the plans were found. If the model investigation had been initiated earlier in the design process there might have been a cost savings in eliminating changes which will now take place during construction. Earlier on in the design process several changes were made to the concept.

The original scheme handled the proportions more delicately, incorporated an alternate roofing solution, and allowed more natural light to penetrate the clinic's main circulation corridor. Changes were not directed by architects, but by the Value Engineering process as a cost reduction method. If the amenities of the design could have been communicated interactively to show the differences between the Value Engineering choices and the original design, the original concept might have had an increased chance of survival. This assumption is based upon the comments received from those interacting with the design.

Fig. 6.7.

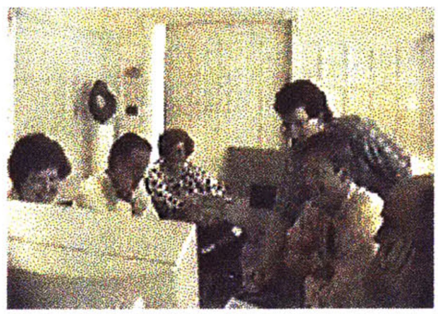


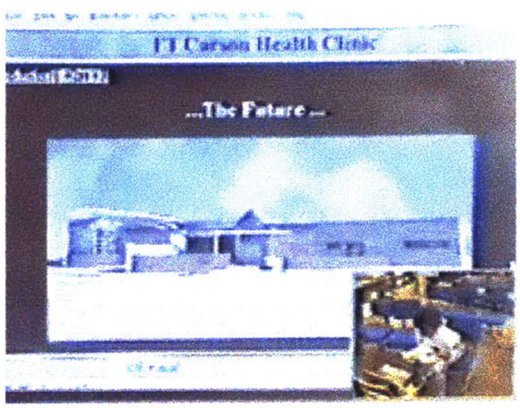
Fig. 6.8.

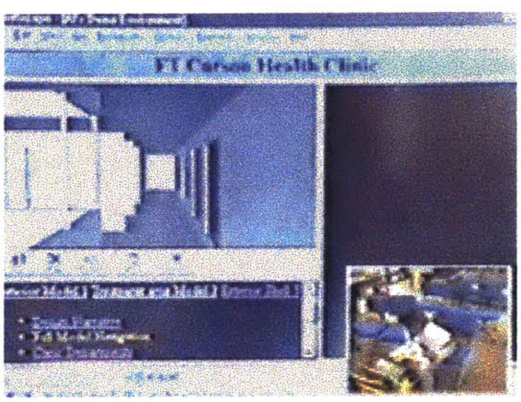
Fig. 6.9.

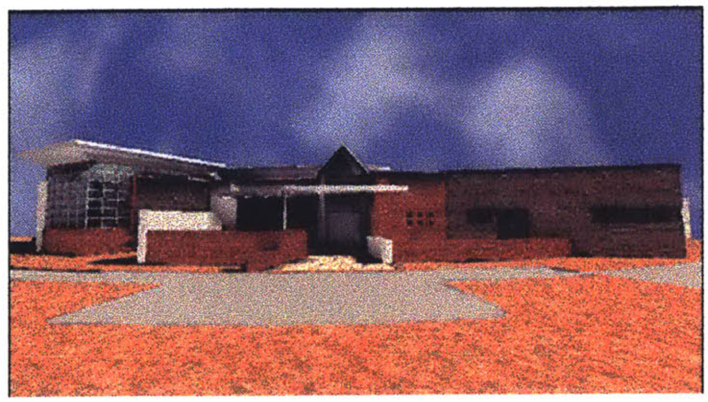
Figures 6.7 -6.9. Video capture of the architectural project team in Atlanta interacting with the VRML model and Netscape composite environment while receiving instruction from M.I.T.

Most reactions were very similar. Comments responded to the environment as a combination of linked information and separately, as subjects interacted with the model alone. Participants in the design professions reacted to the experience as a "*clear spatial communication*" of the intended project. Several architects felt that exploring the model in this manner was very comparable to visiting the building for the first time, even though there were no materials attached. Most also felt that the representation was exactly what they had imagined the space to be. One unexpected comment came from a member of the design team: "*I did not realize the lobby was so complex, on the other hand, I expected PT (physical Therapy) to be much more than it is. In reality it is really too shallow to get the full affect of the sloped ceiling.*" After showing unfamiliar non-designers prints of plans sections and elevations, they were very surprised in experiencing the interactive model. Non-designers were surprised most by the interiors, in that they had only been able to imagine the room size (from plan), Overall the experience was a complete change of understanding from the non-designer point of view.

Comments on 2D media indicate a little understanding of elevation, some understanding of plan, but rare (or no) understanding of how plan-section-elevation work in combination. Once in the interactive view, non-designers quickly picked out objects they were not able to identify from the drawings.







Figures 6.10 (upper left), **6.11**. (lower left)
Screen captures of environment testing via video teleconference involving architects from Washington D.C. and M.I.T.
Lower right corners of each figure show camera view of MIT location with computer screen from Washington in background.

Fig. 6.12 (right) Computer rendering of building also shown on environment main entry page.
More detailed description provided in appendix d.

Most of the interaction and explanation of the system was accomplished remotely without ever having met some of the people involved face to face After a few moments of familiarization with navigating, attention turned to the subject building. In essence, participants forgot about the method of viewing and were engaged in a discussion of the design. This was very much a desired affect and demonstrates the tool as being a useful form of communication. The linking of information other than the model was necessary in terms of wayfinding for those unfamiliar to the design (since no signage was placed in the model). Combinations of the interactive model with still simulations really "brought the building to life" as commented by one viewer.

6.1.5. Comments for Process Improvement & Lessons Learned

Navigation and Collision: Some users and designers asked for improved navigation. Control was later regulated by using key strokes instead of the mouse. Another solution for making navigation more intuitive would be to use a gameport and joystick . Another method of control would be in the manufacture of the VRML file by using more Levels of Detail and therefore having smaller files experienced at one time. Although most people did not seem to mind the fact that collision was not included in this version, the lack of collision does make it difficult to navigate and easy to become disoriented. Several browsers (including the one used here) have collision preprogrammed and allow control with a simple on/off toggle. Most however do not recognize anything other than primitive geometry which makes the switch unusable in complex environments.

Orientation: One of the more important cues to utilizing a series of perspectives is the connection to the overall concept. Being able to interactively pinpoint a user location in perspective within the overall concept plan is absolutely necessary as a point of reference. This was also found in experiment one and was emphasized in comments throughout this case. The perspective/plan interface currently exists in a software package tested in case 6.2. Investigation is now underway to develop a script which will support this connection for any model in VRML. A lower form of this interface can be accomplished with HTML alone by creating "hotspot" links within the model. The links may be named something such as "where am I?", for instance, and linked to a screen shot of the concept which pinpoints that specific geometry. This of course is inefficient and would be prohibitive in a larger model.

Lighting: More comments on the lighting were received from the architects than from any other group. They felt that since the level was low (during the experiment) that people other than designers would not understand the vertical planes while navigating. When exposing the environment to non-designers however, this was not the case (since the FOV was increased) as was also shown in experiment one. Regardless, the lighting and materials within the VRML file may be altered directly within the code, and should not present any problem in future projects. Lighting on material may be adjusted by object, and directional or ambient light may be added to the scene as a whole.

The fine tuning method for lighting will either come from more experience with the code settings or better VRML building/conversion tools. Other browsers presented much brighter and more subtle lighting within the same code but had other bugs that could not be overcome for this experiment.

Method of linking information: The method for linking other external information was accomplished in three ways:

- quick links to a few major interest points- which are always visible in the environment
- Table of contents which lists all major groups and provides links to them
- links to model elements directly - which in turn presents a text list of all types of information on that item (other models, photos, narrative-sound or text, video, etc)
- User -visitor comments on the project were linked with a pre-authored script

These proved to be very successful in combination and were well received in terms of accessing any information at any time while providing a quick method of returning to a previous point.

Other links requested by the users include:

- a direct hyperlink from the model to the specific area on the cad drawing (and reverse). This has now become possible within the last few weeks according to recent plug-in software development claims on-line.
- an integration of other proprietary software to include more sophisticated comment programs and project status and management programs
- addition of on-line chat room - which would keep a record of the conversation
- addition of more sound narrative links - users felt that although hearing sound is a slower process that reading, they could listen (and enjoyed listening) to narrative while accessing other information.
- dimension information in interactive perspective

Other Comments:

Another link that was not requested but seems a logical next step is the incorporation of screen shots with "redline" capability. If one could redline the model or drawings directly from the browser and record with a comment to submit as a link, the tasks of correcting and collaborating over a distance would be improved. One of the better known JAVA applets generates a script which will allow the user to "draw" directly on a webpage while in browsing mode. If a similar tool were incorporated here the use would be immediately practical.

