Design in Virtual Environments Using Architectural Metaphor

A HIT Lab Gallery

by

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Abstract

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This thesis explores the application and limitations of architectural metaphor in the design of virtual environments. Architecture, whether physical or virtual, is the expression of a society realized as meaningful space. Physical and virtual architecture have their own constraints and context, yet both use architectural organization as a way to order forms and spaces in the environment. Both strive to create meaningful place by defining space, and both must allow the participant to develop a cognitive map to orient and navigate in the space. The lack of physics of time and space in the virtual realm requires special attention and expression of its architecture in order for the participant to cope with transitions. These issues are exemplified by the development of an on-line gallery of virtual environments. Conclusions reached by the development of this design are discussed in the context of orientation, navigation, transition, enclosure, and scale.

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INTRODUCTION

This thesis is about the study and exploration of architecture. It is not about the architecture of the physical world, however, and is not designed to be built in physical form. Rather, it is the study of virtual architecture, that which can only exist on-line, in computers, and accessible on the Internet. It is the study of architecture as a spatial expression of society, liberated from the bonds of the physical universe and given new life in its freedom from physical constraints. By looking at physical architecture as a case study of how it relates to the virtual realm, one can examine the strengths and limitations of architecture as a medium for social interaction, independent of its existence in the physical realm.
CHAPTER I: BACKGROUND

Architecture Defined
To begin, a definition of architecture is offered which envelopes and relates the fields of physical and virtual architecture. Architecture is defined as the making of a place by the ordering and definition of meaningful space, as developed in response to a need or program (Ching 10). It is also described as the expression of society or culture in spatial, experiential form (Campbell, "Virtual Architecture"). Both of these definitions describe architecture as a concept or idea which has both physical and virtual expressions (Figure 1.1).

Physical architecture is the embodiment and expression of societal values in physical form (like bricks and mortar). It is that which is traditionally studied in schools of architecture and for which designers become licensed professionals. We witness physical architecture as buildings, parks, plazas, cities, suburbs, and landscapes. Like physical architecture, virtual architecture, "...need(s) to be designed. The world and the experience that one can have in it must be consciously shaped" (Best, Idiot’s Guide 2). However, virtual architecture is that which embodies and expresses values of society in electronic form, with polygons, vectors, and texture maps. Lacking physicality, it does not exist on a geographic site as traditionally understood. Rather, it is accessible via computer and human-interface technology anywhere one has access to the Internet.

Example of Physical Architecture
The Gothic cathedral Notre Dame de Chartres is an excellent example of physical architecture (Figure 1.2). It is a physical building in a specific context, with a well-defined entry off of an urban plaza. It uses physical materials of stone, metal, wood, and glass, as well as light, to order forms and elements in space to create meaning. From the plaza outside, a procession begins as one enters the building, passing through a clearly marked threshold into the interior of the cathedral. One walks along the body, or nave, where one experiences numerous icons and symbols which are given an expression different than the architectural elements which serve a structural function. The icons themselves refer to times and places to which people of a specific culture can relate. From the nave, one passes the crossing to the apse, a heavenly space at the end of the procession which serves, conceptually, as the heart of the building. It is a place for communication with the spiritual, a sacred space among the profane.
While there are countless examples of physical architecture which have been designed and built over the millennia, there are far fewer examples of virtual architecture due to the relative youth (decades) of electronic media and computer technology. Nonetheless, the design of virtual spaces is an architectural exploration. By, "...placing the human within the information space, it is an architectural problem; but beyond this, cyberspace has an architecture of its own and, furthermore, can contain architecture. To repeat: cyberspace is architecture, cyberspace has an architecture, and cyberspace contains architecture" (Novak, "Liquid Architectures" 226).

Examples of Virtual Architecture

The earliest examples of virtual architecture as mediated by networked computers are the text-based environments of MUDs (multi-user domains) and MOOs (MUD, object oriented). In MUDs and MOOs, multiple users to log in to a shared environment on a computer network and interact using text. Although the interaction takes place in one-dimensional text, the participants in the MUDs relate to their environments with two-dimensional maps (Figure 1.3). Often, but not always, the maps mimic or represent physically constructable environments.

In time, MUDs and MOOs acquired a graphic interface (Morningstar and Farmer). The interactions, which still took place in text, were then represented visually (Figure 1.4).

In recent years, we have witnessed the birth of the World Wide Web (WWW, or the Web). Using graphic user interfaces called information browsers, people can download textual and graphic data from the Internet to their own computers. The data is hyperlinked (FOLDOC), which means that certain words or images, when selected by the participant, invoke the downloading of other data. In most cases, the data is represented as pages (figure 1.5). However, with hyperlink technology, the pages need not be read...
consecutively, like a book. Rather, discontinuities in the way information can be accessed have enabled the spatial (rather than linear) organization of data. Furthermore, the spatial organization of the data sets are often represented as images or maps. Often, these graphics portray buildings and cities of the physical world.

Figure 1.5: eWorld’s Web City on the World Wide Web (Apple Computer, Inc.).

The capabilities of the Internet are not limited to two-dimensional data. Three-dimensional environments have been created and shared in real-time as virtual worlds. The earliest of such environments were "stand-alone" worlds without hyperlinks (figure 1.6), but could be shared by invited participants across the globe (Mandeville et al.).

Figure 1.6: GreenSpace I (Human Interface Technology Laboratory).

Recently, hyperlink technology of the World Wide Web has been combined with three-dimensional modeling languages (like VRML) to offer the potential of a rich experience of virtual environments, interconnected via the Internet (figure 1.7). These environments are filled with multiple participants on-line, interacting in interconnected three-dimensional virtual worlds.

Figure 1.7: Images from Worlds Chat (Worlds Inc.).

Yet another example of virtual architecture is that of computer games. From the two-dimensional mazes and playing fields of early "stand-alone" arcade games to the complex three-dimensional environments of recent networked games for personal computers (figure 1.8), participants interact in specific virtual environments which are represented spatially.
One last example of virtual architecture is the work of Marcos Novak (figure 1.9). Novak’s work, self-defined as "liquid architecture" (Novak, "Liquid Architectures"), challenges the constraints of the physical world and responds to the context of the virtual realm. However, the abstract and unfamiliar forms and spaces which result are often found to be disorienting and distracting, becoming the focal point rather than the background environment for on-line interaction.

Most of these examples of virtual architecture have one thing in common: they use the metaphor of physical architecture to one degree or another in order to represent electronic information. "The architectural metaphor of cyberspace validates the designer’s work; just as spatial cues help to orient us in a real building, they also offer a visual structure for abstract information, revealing relationships and hierarchy" (Anders 78).

However, most of these examples tend to mimic the architecture of the physical world, recognizing and responding to its constraints. Few examples of virtual architecture respond to the constraints and context of the virtual realm. Those that do are often found to be disorienting and difficult to navigate through. Therefore, there is a need to explore and to discover which principles of physical architecture need not apply to the virtual realm (Schmitt et al.), and which ones are necessary for the participant to inhabit a meaningful environment without disorientation.
Theoretical Position
This study demonstrates that the use of architectural metaphor is appropriate for the design of meaningful spatial relationships in a virtual environment. It further explores the limits of this metaphor, to provide an understanding of where the design of physical space is or is not appropriate for the virtual realm.

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CHAPTER II: HYPOTHESES

This thesis is based on the development and investigation of several hypotheses. Constraints, architectural parti, hyperlinks, the making of place, and cognition were all key issues which commanded attention as they influenced the design development of virtual architecture.

Constraints
The virtual realm lacks many of the constraints and conditions of the physical world, while it has its own set of constraints and conditions. "Cyberspace must be made: it cannot be discovered. Cyberspace is a to-be-constructed geography, a new planet, not yet laid out and without weather" (Benedikt, "Unreal Estates" 56). The virtual realm, by its nature, has neither gravity nor requires a response from an architectural structure. It has no climate which requires a surface of enclosure to define and protect interior space as understood in the physical world. Furthermore, there are no geographic limits, no site boundaries or property lines, to contain and define the bounds of the architecture within (Campbell, "Nature of Cyberspace").

Although there are no such physical constraints, there are certainly other constraints which influence the development of virtual design. Technical constraints and limitations affect the design of virtual architecture no matter how transparent the interface (see Appendix A). "Without natural laws to guide or contrast with the architecture, we must rely upon cultural conventions to situate ourselves. The conventions of architecture can have very real significance here" (Anders 106). Like the architecture of the physical world, there is a socio-cultural context in which the design is developed. Furthermore, human factors like cognition and perception strongly influence virtual design in the absence of traditional, physical factors (Furness).