6.2. Multi-User Environments

This next case uses a specific software which supports multi-user environments, "Cybergate" by Black Sun Interactive. In this case, a direct link between the navigators location in plan is correlated to the user view in perspective. The main point of interest with this environment is that the method for browsing the web has now taken on a sense of place. Three dimensional VRML structures have been lit and rendered, and hyperlinked to other 3D and 2D locations .

This essentially creates a new method for browsing the web by associating landmarks with subjects rather than menus. The viewer is able to save links in the traditional way but the method of finding new links also involves navigation of a simulated three dimensional space. In this format, a visit to a new site is likened to visiting an actual place. The other important point to this case is that it a "multi-user" environment which means that one model is accessible to many (as many as the web and server will allow) simultaneously, in the ability to read and experience the file.

This case emphasizes the many possibilities of maneuverable form becoming more prominent in Cyberspace. The intent of the creators of VRML and also Cybergate was to link worlds to form "place" which only exists over bandwidth. If more creators of virtual space linked their worlds in this manner, it would be possible to have a " virtual space" which physically exists on hard drives all over the world (created by people who have never met). The experience would then be accessible from any location in the world and would separated by boundaries of hyperlinks. This combining of worlds from other users and locations may be accomplished with most other VRML browsers and the implementation of the WWWInline node, however only a select few support multi-user functions at this time.

6.2.1. Process and Parameters

The process for conversion of an architectural model to conform to this environment is similar to that in experiment 6.1, since it is also VRML based. This browser is still in beta and restricts which worlds may be "Inlined"(reference within the code which calls models or model parts from various URL's), therefore some nodes are currently not supported. Cybergate provides a list of additional specifications that must be checked within the converted code in order for navigation to be more meaningful.

The model for a multi-user environment is centered around the average avatar eye-level. The walking plane is once again the XZ plane (as opposed to the XY plane which is the default in many modelers including Autocad) this may have to be raised since the models in Autocad might have to be scaled up in order to appear relational in scale to the average avatar. Other than these points, the code should follow the same basic principles as in the first case. Hyperlinks may also be attached and linked. "Fast Rendering" within the browser should be turned off to reduce artifacts caused by lighting and material. Ambient lighting quality should be manually removed from all material if created by default within the initial conversion. Is it also possible to program collision within the model but time consuming at this point since once again, only simple primitives are supported. This means that complex forms must be broken up into primitives and separately layered for specification to include which side is the boundary is accessible. A wall with an open door in it for example, could not be singularly programmed for collision since (as one object) the door opening would not be recognized. This example would have to broken down into two primitives (one on each side of the door) and separately layered so that the geometry coordinates will be in the proper hierarchical structure and recognizable after conversion.

6.2.2. User Interaction and Comparison of Environments

The Carson Health Clinic model was also placed in this format and experienced by several of the original participants while also being opened up to the entire Internet. The participants were in remote locations and communicated through the chat window. While the environment was being explored by staff, two unidentified "visitors" wandered into the world, navigated up to the front of the building and entered -- with comments on the building--

Since this browser incorporates and confirms many of the lessons learned in the previous experiment, particularly "eye-level perspective" to "overall perspective" correlation. It also incorporates several other degrees of freedom for the viewer which enable the participant to move head tracking without altering body position for a more meaningful, more intuitive interaction. Since this is a proprietary system it cannot be redesigned to incorporate the information in the previous example. It can be used in conjunction with Netscape information however, while using the navigator for browsing 3D simulated environments. Two main limiting factors are 1) possible inconsistency in lighting among remote monitors, and noncompliance with the LOD node which makes representation of an entire building in this format difficult. One method to overcome this would be to use more barriers (doors) and hyperlinks to break up the file.

Another difference that this environment presents besides opportunity for more texture without degradation of speed, is the degree of freedom to the observer. "Quick keys" are a manageable substitute for a Joy-stick and also allow the viewer to look up and down within the space without becoming easily disoriented. General movement is very smooth and much quicker that most other parsers will allow, the rendering engine is also noticeably improved. The fact that others are viewable within the space adds a certain sense of scale to the environment regardless of what props may exist in the scene to give visual cues.

After maneuvering for a short time with others in the environment, one begins to associate themselves as being "within" the scene, and the geometry then takes on the character of a building. This is a much different experience than browsing with a two dimensional web browser or manipulating a VRML model in a single-user environment. This is also the same principle that makes more sophisticated VR environments successful over most screen based viewing: a direct association with the environment and (in this example) a mid level of immersion.

Observation of characters in a space have shown that they tend to relate to the space similarly to that of an actual space. This is most likely a response from the navigation, orientation, and gravity constraints placed on the avatars, which are similar to reality (with the exception of hyperlinking or "beaming") Beaming allows a direct transfer of avatar body from one location to another my clicking directly on the desired point of entry rather than navigating the body directly to the gate. An unusual situation exists where you may exclude people visible in the area from your private conversations, by choosing a private chat room. Electronic business (and personal cards) are also exchanged among visitors.

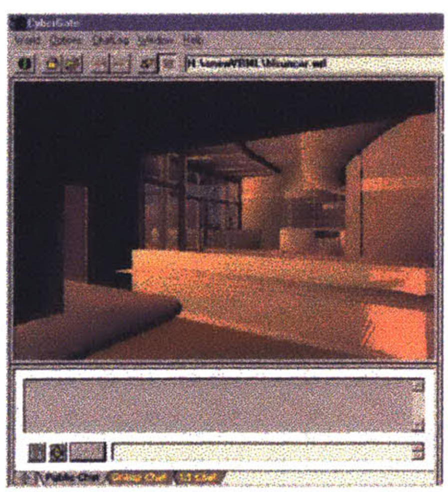


Fig. 6.13.

Cybergate multi-user browser transmitting the Carson Health Clinic (interior view)

7. Experiment 3.

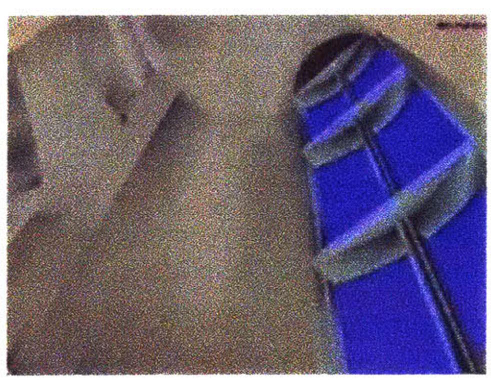
Using Total Immersion to Impact the Architect's View

Reverting back to immersive environments, this case combines VR and the point of view of the designer to examine how mental imagery is altered by experiencing form immersed. Both cases 7.1. and 7.2. involve architects and unbuilt form. The first example involves an actual program which was designed but never built, the second involves abstract form and is not intended to be built.

7.1. Exploration of Unbuilt/Work in Progress

This case uses the an investigation of the Mikveh Israel Synagogue originally designed by Louis Kahn. Due to disagreements with the clients, Kahn departed the project and the design was never built. Until now, this project was only visualized in miniature and in two dimensional sketch form, some of which were unresolved in design as the construction of a computational model proved. The pursuit of a better understanding of this project and other unbuilt works came during the Spring of 1996 at M.I.T., and was initiated by Kent Larson and Takehiko Nagakura. With a team consisting of myself, Mark J. Sich, and Daniel Brick, we began to model and render the project site. The ultimate goal of the effort was to create a replica that is heightened in realism and also interactive in experience. In preparation of this, we were eager to enter and explore the buildings at full scale using the immersed VR environment.

Fig. 7.1 (left) showing participant in apparatus while monitor captures real-time view.
Fig. 7.2. (right) screen capture of interactive views (main interior space)



Figures 7.3. & 7.4. Screen captures of interactive HMD views.
Left - view down into main space w/ pews & chandeliers.
Right - looking up into one of the 54' high cylinders.

In the spirit of Kahn, the project was a study of light and form. For this purpose we chose the Lightscape Visualization System to study the interior spaces as they interact with natural lighting during the varied times of day. After polygon optimization, the model was rendered to a minimal level for the purpose of exporting to the immersive environment. By increasing the size of the mesh within Lightscape and limiting the number of iterations to yield a result under 50% light distribution, a suitable size file was generated for maneuverability. The ambient and brightness levels within the space were increased slightly to improve visibility. The files were then exported to two formats, inventor (.iv), and VRML. One format would allow immediate access into the building at full scale while the other served as a base code for adding additional information to the structure via hyperlinks.