Architectural Parti
The design of an environment, whether physical or virtual, requires an organization to be meaningful and understandable by a participant. "In dealing with vast arrays of data, a non-architectural approach to the organization of information in the electronic realm can be a liability" (Anders 79). This organization, or parti, serves as a point of departure in design by which all organizational and hierarchical decisions are made. Architectural parti can be used for the organization of rooms as well as for the relationship of information as data sets.

Hyperlinks
The technology of hyperlinks breaches the space-time continuum. "In virtual space, we move from destination to destination, from piece of information to piece of information. Distance is no longer a relevant measure of travel" (Best, Idiot’s Guide 20). That is, a participant moves by "jumping" between spaces which are not necessarily geographically adjacent. These links, like the jump cuts of a film, can be jarring to the uninitiated participant. If given an expression similar to doorways and portals, links can be understood as ways to move between spaces. These should not be given the expression of a standard door, however, and should express or indicate to the participant that accessing it will lead to something different than simply the next adjacent space in the same virtual world.

Furthermore, hyperlink technology in its current state is such that it takes significant time to download and display a new virtual environment. This download time, which weakens the intent of the "instantaneous" transport to other worlds, needs as a spatial expression.
Place
Physical architecture is designed and built to create meaningful places in which society can inhabit and interact (Campbell, "Virtual Reality"). If architecture did not perform this function, it would exist as sculpture in its own universe (Novak, "Liquid Architectures" 243). Architectural place is created in the context of the geographical limitations of the physical site, approached from other spaces and places. A virtual world, without a geographical context and a traditional means of approaching a site, exists in the context of abstract, infinite space. An attempt must still be made, however, to create meaningful places in this limitless space.

Cognition
Without the constraints of the physical world, the participant is left with few cues of how to explore and understand the virtual realm. Wayfinding, the dynamic process of using our spatial ability and navigational awareness of an environment to reach a desired destination (Satalich 7), is accomplished by the development of and reference to a cognitive map. A cognitive map is the means by which information about the relative location and attributes of one’s environment is acquired, coded, stored, recalled, and decoded (Moore). Cognitive mapping, "...is particularly important in enhancing the experience of people in places where they are not frequent visitors" (Lang 144). To develop a cognitive map in an unfamiliar, informational, and spatial environment, one must be able to orient and navigate intuitively (Benedikt, "Cyberspace" 123). The architecture should respond to the methods of navigation and should serve to orient the participant to allow the development of a cognitive map.

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CHAPTER III: METHODOLOGY

Media
These hypotheses were explored through the design development of a specific example of virtual architecture. Traditional media used to develop the design included acrylic paints, pencil and pastel sketches, and ink drawings. Electronic media were also used, including computer-aided design for two-dimensional drawings and three-dimensional models, as well as still-frame and real-time rendering of those models with animation and virtual reality technology.

Face-to-Face Interaction
The progress and development of the design was mediated through critiques by a number of people. These included regular presentations to the supervisory committee and thesis advisors, as well as technical personnel and programmers of the software used in the real-time simulations.

Virtual Interaction
A World Wide Web site was also constructed to record the development of the thesis-in-progress (see Appendix B). This enabled the on-line publication of text, images, and models of the thesis and related ideas of virtual architecture. This publication led to dialogues, via email, with interested students and professionals around the globe who wished to offer their opinions, ask questions, and engage in discussions as the design developed. These discussions were then recorded on the Web site as a record of events and to further promote discussion.
CHAPTER IV: PROGRAM

General
The specific project designed to explore and exemplify this thesis is an gallery of virtual environments. The virtual environments in the gallery are those of an architectural subject matter created at or in conjunction with the Human Interface Technology Laboratory (HIT Lab) at the University of Washington. The HIT Lab has generated hundreds of virtual environments, dozens of which pertain to or represent architecture. Many of these environments are recorded as text, still frame images, or video. Others are actively demonstrated in real-time simulations with virtual interfaces. However, none of these environments are organized or related to one another such that they can be demonstrated efficiently or cohesively. Furthermore, as technology continues to advance in terms of file formats, software, and peripherals, there is a risk of out-dating many of these environments and a need to archive them. The gallery is intended as a means to organize and to demonstrate the virtual environments for the HIT Lab, as well as a way to archive worlds no longer actively demonstrated. In addition to this, the gallery serves the function of an on-line gathering place for multiple participants interacting in three-dimensions.

The gallery, as virtual architecture, exists "in" the computer and is experienced with the interfaces of that computer. While the gallery can be explored best with advanced virtual reality hardware and software for real-time simulation, it also exists on the Internet, accessible on-line to any machine with access to the World Wide Web (see Appendix B). A VHS video tape of a real-time simulation of the gallery can also be viewed (see Additional Material).

Specific
The gallery itself is composed of several interlocking elements which creates a composition of various spaces (figures 4.1 through 4.3).

Figure 4.1: Exterior View of the Gallery.

Figure 4.2: Axonometric Diagram of the Gallery.
There is a single entry point into the environment, at an entry vestibule. One has a view of the gallery from this vestibule, and is directed to approach and enter the gallery spaces by environmental cues of forms and elements (figure 4.4).

One moves from the vestibule along a circulation spine, passing through a slit in the planar threshold to the interior (figure 4.5). Within the circulation spine, one interprets symbolic signage and directional cues from the environment to orient oneself and move into the galleries (figures 4.6 and 4.7)
The galleries themselves are arranged as four "rooms" around the spine. They feature the work of the HIT Lab’s PolyShop project (figure 4.8), the GreenSpace project (figure 4.9), the CEDeS Lab (figure 4.10), and the work of students in the University of Washington’s College of Architecture and Urban Planning, or CAUP (figure 4.11). The galleries are relatively dark rooms, with spatial proportions and an orientation different than that of the circulation spine. This was done to enhance the sense that these spaces serve a different function than the others. Each is given a different color, red, violet, blue and green, starting with the warmest colors near the entry and the coolest farthest from the entry to aid in their differentiation for orientation purposes.

Figure 4.8: View within the PolyShop Gallery.

Figure 4.9: View within the GreenSpace Gallery.

Figure 4.10: View within the CEDeS Lab Gallery.
Each gallery features a thick display wall with deep-set images representing various worlds (figure 4.12), and creating the illusion of stained glass. These images, or texture maps, serve as hyperlinks to the worlds they represent.

When the hyperlink is activated, the world signified by the texture map is downloaded to become the environment in which the participant is immersed. The time it takes to download the new environment is represented spatially as a tunnel which one moves through until the new world is ready for real-time rendering (figure 4.13). The tunnel is again displayed when one leaves the environment to return to the gallery.

Secondary to the main galleries, there is an archive space for storing virtual environments that are no longer actively demonstrated at the HIT Lab. It, too, has an orientation different from the circulation spine and the galleries, as indicated by its spatial proportions. The entry to the archive space, while accessible to all participants, is de-emphasized to the casual visitor by use of dim lighting. However, in recognition of the fact that informed participants will need to interact in the archive space, additional lights turn on upon entry into the archive, enabling them to navigate throughout the space (figures 4.14 through 4.16).
Finally, there is a main hall at the end of the circulation opposite the entry vestibule (figure 4.17). This main hall serves as a gathering place for multiple participants who wish to meet and interact. The program for this space is ambiguous, as the presence of networked multiple participants in three dimensions is sparse and relatively new. Additional functions will be added to the main hall as the interaction among on-line participants increases in three-dimensional environments realm.

As the circulation spine passes through the main hall, some of its elements continue and terminate in an enframed view of the blank void in which the virtual architecture of the gallery lies. This is done to enhance the participant’s awareness that there is no physical context for the site (figure 4.18).

There are also long corridors extending out in all directions from the main hall (figure 4.19). These are expressions of hyperlinks to other virtual environments not related to the HIT Lab or its virtual environments. In time, as other examples of virtual architecture are designed and built, these corridors would lead to those worlds.
Figure 4.18: View of the Main Hall, with Enframed View of Void.

Figure 4.19: Another View of the Main Hall, Featuring Hyperlink Corridors.

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CHAPTER V: CONCLUSIONS

The design development of the provides an understanding of the limitations of the metaphor of physical architecture in the virtual realm. The discussions which took place about the hypotheses, both in face-to-face meetings and on-line, have been recorded on a World Wide Web site (see Appendix B). The conclusions that been reached from all of these discussions are broadly categorized into the topics of orientation, navigation, transition, enclosure, and scale.

Orientation
The ability of a participant to orient oneself in architecture, whether physical or virtual, is critical to the success of the design. The project designed as part of this study indicates that orientation can be established by using a clear parti, landmarks in a grid, and the enhancement of direction and depth perception, especially when physical constraints are removed.