Our first encounter with the space was very revealing. Before entering we had setup a number of interior renderings for preliminary raytraced stills. In doing so, many vantage points within the model were explored but none captured the feeling of the space as the series of moving interactive views of the immersed experience. Would Kahn approve of our interpretation? Although depicted beautifully in sketch this was indeed the first time anyone had experienced the form of the interior at full scale. Renderings of the space are telling and may become hyperrealistic but neither they nor an animation can convey the space from the vantage point of full scale. The series of moving stills revealed surprising points about the building even though it is rather simple in form.

One of the debates we had early on in the process concerned the addition of the light fixtures within the space. The surviving sketches clearly showed the placement and type (with one variation in shape). The form suggested that perhaps they may have been designed by someone on the design team other than Kahn. Including them would greatly increase the polygon count since each lamp demanded a globe, and would perhaps make navigation within the model impossible. It was decided that a compromise should be made in the initial effort and the fixtures were placed but the globes were minimized to cubes. The radiosity renderings looked interesting but the experience made the reasoning for the fixture placement fully apparent, even though they are somewhat abstract.

The only scale cue within the building were the pews and even these are distorted to some degree. The height of the structure is quite grand and is so high it forces one to disassociate human scale from the building once again. The placement and structure of the fixtures however form a datum between the bowled ceiling and the finished floor. This addition completely changed the experience and was best realized while "walking" through the space. Other constricted circulation spaces were also revealed during the immersed walkthrough and can be best understood through observing a series of moving frames interactively. The smaller spaces could only be rendered effectively by using a distorted camera lens to encompass the view. With interactive viewing however, the FOV remains constant, while head/eye movement collect information on the multiple vantage points to form a complete mental/visual picture of the space.

7.1.1 VR, Hyperlink Technology, and the Three Dimensional Archive.

This environment has been experienced in a number of ways and in different formats such as: 1) a VRML file with a browser tracking an HMD (Johnson, 1995); 2) as an inventor file translated from Lightscape and viewed with Performer in an HMD, and 3) as a VRML file within a browser on screen. The result was an increased learning experience within the space via the immersed views. This was then supplemented by creating a historical archive with the screen based version, linking additional information. If the browser and HMD could be linked with an interaction device (mouse, data glove, etc), the use of sound, images and text could be combined for a total immersed interactive tour of the building. In its lower form, this could be combined with the program in experiment 6.1. to communicate the design on-line, providing a low level interactive experience over the Internet. During the reconstruction process, there were several areas that remain a mystery in terms of Kahn's intent. If this model were shared digitally, then students might attempt a multi- dimensional discussion of what the other options might have been, by providing design examples in three dimensions.

7.2. Student Abstract Design

The final case is one which involves an architect and abstract structures. The structures investigated were created by a program authored by Jeffrey C. Krause who is the test subject of this case. Forms which are architectural in nature are created by the computer through a limited series of instructions, and by objects with various behaviors interacting with each other. For several reasons investigation of this case using virtual environments was very revealing in terms of designer action, form description, and perception of the form.

Since the products of the computer are in this case abstract to the extreme, the products are practically devoid of any architectural iconography. The models themselves are comprised of structures which "create, multiply, destroy, and transform", the result of which is raw form. Jeffrey's overall goal was to investigate new methods for designer interaction with the computer. The goal of this case was to capture changes in *form visualization* by collecting his impressions on the creations before and after having experienced them (interactively and immersed). This information was then analyzed to understand how the experience might have altered his design algorithm and overall spatial perception.

Fig. 7.5.

Fig. 7.6.

Fig. 7.7.

Figures 7.5. - 7.7. J. Krause in apparatus observing his structures for the first time interactively and in simulated full scale. Jeffery was completely engrossed in the observation for the duration of each test. *Note: Figures are described in detail in appendix d.*

7.2.1. The Secondary 3D Sketch

Here the designer was the secondary creator of the space and in most cases, visited the structures for the first time immersed. The fact that there are no interpretations needed of traditional objects (doors, apertures, equipment, etc) allows the direct observation of the architect and the environments' spatial impact. The *meaning* of the form is therefore irrelevant, it is the designers interaction and understanding of object and space which is of interest.

The scale of the structures were not altered for this exploration. In most cases, the files were very urban in feeling and scale.

Files tested and their properties:

- **Scene 1**: *Col.flt-* generator of columnar shapes with other orthogonal primitives and orthogonal operators
- **Scene 2**: *Int.flt* - generator of several types of primitives including curved shapes and interior spaces
- **Scene 3**: *Smo2.flt* - generator of tall structures, tower-like in shape and having heights comparable to multi-story buildings.
- **Scene 4**: *Tmp.flt-* multiple operators with high complexity

The files structures used were dxf converted with minimal rendering (for maximum maneuverability) to MultiGen (.flt) files and viewed in the HMD using "Performer". Some files were viewed with alternate rendering increasing in complexity and decreasing in maneuverability. Jeffrey spent a total of two hours twelve minutes immersed without side affect. During this time he was completely engrossed in the experience and exploration of the subjects. Within seconds of being immersed, he stopped interacting with the apparatus and began to become intellectually involved with the objects. Throughout each test he expressed his thoughts verbally about the objects as he encountered them and pointed to objects of interest. He later realized that while being immersed, he was unaware of "what his body was doing".

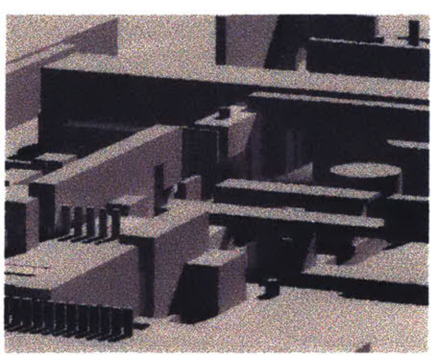


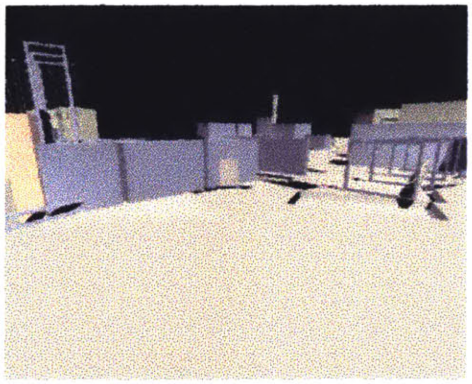
Fig. 7.8. Flyover of scene 1.
Columnar form generator
Orthogonal structures and
operators

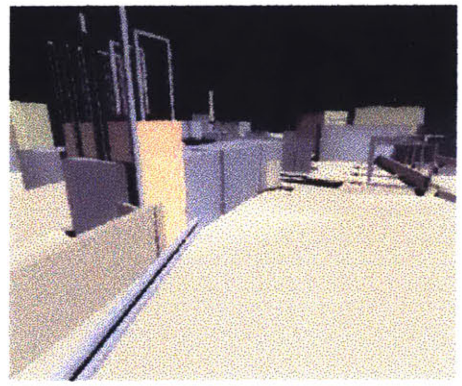
7.2.2. Before and After Experience Comparison

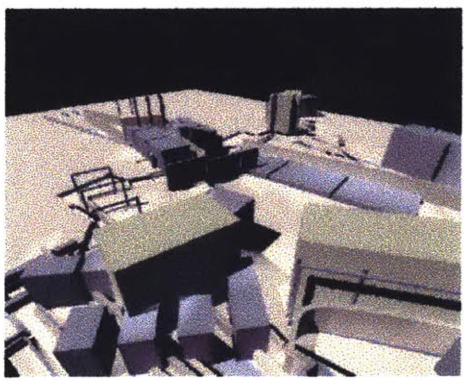
All of the files tested were generated by the computer with Jeff's instruction. He chose a number of operation limits by observing the interactions of shapes from plan view. On occasion, the resulting geometry was viewed in wireframe and on rare occasion, in perspective but only as a single frame. For these reasons his familiarity with the files were mainly from the plan view and spatial cognition was limited. The immersed experiences always began at the ground plane of the environment with the main complexity of the geometry (usually at the center of the model) at a distance. The first task was always to begin to navigate toward the geometry. A methodology for navigating through each space depended upon the scale and clustering of the geometry. Files that resembled "landscapes" or those dominated by objects (rather than negative space) were viewed from above more often than from ground level, and at increased velocities. Files that had more spatial qualities were more often viewed at ground level as would be expected, and more time was spent observing the smaller details that were artifacts of the agent interaction.

Impressions: Most of the files were only recognizable from plan. For this reason Jeff continuously increased elevation in attempt to identify the files. More often, he chose a view that was slightly above ground level in order to see the moving perspectives while also receiving the overall conceptual view. This action agrees with lessons learned in the previous cases concerning referencing perspective views for orientation. In this case, the conceptual vantage point was also a result of being anxious to experience the whole environment.

The tests overall were considered to be "very experiential as a spatial models" and provided a "real feeling of the spaces and voids". Movement for all of the ambiently lit models were perceived as being "very smooth without even one frame drop". Jeff commented that although the files had a rationale in plan, they were more interesting to experience in perspective, especially those areas of high complexity. He felt that constant movement was key in understanding the shapes and their relationships. A usual pattern of movement was: an overall flyover or fly-through until spotting an area of interest, then moving to that area of interest to stop and observe. So called "still' observation was accomplished by distorting tracking (movement of the head in directions other than 360 degrees horizontal to ground), and by placing the head "inside" geometry.







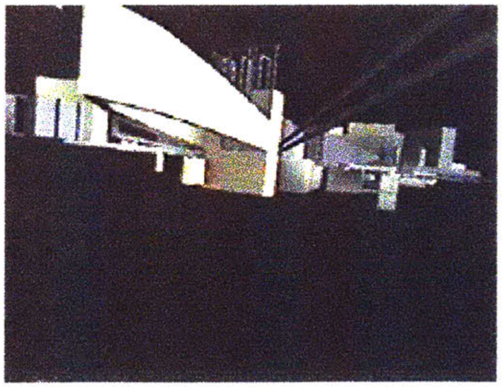
Figures 7.9 (upper left) & **7.10** (upper right) Show Scene 2 with high rendering slightly above ground plane.

Fig. 7.11(left) Flyover of Scene 2

More detailed descriptions of these images found in appendix d.

The views above are screen captures from within the HMD. These files were high in geometry complexity. They were rendered with Lightscape and converted to be viewed with a VRML browser with HMD and head tracker. Although the movement was not as responsive as the Performer files, the presence of shadows help to communicate areas of high geometry interaction. Here, differences in color identify the differences in agent operators

Fig. 7.12 Scene 2
Observing detail with head placement "inside geometry".



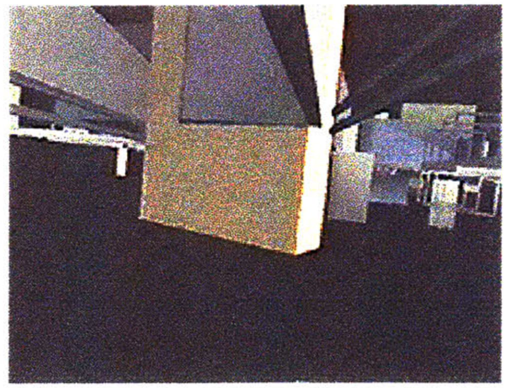
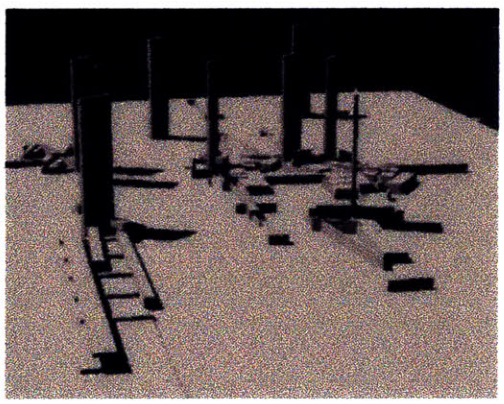


Fig. 7.13
Scene 2. Views from below ground plane

Fig. 7.14



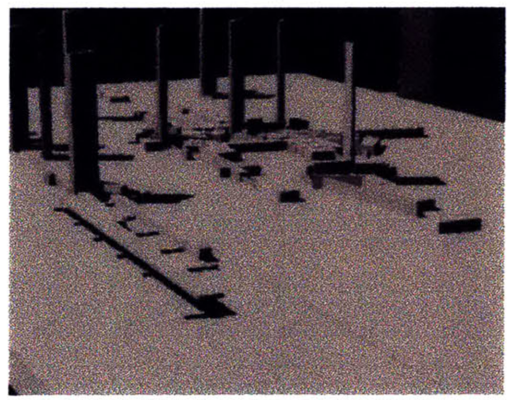
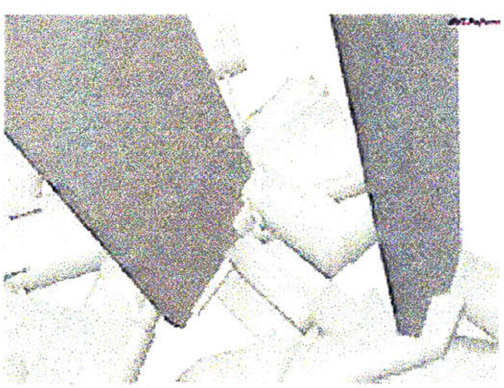


Fig. 7.15
Scene 3. Flyover with low lighting

Fig. 7.16



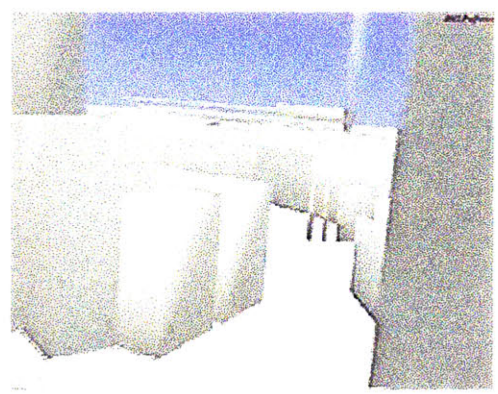


Fig. 7.17 Scene 3.Peering down between tower-like objects (abstract lighting)

Fig. 7.18 Scene 3. Perspectives between towers near base. (abstract lighting)

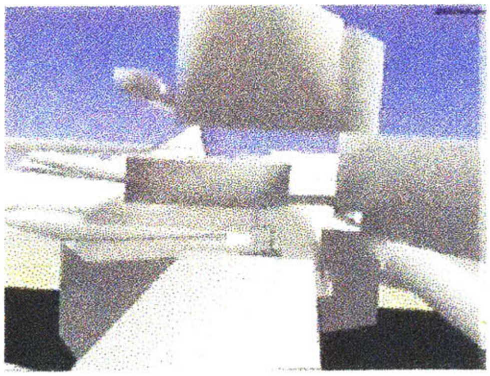


Fig. 7.19 Scene 4 at ground plane

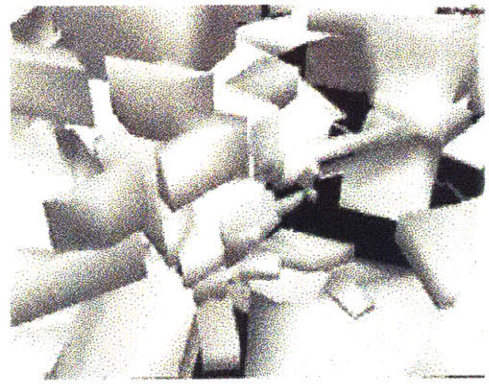


Fig. 7.20 Scene 4, observing complexity

Unexpected occurrences within the forms

Some of the smaller details were originally not noticeable in plan and were discovered for the first time while immersed. Several byproducts of the apertures existed which did resemble relatable apertures, and doors, etc. Several of the explorations were likened to a surreal "dream-like" experience. One unexpected view was in the magnitude of the structure heights; Jeff had not realized how high in elevation some of the objects had been generated. Since his only reference were from a previous plan view, he felt that much of the hierarchal information was lost in perspective, but that the views and experiences were more interesting from the moving perspective vantage points. He commented several times on the voids created by the program. Apparently, the absence of form had made a greater impression after the immersed experience. Some of the major fascinations associated with the experience were in 1) observing the smaller details, 2) the surprise in the spatial quality of forms generated below the ground plane, and 3) curiosity about the forms in section.

Will the experience change the design process?

After walking through all of the files the total experience definitely impacted the designer's perception of what he had originally generated he commented: " I did not understand the forms from seeing them in plan" and "After viewing the files from inside the head tracker, I have a much different understanding of the forms -- the experience is very different--" "and a much better understanding of how the forms are interacting". Although the program is still in a developmental stage, he felt that if he had used VR early on in the process, he would have created more operations in elevation and section.