Architectural parti, the organization of and relationship between elements and information in space, is vital to the understanding of that space by the participant. Partis may be linear, radial, clustered, or fall into many other categories of geometric arrangement. In all cases, however, it is used to provide the participant with a broad understanding of how the architecture is organized.

By developing a design with enough variety of forms and spaces, yet keeping them organized clearly, landmarks in the grid are established. The "grid" is the conceptual and regular placement of forms and spaces in a rhythm or regular pattern. "Landmarks" are the variations in the pattern which serve as unique elements or points of reference by which to orient oneself in architecture (Lynch). They are critical to orientation in both the physical and the virtual realms.

The ability to establish a participant’s depth perception and direction in space is also valuable for orientation (Henry). These orienting devices are accomplished in both the physical and the virtual realms by use of color and texture, lighting, and atmospheric and linear perspectives. Lighting as an orienting device is harder to establish in the virtual realm because of the computational expense it requires from the simulation technology (Nimeroff). Solid colors require less computational overhead than textures in virtual environments as well. The visibility of atmosphere, like mist, can establish some depth cueing in the physical world, but too much of it, like fog or smoke, can disorient participants. The same is true of the virtual realm, although heavier mist or fog can actually aid one’s orientation in the virtual world by exaggerating depth cues and eliminating distant, distracting elements.

A participant’s understanding of one’s sense of direction is just as important in the virtual realm as it is in the physical (Satalich). However, without the context and constraints of horizons and gravity, there is no inherent sense of up and down. The project in this study indicates that although each space or room has proportions which imply an up and down, these "local ups" did not need to correspond to one another from room to room. Thus, without a "global up," one’s sense of direction and orientation is with the body in relationship to an immediate space, even though the orientation of other adjacent spaces may differ.

Navigation
The success of physical and virtual architecture depends not only on how easily one can orient oneself in the design, but also how well one can move, or navigate, through the environment (Bednar). Participants
navigate using cognitive maps, varying degrees of freedom, and by a combination of environmental cues and tools.

Successful navigation depends on one’s ability to develop a cognitive map \cite{Lang}. For a participant to establish a cognitive map in an environment, whether physical or virtual, that person must be able to move and explore freely in the environment. Software functionality like pre-defined paths of movement and pre-defined viewpoints of key spaces diminish a participant’s ability to construct an accurate cognitive map of the space. These tools, however, prove to be efficient ways to navigate through a world after a participant has already built a cognitive map of one’s surrounding environment.

In the physical world, one typically navigates through one’s environment in three degrees of freedom: movement along the earth’s surface as a plane (X and Y), and rotation by turning one’s body around (yaw around the Z axis). In the virtual realm, there can be up to six degrees of freedom to navigate through Cartesian space: movement along three axes (X, Y, and Z), and rotation around these axes (roll, pitch, and yaw). Movement in all six degrees of freedom evokes the sensation of oneself as a free-floating body in space. With six degrees of freedom, and without a "global up" or gravity, the architecture need not be expressive of an inherent up or down for one to navigate.

Whether limiting movement to three degrees of freedom with a "global up" in the physical world, or by allowing six degrees of freedom with only "local ups" to orient participants virtually, the architecture needs to offer several other cues as aids to navigate in space. The physical world offers signage, symbols, and text, in addition to architectural elements \cite{Beck}, all of which are often culturally specific aids to navigation \cite{Rapoport}. There are also tools such as compasses and maps by which one navigates in the physical environment.

In the on-line virtual realm, the architecture is accessible to participants of all cultures and languages, so text is a limitation. Although the on-line culture has its own set of symbols and iconography, there are few well-established ones for navigation in three-dimensional space at this time. While software tools like compasses and maps are also available in the virtual realm, these are not as intuitive or as accessible as using the environment itself to guide in navigation. A viable solution, then, is to use abstract architectural elements and environmental cues which transcend cultural interpretations to aid in the navigation of virtual architecture.

**Transition**

The metaphor of physical architecture can be used for orientation and navigation through virtual architecture, with minor limitations. This metaphor also applies to transitions in the virtual realm, but with stricter limitations. Issues related to transition that are considered include the establishment of a context and acknowledgment and expression of hyperlinks.