The subsequent phase of his own project was solidified immediately after the experience which was adding behaviors and operators that would function in section simultaneously with the plan and defining new operator limits.

The moving perspectives presented a first close view to seeing how the different types of objects were interacting. In terms of movement and perception, it was noted that moving from the plan view down into a close proximity perspective also provided new and different understandings of the forms and their interactions, as opposed to the other extremes (perspective eye-level view and plan). Orientation was also more understandable in immersion (for these abstract structures) than from a screen based viewer. He rationalized that the directions of view (by head movement) remain constant in immersion, while in a screen based viewer (manipulated by mouse) are much more likely to become confused. The use of immersion was so beneficial in this case that it was preferred even if high definition had to be sacrificed.

Improvements

The main request was one that agrees with the larger proposal of this thesis: the ability to view design (or in this case "object generation") from an immersed vantage point during the process. Interest was expressed in being able to see the forms generate and to influence those forms while they are being generated around you in full scale. The other request was a more sensitive navigation system that would allow a separation of view direction and movement while providing higher velocity.

8. Compilation of Views

8.1. The Medium is the Controversy

During the past few years virtual environments have found several applications in medicine, education/ training, entertainment, military strategy, and art. Although the scenes used in the case tests were abstract, many environments exist today which represent reality "better than reality"(Negroponte, 1995). Scenarios which are too costly (or life threatening) to test and/or reproduce, are now simulated (Pimental, 1992). Architectural expression should undoubtably benefit from the use of real-time simulations. The question posed was not "how much of a difference does it make in use" but "how similar *is it* in use", meaning how effective are VR environments and their adaptations to communicate futures of the real world? Finding the similarities and implementing the system will help to reduce the need for the constant paper reproduction of work manufactured in a computational environment. More effectively, in the design professions, it should reduce the need for translating three dimensional thought to paper (2D) only to return it to the third dimension for production. The immediate cause and effect of three dimensional thought should be viewable, linkable, shared, and most of all, malleable. The simple cases presented clearly show that the symbology of virtual environments is more easily understood than that of two dimensional plans by non-designers. We do not have to test this in a virtual environment to note the differences of client impressions before and after construction.

In Marcos Novak's "TransTerraFirma: After Territory", he speaks of *"liquid architectures" as being architecture without doors and hallways, where the next room is always where it needs to be and what it needs to be.*" Liquid architecture, he states *"makes liquid cities, cities that change at the shift of a value, where visitors with different backgrounds see different landmarks, where neighborhoods vary with ideas held in common, and evolve as the ideas mature or dissolve.*" It is not the literal vision of this statement which has sparked the interest of this inquiry, but its reflection of reality that could be greatly enhanced with the tools his vision provides. The building of digital spaces should not be completely diametrically positioned to the creation of actual space. Even though the Net is often described as a "mirror world" and does often provide freedom from the burdens of reality, it also holds a liberating key to dilemmas of real world building -- through simulation--.

By connecting these hyperlinked "liquid architectures" in digital space we might bring together an architectural vision stitched by many, and later realized with brick and mortar, rather than only in erasable bits. The temptation, is to respond by prematurely concluding this medium should only be used for (contemporary) architectural aesthetics that fall in line with stereotypical computer images. In fact, there is a great deal of room for creativity in expression that does not limit itself to hardline. This is provocatively proven in efforts at the Banff Center for the Arts where virtual space has become a canvas for expressive investigations in "landscape, identity, and materiality and the body."(Moser,1996)(image p.9).

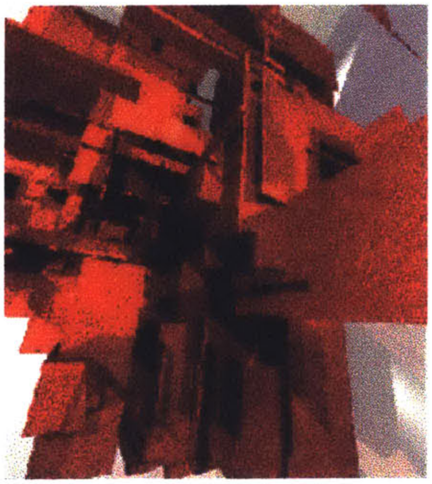


Fig. 8.1 Virtual space with out physical limits
"Liquid Architecture"
Taken from **"TransTerraFirma: After Territory"**
by Marcos Novak

Novak discusses the creation of virtual cities,
and the architecture that defines them
(http://flux.carleton.ca/SITES/PROJECTS/LIQUID/Novak1.html)

8.2. Benefits of Ambiguity and Interpretation

The cases show that minimalism in spatial communication (similar to the traditional sketch), may be more telling than overloading the interactive scene with a barrage of textures and colors. The benefit of using abstraction is that it communicates form spatially while still leaving room for intervention. In some cases, abstraction with regard to materiality (in the conceptual stage) might help to focus the user on the spatial characteristics alone. By not completely "painting the picture" the scene appears more adjustable and open to interpretation. Incorporating virtual (real-time) environments in a product which allows interactive alteration will dispel the fear that the computational model is fixed.

The computational model is very appropriate for presentation and visualization, but should be exploited as a malleable tool, rather than likened to the physical model. In the later stages of the design process, the interactive scene may be supplemented with design/material options and experienced with multiple media as Chapter 6 has shown. Although the prime focus of this exploration was *visual*, other more subtle impacts may be made by incorporating relevant information to the other senses. Many advancements have already been made in the "virtual senses" to include haptics with great sensitivities of touch, 3D sound, and olfactory stimuli.

8.3. Comparison of Perceptions

After observing participants within the apparatus across a number of explorations, it is interesting to note the similarities in action that indicate comfort and belief in the environment. Usually common cues changed over the short-term. The subject either becomes more comfortable and involved in the experience or sustains rigidity and displays symptoms of simulator sickness.

Observed cue patterns of comfortable- believing participants:

- gradual loss of body stiffness
- ease of movement - *more freedom under the tracker-*
  the participant begins to interact with the virtual environment intuitively
  -more head movement
- pointing toward objects in question
- swerving/moving to avoid objects
- hands no longer touching the HMD
- sometimes looks for hands or feet while immersed

Notes on Lessons Learned:

The superior communicator to the non-designer in terms of scale is the immersive environment. Screen based environments must be carefully crafted to control camera lens and perceived scale within the viewer for effective results. From observing participants in both the immersed and screen based environments, we find that the greatest communication of form is one that combines moving perspective views with some conceptual frame of reference. The ability to adjust viewpoint without altering elevation greatly enhances the comprehension in screen based viewers. In comparison, immersive environments do allow better orientation cues over the screen based views especially in larger simulated spaces (this could have also been impacted from the monoscopic HMD used). In large scaled scenes, the preferred vantage point is one above ground level which provides perspective and conceptual views simultaneously. For navigational purposes collision may not be needed in immersive environments but is necessary in screen based viewers due to the interface.

8.4. Project Feasibility- Recommendations for Future Research

Both types of environments were shown as successful communicators of spatial (and object) models. One of the largest tools derived from this experience was the methodology and process for translating complex architectural models in successive levels of detail to a form language (VRML) for communication over the Internet. The opportunity to test multiple media types in combination with this also provided insight on how future applications should be crafted. Although high-end processors continue to be cost prohibitive, more research must be conducted with immersive environments, especially those which combine VRML structures and IBM compatible computing. Client advocacy combined with professionalism in architecture are the motivators for providing high quality design with maximum client/user satisfaction. This project is scheduled to continue its progress at the U.S. Army Health Facility Planning Agency for the design and development of medical and research facilities.

Further improvements will include the completion of a script which will allow direct perspective to conceptual view correlation. Other pursuits include: improved lighting rendition, experiments with various texture complexity, and most importantly, interactive editing of rendered geometry. Incorporation of other existing (sophisticated) project management/user comment engines will also be attempted.

The most progressive multi-media Internet/Web applications are at this time being developed for 32 bit Windows platforms as shown in chapter 6. The goal however, should be an integrated environment that speaks to all platforms and promotes data sharing over bandwidth. Certainly, more advances will be made in VRML editing tools with dramatic changes within the next year. This study predicts the more successful widespread use of the medium to communicate architecture and form.

Appendix A- system for case 1 (chapter 5) [Immersed Environment]

Hardware

Reality Engine II Graphics Pipe 0 at IO Slot 3
Physical Adapter 2 (Fchip rev 2)
2 150 MHZ IP19 Processors
CPU: MIPS R4400 Processor Chip Revision: 5.0
FPU: MIPS R4010 Floating Point Chip Revision: 0.0
Main memory size: 128 Mbytes, 2-way interleaved
Secondary unified instruction/data cache size: 1 Mbyte
Data cache size: 16 Kbytes
Instruction cache size: 16 Kbytes
I/O board, Ebus slot 3: IO4 revision 1
Integral EPC serial ports: 4
Multi-Channel Option board installed
Integral Ethernet controller: et0, Ebus slot 3
Integral SCSI controller 1: Version WD33C95A
Disk drive: unit 2 on SCSI controller 1
Disk drive: unit 1 on SCSI controller 1
Integral SCSI controller 0: Version WD33C95A
Tape drive: unit 6 on SCSI controller 0: DAT
Integral EPC parallel port: Ebus slot 3
VME bus: adapter 0 mapped to adapter 13
VME bus: adapter 13

Software:

Autocad 13 -was used as a modeling program. The files were exported as 3D Studio files.
3D studio was used as a file converter - form here the files were converted to 3D Studio ascii files.
Medit - was used as a scene builder and material editor, the files were imported as ascii.
Performer - served as the VR walkthrough program
Voice recognition- was used as a navigator - The HARK system

Appendix B-

questionnaires for case 1 (chapter 5)

Sample Questionnaire ---and Process

Subject is placed in the central location of the lobby directly adjacent to the main stair and facing into the lobby.

Interviewer: Take a look around, try out the commands, try to navigate.
Sub begins to move.
Int: Look at your surroundings. Do you recognize this space?
Does the space look familiar to you?

If not, the subject is directed into the main lobby space to look in the direction of the main "landmarks of the space. These landmark s consist of the main stair, the ticket booth, and the information counter. they can be seen from the central lobby space which is distinct itself. The lobby is symmetrical for the most part.

If the subject still does not recognize the space they will be directed outdoors onto the plaza area, and then to turn and look at the exterior of the building.
In most cases the subjects were concerned about falling off of the edge emphasizing the success of being totally immersed. Seeing the exterior of the building placed the interior space itself in context. Seeing the exterior of the building itself in context with its surrounding was apparently noticeable to the subjects but not important in the recognition of its identity.

After the realization of the place, the subjects were once again brought inside the main lobby.

Int: take a look at your surroundings. Is there anything that looks different to you? (in comparison to the recollection of the real space) The subjects usually listed a few items while they were exploring the space.

probe: is there anything else that looks different to you in any way?

Int: where is the light source coming from?
Int: how about the placement of the ceiling and floor....does the ceiling look like it is at the right height?
-Does the floor look like it is the proper distance away from you?

The height of the observer was slightly altered to compensate for the variation in ground planes throughout the model. The subject was unable to move vertically in the space and therefore had to have an average vantage point to observe all levels. The heights of the observers in the space were kept the same throughout the testing even though their heights in reality altered. This may have had some affect on the way they normally view their surroundings but served to maintain the same views for all participants. The level was maintained in the program by raising (or lowering) the height of the tracker to correspond to the height of the subject.

The subjects were then asked to estimate distances and heights of objects. The same objects were used for all subjects. They include three that are general to all subjects and others that were located in the most familiar part of the floor plan i.e. in that part of the plan in which they spend the most time.

Questionnaire continued:
The generic dimension/distance estimate:
Int: Estimate the distance between the two columns in the main lobby space,

Int: Estimate the height of the short partition in the main lobby space. (this is the one adjacent to the stair which access the lower level)

Int: - estimate the floor to ceiling height
Subjects were allowed to move around and take any vantage point they felt necessary in order to make the best judgement.

All of these questions were repeated in models 2 and three and then finally in the actual space to compare perceptions.
Scene change:

The scene was then switched to the abstract model. This model was varied in color, texture, and lighting the dimensions of the space were not altered at all.
Int: Observe your surroundings. Tell me what has changed if anything?

Int: Can you tell where the light source is coming from?
In all cases the subjects reported dimensional changes, even though they were exactly the same as in the previous scene
Int: Go to the columns again
Have they changed?
Int: Estimate for me again the height of the
-short partition
-floor to ceiling height

The scene was changed again.

In this scene a partition in the main space was deleted and all of the column placements were shifted approximately 10 feet. Lighting was increased with no shadows. the ceiling (in fact the entire roof) had been slid off of the partitions to reveal the sky. a darker color and texture was applied to the floor. The other colors were the same as in the first scene. The questions were repeated.

3d 2d recognition-
the scene was brought back to the original model in its original conditions. The subjects were told to go to Laverdes and were led to a back staircase and corridor that none have ever seen in real life. The subjects were told to make a mental note of the staircase and corridor in relation to their surroundings.

The subjects were then brought out of VR and shown a 2d plan. They were then asked to identify the stair and corridor they had last seen.

Appendix C- Technical data 2 [Outline for Creating VRML for Architecture]

The following is an outline of the process used in chapter 6. To convert large- high detail architectural files to VRML. Over a period of several weeks, most of the available products were tested to form a conversion. The methods listed below were found to be the most successful. This is provided in outline form only as a record of the case. More advanced tools are expected to be available in the near future which will quickly make this method obsolete.

Subject for chapter 6 incorporated the following software

- Autocad 13 was used as a modeler.
- initial converters were 3D Studio version 4 VRML plug-in (which is freeware and can be found on-line) and Caligari Fountain (an introductory program for conversion is often included in common VRML reference books on cd rom.)
- "VRML Express" was used as a text editor for VRML customization
- The Perl Script "Data Fat Munger" found at the URL (annotated under bibliography) was used to reduce the size of the file (once complete) by eliminating unnecessary precision.
- Live3D was used as a VRML browser

These instructions pertain to the modeling algorithm associated with Autocad 13.

The planning must begin in the modeling stage. Any unnecessary geometry must be eliminated. Use surfaces when possible or model with solids, explode, then eliminate faces. If blocks were used, they must be exploded before conversion otherwise the geometry may not be read by the browser.

Before modeling there are three main issues to consider: 1) the routes within the building in order to break up the files size by turning geometry on/off , 2) which object geometry will be hyperlinked, 3) materials.

Depending upon the size of the minimized file, most often an entire building should be broken up into layers by how it is experienced. Since one cannot usually view an entire building interior in one frame, a choice should be made about where boundaries within the experience will be. An example of this is a corridor with doors to other rooms. In a case like this, the geometry behind the doors might be eliminated and the door might become a hyperlink to the contents behind it. The rationale is to increase performance by viewing the files in pieces rather than have the entire model geometry in memory. The act of switching geometry on and off within a browser may be initiated with the ***LOD*** (level of detail node).

Another method of breaking up the file is via the ***WWWInline*** node. This allows other parts of the model to be viewed when in proximity. Once approached, the geometry begins to load as an external reference from another location. The file itself is separate (and may exist anywhere on the Internet) but is referenced as an item within the main file. The difficulty with this is that the exact placement within the coordinate system must be known, which is difficult in a complex architectural scene..

Layers should define any item of geometry which will be called out as a separate material and/or as a separate hyperlink. Once the initial conversion is made, layer name information is retained within the file. This is valuable because complex boolean operations in modeling and architectural form make the geometry description a vast network of Cartesian coordinate locations. The geometry may be defined within the VRML file as hundreds of pages consisting of three column lists of coordinate points. This is true since the description triangulates the polygon description.

Returning to the issue of hyperlinks, identification of the item is not the same as material definition. Using the door example again, if we placed all doors on the same layer, then this would be identified within the code as "door" or what ever the layer name is. In this instance it would be difficult to identify which coordinate points belong to a specific door. To hyperlink a (specific door), the item should be placed on a separate layer for easy identification after initial file conversion.

Scale and Camera- The type of view within the final space can be controlled by specifying a camera viewpoint. An expected field of view within the space may not be translatable directly. One way to combat this is to scale up the file in proportion. Autocad models may have to be scaled up by as much as a factor of 5 or 6 times. VRML units may be arbitrary. Usually they are in meters unless otherwise noted. A model built to scale will be translated proportionally but may not be interpreted at the correct scale. Scale control may be altered within the modeler or within the VRML code itself using a simple command. When setting camera viewpoints they should be at eye-level. The units that determine what "eye-level" will be depend upon the browser and if the model was scaled.

Rotation - The model used here was converted in the two options listed above.
Although the model can be rotated form within the code, a more successful conversion using the 3DS plug in was accomplished by rotating the project within the modeler. Consider that most VRML

models and parsers reference the XZ plane as the ground plane with the Y coordinate pointing up -- here the Y coordinate is the third dimension -- . Autocad and most other architectural modelers use the XY plane as the ground plane with the Z coordinate pointing up. When using Caligari Fountain as a translator the file should not be rotated since this is a part of its conversion process.