In both the physical and the virtual realm, architecture is best understood as approached in a context. Physically, a sense of arrival is established in geographic, Cartesian space as participants must approach a building from the outside in order to enter it. Thus, a context is often perceived and understood from the exterior. In the virtual realm, however, there is no inherent starting point from the exterior. Still, it is helpful for the participant to view the design from an "exterior" or "god’s eye" omniscient viewpoint before moving into the virtual architecture. This heightens the sense of arrival, aiding in the establishment of place, and also helps to orient the participant. Thus, a sense of approach is still achieved in the lack of an exterior context.

In the physical world, participants move through the time and space relative to one another under the laws of physics. Distance and time are integral and inseparable, as one moves through space over a period of time. In the virtual world, however, hyperlink technology does not require that movement through space and time continuously. Links allow immediate access to other data, and participants (conceptually) move through space without moving through time.
However, not all links actually allow "immediate" access to sets of data, and not all data carries equal weight in relevance to the environment from which one accesses it. Thus, links which move the participant between sets of spatial data expressed as virtual worlds can be categorized into different categories, and these can yield different architectural expressions. There are two metrics by which the character of the link is determined: whether or not the data on each side of the link is geometrically adjacent, or contiguous, and how closely the data in each virtual world is related. The combinations of these factors yield four possible kinds of links, three of which are relevant.

One combination of these metrics yields a kind of hyperlink which connects spatially adjacent rooms of a specific design of virtual architecture, and in which there is a strong informational relationship between the worlds. These links, developed as "level of detail" switches, can be given the transparent expression of a door if the computer running the simulation has pre-loaded the adjacent rooms into memory. If this is not the case, these links require architectural expression as airlocks or vestibular spaces between rooms to allow the participant to move through the space freely, even if the room one is moving into is not fully loaded and rendered.

A second category of hyperlinks is that which connects two spaces (or rooms) which are not spatially adjacent but do contain related information. These links deserve special architectural articulation as something other than a doorway into an adjacent room, like a texture-mapped "window." The metaphor of moving through space is appropriate to the time it takes for this hyperlinked world to download and be rendered.

A third kind of link is that in which the data sets on either side of it are geographically adjacent, but describe unrelated data. Mathematically, the possibility of such a link exists, but the probability that the unrelated worlds have links to each other in the same Cartesian space is infinitesimally small, so this is considered a null category.

Finally, there are links to places which are neither spatially adjacent nor of directly related information. These links, too, require articulation as elements in the design which are not ordinary doors. Again, the metaphor of a spatial transition is appropriate while the world is downloading. However, this transition to unrelated data, and the links expressing it, should be different from links leading to related data in order to inform the participant of that fact.

**Enclosure**

Whether developed as physical architecture or virtual architecture, designs use enclosure as a device to separate and define spaces and rooms. Site limitations, separation of function, the creation of interior space, and the movement between solid and voids are all factors which influence the creation of enclosure.

In the physical realm, designs inherently exist on a physical site. That site has geographic boundaries as defined in a social, cultural, or political context. The limits of a site or property serve as strong indicators for the presence of surfaces of enclosure. Virtual architecture, on the other hand, inhabits unlimited and infinite expandable space. Without limits to the site, there is little indicator of where to place surfaces of enclosure.

In both the physical and the virtual realms, surfaces of enclosure exist around spaces to signify separation of function. In the physical world, this is also done for issues of privacy, either visual or auditory. Issues of privacy do not exist as such in the virtual realm, as the representation of other participants and the representation of oneself to other participants is often under one’s own control, aided by software functionality.

Functions are also enclosed in the physical world to define interior spaces which shelter these functions from unfavorable climatic conditions. There are no such conditions for virtual architecture, and therefore
surfaces of enclosure are not justified by climate. Rather, virtual spaces are given surfaces of enclosure to reduce the amount of information a participant is exposed to at any one time. While information overload does present a risk to participants in the physical realm as well, it is more likely in the information-rich virtual realm (Wurman).

In the physical world, movement between spaces takes place in the voids which penetrate solid surfaces of enclosure. To walk from one room to another, one passes through a doorway (void), between the door jambs, above the threshold or sill, and below the head (all solids). Thus, solid elements are not passed through, but between. In the virtual realm, collision detection with hyperlinks are often necessary to achieve movement between spaces. This means that a participant must pass through a polygon (conceptually, a solid) to achieve a transition to the next space. At the same time, passage through polygons rendered as solid walls simply puts the participant on the other side of those polygons without activating a link to another world. Conceptually, the rendering of surfaces of enclosure is inverted, in terms of solids and voids, from their function in the virtual realm.