The files used were converted from Autocad to 3D Studio.
Once imported to 3DS , materials, lighting and camera viewpoints may be specified in the usual way and then converted along with the geometry. Once the conversion plug-in is loaded it may be found in the PXP options. The difficulty here is that the materials chosen will not usually be represented accurately by the rendering engine within the browser. This should be a short-term problem with the new generation of development tools arriving. Another problem is that although the camera viewpoints will convert, navigation from those points may produce an undesired rotation of the model.

Caligari fountain has a much more efficient conversion tool and will accommodate far more types of files for import. One of the best conversions from Autocad to VRML is by a first conversion to a .3DS then to a 3DS Project file, from there import into Caligari and export to VRML. Some side affects from the Caligari conversion are seen as well but this can be edited by hand within the code.

Settings within the editor before transport in terms of camera view, lighting, and materials, warrants experimentation. Once the code has been initially translated it must be altered by hand for optimal results. Two tools are used together to do this efficiently, the VRML browser and a text editor.
Some VRML editors may be available on-line and are worth the search effort. They may have debugging functions (to check file syntax) and automatic node insertions which may not consider placement, but will save time and eliminate spelling/syntax errors. Use of the "find" command within a text editor is also a valuable time-saver since it can be used to skip over hundreds of pages of coordinate point listings to find the layer key words. With these two tools, alterations to the file can be made in the text editor, saved, and then immediately viewed in the browser. Caligari often generates residual information at the beginning of the converted file, most which can be eliminated.

Another byproduct of some converters is that they attach ambient lighting qualities to material properties. This may give the scene a flat appearance. This may be improved by eliminating the ambient qualities by hand and adding directional lighting.

The issue of texture will not be discussed in detail here since a more abstract controlled view was desired for the subject case. Low resolution textures can be accommodated with a variety of mapping instructions within the code.

The following is a small part of a sample code used in Chapter 6 with notes to the right defined by "<".

```
#VRML V1.0 ascii                                          <Standard header

# a small part of big al's thesis                        <These two lines are for information and
# Ft Carson Health Clinic, Colorado Springs, CO           are commented out
Separator {
   SceneInfo {                                            <Overall Caligari Scene info
      fields [ SFVec3f background, SFVec3f environ,
      SFVec3f fogColor, SFBool fog, SFLong fogNear,
      SFLong fogFar, SFString envName, SFString backgroundName ]
      background 0.502 0.502 0.502
      environ 0.000 0.000 0.000                           <Most of the VRML structure was
      }                                                    designed manually. The main
                                                           function of the converter is to translate
   DEF Cameras Switch {                                    geometry created visually with the
                                                           modeler.
   DEF Entry PerspectiveCamera {
      position -6.5 -4.080 146.740                      < Beginning of camera viewpoints
      orientation 0 0 1 0                                     placed manually, each is a specific
      focalDistance 5                                         point of interest within the model
      heightAngle 0.95                                        and will allow animations from
                                                              point to point as well as easy
      }                                                       reference to prevent disorientation

 DEF Lobby PerspectiveCamera {
      position -6.5 -4.080 -31.420
```

```
        orientation 0 0 1 0
        focalDistance 5
        heightAngle 0.95
        }

    DEF Pharmacy PerspectiveCamera {
        position -8.300 -4-35.202
        orientation 0 1.0 0 1.8
         focalDistance 5
        heightAngle 0.95
        }
    DEF Reception PerspectiveCamera {
        position -12.300 -4. -45.202
        orientation 0 1.0 0 -1.4
         focalDistance 5
        heightAngle 0.95
        }

    DEF PT_CONT PerspectiveCamera {
        position -97.461 -4. -36.777
        orientation 0 1.0 0 -1
         focalDistance 5
        heightAngle 0.95
        }
DEF Clinic PerspectiveCamera {
        position -67.134 -4. -93.655
        orientation 0 0 1 0
         focalDistance 5
        heightAngle 0.95
        }
DEF Clinic2 PerspectiveCamera {
        position -60.706 -4. -168.864
        orientation 0 1.0 0 -1.7
         focalDistance 5
        heightAngle 0.95
        }
DEF Treatmt PerspectiveCamera {
        position -33.076 -4. -168.864
        orientation 0 1.0 0 1.8
```

```
        focalDistance 5
        heightAngle 0.95
        }

DEF PT2 PerspectiveCamera {
        position -106.314 -4. -0.692
        orientation 0 0 1 0
         focalDistance 5
        heightAngle 0.95
        }

 DEF East PerspectiveCamera {
        position 275.251 -4-91.647
        orientation 0 1.0 0  1.7
        focalDistance 5
        heightAngle 0.95
        }
DEF West PerspectiveCamera {
        position -239.382 -4-91.647
        orientation 0 1.0 0  -1.7
        focalDistance 5
        heightAngle 0.95
        }

        }
    Translation {
        translation 0 2.2 0
}
    Switch {
        whichChild 0
     }
    TransformSeparator {
        MatrixTransform {
            matrix
                1.000 0.000 0.000 0
                0.000 0.000 -1.000 0
                0.000 1.000 0.000 0
                4.827 4.089 1.121 1
         }
```

```
    DEF LocLight PointLight {                                    <Beginning of light definitions
        color 1.000 0.647 0.376
        on TRUE
        location 0.000 0.000 0.000
        intensity 1.300
    }
}
TransformSeparator {
    MatrixTransform {
        matrix
            1.000 0.000 0.000 0
            0.000 0.000 -1.000 0
            0.000 1.000 0.000 0
            -3.631 3.046 5.116 1
    }
    DEF LocLight_1 PointLight {
        color 0.008 0.698 1.000
        on TRUE
        location 0.000 0.000 0.000
        intensity 1.300
    }
}
TransformSeparator {
    MatrixTransform {
        matrix
            1.000 0.000 0.000 0
            0.000 0.000 -1.000 0
            0.000 1.000 0.000 0
            1.226 2.930 -5.390 1
    }
    DEF LocLight_2 PointLight {
        color 0.800 0.800 0.800
        on TRUE
        location 0.000 0.000 0.000
        intensity 1.300
    }
}
DEF NoName_1 TransformSeparator {
    MatrixTransform {
```

```
    matrix
        1.000 0.000 0.000 0
        0.000 0.000 -1.000 0
        0.000 1.000 0.000 0
        0.000 0.000 0.000 1
}
DEF NoName_1 Group {                        <Beginning of grouping of
    Separator {                                 geometry with material qualities listed
        MaterialBinding {                   first
            value OVERALL
        }
        Material {                          <Beginning of group material description
            ambientColor [
                0.300 0.300 0.300,
            ]
            diffuseColor [
                0.941 0.941 0.941,
            ]
            specularColor [
                0.300 0.300 0.300,
            ]
            emissiveColor [
                0.000 0.000 0.000,
            ]
            shininess [
                0.180,
            ]
            transparency [
                0.012,
            ]
        }
        MatrixTransform {
            matrix
                1.000 0.000 0.000 0
                0.000 1.000 0.000 0
                0.000 0.000 1.000 0
                0.000 0.000 0.000 1
        }
        Coordinate3 {
```

```
point                    [
     -61.211 94.419 -4.354,
     86.988 94.419 -4.354,
     -61.211 94.419 -16.062,
     37.021 94.419 -16.062,
     -10.639 94.419 -16.062,
     -69.651 94.419 -4.354,
     -91.862 94.419 -16.062,
     -69.651 94.419 -16.062,
     86.988 94.419 -16.062,
     37.021 95.365 -16.062,
     28.519 95.365 -16.062,
```

< Cartesian Point locations

ACTUAL FILE BROKEN FOR EXAMPLE

```
     -13.135 28.887 8.881,
          -13.629 28.742 8.881,
          -13.472 29.043 8.881,
          -13.204 29.122 8.881,
     ]
}
ShapeHints {
     creaseAngle 0.698
     vertexOrdering CLOCKWISE
     faceType UNKNOWN_FACE_TYPE
}
```

<Beginning of new layer geometry definition.Vertex ordering must be clockwise. In this case the Layer name is: STOR_FRNT and was identified in Autocad.

```
DEF STOR_FRNT IndexedFaceSet {
     coordIndex [
          30, 43, 0, -1,
          43, 41, 0, -1,
          0, 2, 30, -1,
          2, 31, 30, -1,
          41, 1, 0, -1,
          41, 45, 1, -1,
          45, 198, 1, -1,
          2, 225, 31, -1,
          14, 3, 19, -1,
          3, 70, 19, -1,
```

< Cartesian Point locations describing how polygons should be drawn.

Appendix D -Clarification of Color Images for Archival Purposes

Figure 1.1. - a simulation of a white paneled room within Lightscape. This also shows a proposed luminaire which is pulled away from the wall - brightest area indicates reflected light from panel/luminaire

Fig. 1.2. - another view of the scene from **Fig. 1.1**. showing luminance values in color. The different shade correspond to the values at the bottom of the image. The color spectrum at the bottom ranges from blues (left) to green to yellow to red(right).

Figures 3.1. and 3.2. - a multi -user browser with chat frames. Two avatars are facing the screen owner and are centrally located (in each figure).
The avatar to the left is yellow, the one to the right is blue, both stand on a green field.

Fig. 5.1. - a participant wearing and HMD and standing under the head tracker (shown as black). The monitor in the foreground provides a video view of what is being seen within the HMD. The HMD environment in the monitor resembles the one shown in **Fig. 5.3.** page 33. (Model 1).

Fig. 5.2 & 5.3.
Depict screen captures of the HMD views (model 1). Floor has a texture with varying shades of yellow, partitions are dark yellow, waffle slab ceiling is dark green.

Fig 5.4. & 5.5.
Depict screen captures of the HMD views (model 2). Floor and partitions are shades of gray, ceiling is dark green. Overall area is dimly lit.

Fig. 5.6 & 5.7. Depict screen captures of the HMD views (model 3). Floor is very dark brown to black, partitions are yellow in **Fig 5.6** and gray in **Fig. 5.7.** Columns are light pink and the sky (which is exposed) is royal blue.

Fig. 5.8. a test subject within the apparatus. **Fig 5.9** shows the same subject in the actual built space after testing being interviewed. The areas beyond are shades of white and diffuse gray.

Fig. 6.1. & 6.2. Shows possible options of the designed interactive environment one may choose. This is operating within Netscape 2.0. The graphics are bordered by two thin blue strips called frames, the lower strip contains hyperlinked "quick keys" to major points of interest and a comment post. Top left frame shows the interactive model loaded at the building's front view in gray tones. The right frame shows a zoomable cad drawing which has a black background, and red, yellow, purple, vectors indicating a portion of the plan. Lower left frame show table of contents to other hyperlinked information with black background and yellow text. **Fig. 6.2** is another view of the environment with the lobby space loaded in the upper left and a raytraced still in the upper right all are in gray tones.

Fig. 6.7, 6.8., 6.9. All show video capture of architectural project team in Atlanta interacting with the browsing environment. In **figures 6.7 and 6.8.** the monitor is shown in white in the lower left foreground. In **6.9** , attention turns to the monitor at the right while a designer navigates through the building on screen and while receiving instruction from MIT.
Photos have yellow overtones.

Fig. 6.10 & 6.11 - Video capture during a demonstration of the environment in Washington D.C. while being instructed from MIT via video conference. The image depicts the screen as seen from the MIT location. The lower right corner in each image is shown projecting the MIT location, while the main screen is projecting the DC computer monitor. **6.10** shows the environment Enter screen depicting a photorealistic computer rendering of the building. This is shown in **Fig. 6.12.** The building is shown with high resolution textures comprised of red and brown brick, the scene has a brown foreground and a blue sky with clouds.

6.11 shows the videoconference screen loaded with a corridor scene from the model in gray tones.

Fig. 6.13 shows a scene from the Carson model in a Multi-user environment. One abstract material is applied throughout and is represented by shades of bronze.

Fig. 7.1. a participant in the apparatus while the monitor in the foreground captures HMD views of the Mikveh simulation. A similar view to that of the monitor is shown in **Fig. 7.2.** depicting the main space. Lower level and floor are dark brown with red overtones, cylindrical walls are off-white and in shadow, with reflected blue sky entering through windows.

Fig. 7.3 shows a view looking down into the main space with hanging light fixtures. The scene has reddish brown overtones with white highlights.

7.4. shows a view from ground level to the top of the 54' high cylindrical circulation space., shown in shades of gray and white with blue sky entering at window right.

7.5. - 7.7. show Jeffrey Krause interacting with his program's design solutions immersed. The three images show a large range of motion under the tracker which indicate comfort and belief in the environment. All photos have overtones of the yellow lab.

Fig. 7.9. 7.10. Shows scene 2 in a highly rendered geometry with like shades belonging to the same agent type. **Fig. 7.9.** gray base with blue structures at center, one structure at far left is peach.

Fig. 7.10 - gray base with blue structures, lightly shaded box to the left of center is peach.

Fig. 7.10 gray base with blue boxes shown as darkest shades in scene. The two largest form at center are light green.

Fig.7.12. - observing complexity- curved structure at base is yellow with rising blue vertical forms.

Fig. 7.13. 7.14. View below ground plane - **7.13-** predominant form center is yellow with blue structures rising vertically. **7.14-** a closer view of the same yellow form, surrounding geometry is blue.

7.18. Abstract HMD capture of scene 3- forms are in gray tones with blue sky at top.

Fig. 7.19. Scene 4 at ground plane- structures are in gray tones while horizon line is green and sky is blue.

Fig. 8.1. Liquid architecture by Marcos Novak depicted with deep shades of red and a light gray background.

BIBLIOGRAPHY

Anders, Peter, **"The Architecture of Cyberspace"**, Progressive architecture , 1994 Oct., v.75, n.10, p.78-81,106

Bell, Fisher, Baum, Green, **Environmental Psychology** 1990

Cronin, **Doing Business on the Internet**, 1994

Duffy, Francis, **"The Impact of IT [information technology]"** : RIBA journal 1990 Nov., v.97, no.11, p.77,81,83

Finke, Ronald A, **Creative Cognition:Theory, Research, and Applications**, 1996

Johnson, Owen, D, **"The VRML Experience: Integration of Head Mounted DisplayTracking- with VRML Browser"** 1995

Kaplan and Kaplan, **Cognition and Environment: Functioning in an Uncertain World** 1982

Larson, Kent. **"SIGGRAPH 94: The Digital Era Dawns"**, Progressive Architecture, 1994 Sept., v.75, n.9, p.41-42

Matsuba, Stephen, **Using VRML**, 1996

Matgolin, Victor, Bichanan, Richard., **The Idea of Design**, 1995

Mitchell, William J., **"Virtual Architecture: computers are challenging notions of space"**, Architecture 1993 Dec., v.82, n.12, p.39,41,43

Mitchell, William J., **City of Bits: Space, Place, and the Infobahn**, 1995

Mitchell, William J., **The Logic of Architecture: Design, Computation, and Cognition,** 1994

Moser, Mary Anne., Macleod, Douglas, **Immersed in Technology: Art and Virtual Environments**,1996

Negroponte, Nicholas, **Being Digital**, 1996

Novak, Marcos, **"TransTerraFirma: After Territory"** http://flux.carleton.ca/SITES/PROJECTS/LIQUID/Novak1.html

Novitski, B. J., **"CADD holdouts: why some architects refuse to jump on the computer bandwagon",** Architecture: the AIA journal 1991 Aug., v.80, no.8, p.97-99

Pesce, Mark, **VRML: Browsing and Building Cyberspace,** 1995

Pimental, Ken, **Virtual Reality: through the new looking glass,** 1992

Shepard, Roger, N., Cooper, Lynn, A., **Mental Images and their Transformations**, 1986

Schweber, Linda, **"Virtual Reality: Virtually Here"**, PC Magazine, 1995, March, 14, p.168-198.

Scott, Adrian, **"VRML/Java/Javascript FAQ"**,http://www.aereal.com/faq/

Thalman, Nadia & Daniel, **Virtual Worlds and MultiMedia,** 1993

Varela, Francisco, **The Embodied Mind, Cognitive Science and Human Experience,** 1991

Alpha World
http://www.worlds.net/alphaworld/

Autodesk
http://server1.autodesk.com/prod/mm/mnemonic.htm

Black Sun Interactive
http://www2.blacksun.com/index.html

The Data fat munger
http://www.construct.net/vrmltools/datafat.html

Lightscape
http://www.lightscape.com/

Netscape plug-ins
http://home.netscape.com/comprod/products/navigator/version_2.0/plugins/index.html

VRML Repsoitory
http://sdsc.edu/SDSC/Partners/vrml/research.html

VRML Resources
http://www.mcp.com/133244921949234/general/foundry/resources.html

Vream -interactive VRML
http://www.ids-net.com/ids/introduc.html