**Scale**

Issues of scale apply to architecture of both the physical and the virtual realms, although in different ways. Scale issues were studied in terms of "human" scale, the detail of one’s environment, and the development of connections.

The achievement of "human" scale is necessary in both the realms of physical and virtual architecture, although they are accomplished through different means. In the physical world, scale is established by the size of elements relative to the participant. Virtually, the participant has no inherent size, so scale is only indicated through one’s velocity. That is, the scale of one’s environment is indicated by the rate at which one moves through it. Whether scale is achieved by size (physical) or movement (virtual), however, both are affected by the size of openings. A participant gains a sense of scale when passing through a relatively small opening whether by virtue of one’s tight fit or by having to reduce one’s velocity to ensure passage through the opening.

The detail of one’s environment also influences one’s perception of scale. The richness or articulation of surfaces in the physical world can affect one’s sense of scale in much the same way that the size of elements does. Similarly, the detail and number of polygons rendered within a participant’s field of view affects one’s perception of scale virtually. By introducing a range of complexity of detail to the project in this study, it has been found that a participant tends to move through a complexly detailed environment more slowly than a simpler one.

The development and expression of connections can also affect one’s sense of scale in architectural spaces. In the physical world, the detailing of a connection is accomplished as a hinge, a reveal, or any number of other ways to join elements; often, this joint introduces a smaller element at the connection. The presence of these smaller connecting elements introduces a richer scale to the physical environment. In the virtual realm, connections as understood in traditional terms are not necessary. Without physical forces of nature, virtual elements simply exist adjacent to one another as abstract geometry without the need for connecting elements, or the expression thereof. Connections, then, do not serve to enrich the scale of virtual architecture.

- **Forward to Chapter VI**
CHAPTER VI: Suggestions for Further Study

This study has been based on the previous research and exploration by numerous individuals. Although there have been several conclusions reached, they do not indicate that research in this field is final. More study needs to be undertaken in the following areas.

Multiple Senses
This thesis and the project which exemplified it relied on only the visual display of virtual architecture. In the physical world, one’s perception of architecture is strongly influenced by sound and touch, and less so by smell and taste. Interfaces and peripherals which display such stimuli are being developed in addition to visual display. It is suggested that one’s perception of architecture, and therefore the design of architecture would be affected by the added display to other human senses. More research needs to be done in this area.

Language
The use of language, as textual signage, as voice communication with the environment, or otherwise, is beyond the scope of this study. This is because language barriers among cultures who can access the project on-line would inhibit the success of this study if it depended on language to communicate itself to participants. Also, text does not display legibly in current head-mounted display technology. However, these barriers are likely to be overcome with continued development of software and display technology. It is believed that the use of oral and written language, while it serves a similar function in communicating ideas as does architecture, would enrich the experience of the virtual participant.

"Irrational" Hyperlinks
Hyperlink technology has been used in only a limited way in this project: there is a one-to-one mapping of the links and the worlds they connect. Hyperlink technology does not limit links between worlds such that a link from one world to the next must lead back to the first if entered again from the other side. In fact, link in a world could lead to a different virtual environment each time it is accessed. As well, a volume of a certain size or shape, when entered by a link, may yield an "interior" volume of a different size or shape. Thus, complex webs can be constructed with hyperlinks that cannot be modeled in physical, Cartesian space. These possibilities were explored in the development of this study, but it was quickly determined that participants become disoriented when the visual representation of spatial volumes does not map directly to buildable Cartesian space. More research needs to be done to understand the limits of human cognition in non-Cartesian spaces as made possible by hyperlink technology.

Customization
The project developed to explore this thesis has been constructed in a specific scene-describing language and intended for simulation on a limited number of rendering packages (see Appendix A). Although the output rendered and seen with this varying software may yield different results, the environment as a whole is not configurable or customizable. It is thought that in the near future, customization of software, interfaces, and even content of the virtual realm can and will take place, enabling the participant to configure the environment to one’s one personal taste. The project developed for this study was not designed with such capabilities in mind. Further study needs to be done to understand how and why virtual architecture should be developed under personally-configurable conditions.

Dynamic Environments
The virtual realm offers the opportunity to deny the physics of time, space, light, gravity, and solids; all of these have been addressed to one degree or another in the scope of this thesis. However, the virtual realm enables designers to break free of more constraints, such as the static nature of physical architecture as solid matter in and among a void. Study needs to be done into the expression of liquid, dynamic architecture which responds to a participant’s movements and interactions with other participants or with the environment itself (Best, Virtual Environments 25). "A liquid architecture in cyberspace is clearly a dematerialized architecture. It is an architecture that is no longer satisfied with only space and form and light and all the aspects of the real world. It is an architecture of fluctuating relations between abstract elements. It is an architecture that tends to music" (Novak, "Liquid Architectures" 251). Virtual architecture can be as responsive to the individual’s needs and actions as the complexity of the technology will allow.

**Multiple Participants**

Although the architecture developed for this study is intended for use by multiple participants, it has not yet been experienced in this way. It is suspected that the expression of virtual architecture, including the design offered here, will change as multiple participants become commonplace and the on-line culture matures. Issues related to virtual communities will need further study, including how their demands and wishes will influence virtual architecture (Rheingold). The representation of multiple participants of varying scales, moving through spaces in different orientations, has not yet been addressed. It is critical to consider these issues as the field of virtual architecture continues to grow.

- Forward to List of References
LIST OF REFERENCES

Bibliography


**Recommended Readings**


- [Forward to Appendix A](#)
APPENDIX A: TECHNICAL SPECIFICATIONS AND RELATED ISSUES

Technical Specifications
The project developed for this thesis was generated and simulated using the following hardware and software:

DATA GENERATION

Hardware

- Pentium PC (Digital Equipment Corporation)

Software

- AutoCAD for Windows Rel. 12 (Autodesk)
- 3D Studio Rel. 4 (Autodesk)
- Animator Studio 1.1 (Autodesk)
- Photoshop 3.0 (Adobe)
- XV 3.00 (John Bradley)
- Lightscape Visualization System 1.2 (Lightscape)
- Ix2iv (Lightscape)
- ivcat (Silicon Graphics)
- ivfix (Silicon Graphics)
- ivToVRML (Silicon Graphics)

Process

- Textures used for hyperlinks were rendered 3D Studio graphic image files (.gif) and edited using Animator Studio and Photoshop
- Textures were converted to IRIX (.rgb) using XV
- Geometry was created in AutoCAD (.dwg file) and edited in 3D Studio (.3ds)
- Geometry was saved as data-interchange format (.dxf)
- Geometry was loaded in Lightscape and edited (.lp) and textures (.rgb) were applied
- Geometry was rendered as a radiosity mesh (.ls) and the data was converted to Inventor ascii scene graph (.iv) using Ix2iv
- Scene graph was edited to optimize rendering for GreenSpace II software with ivcat and ivfix
- Scene graph was converted to VRML for publication on the World Wide Web using ivToVRML

DATA SIMULATION

Hardware

- Processor: Onyx Reality Engine 2 (Silicon Graphics)
- Navigation: Cyberman (Logitech)
- Tracker: 3SPACE FASTRAK (Polhemus)
- Display: VR4 Head-Mounted Display (Virtual Research)

Software

- Webspace 2.0 (Silicon Graphics)
- ivview 2.1 (Silicon Graphics)
- GreenSpace II (Human Interface Technology Laboratory)

**Related Issues**

Many of the decisions made in the development of this thesis project came about as a result of the technical equipment used in the generation and simulation of the data. They are as follows:

- The use of AutoCAD and 3D Studio to generate the data influences the development of the design to incorporate more planar forms than may have occurred using other software.
- The use Lightscape and its method of generating radiosity meshes to simulate light on a surface minimizes the number of texture maps required, but maximizes the number of polygons used to define a softly-lit planar surface.
- The use of a Cyberman provides six degrees of freedom in navigation, although it is difficult to move at different scales or rates. This influenced the variety of scales of spaces used in the design.
- The use of a VR4 HMD limits the participant’s field of view such that one can only see a limited amount of data at a time. This influenced the shape, scale, and proportion of many architectural elements and spaces the design.
- The use of the GreenSpace II software, based on Open Inventor 2.1, does not allow the implementation of the hyperlink tunnel in real-time. The tunnel displayed on the video (see Pocket Material) was edited by video insertion.
- The use of the GreenSpace II software, based on Open Inventor 2.1, does not allow the use of alpha maps (transparency in texture maps), but does render transparency of materials.
- To detect a link using ivview, the data must be optimized using ivfix.

[ Forward to Appendix B ]
APPENDIX B: WORLD WIDE WEB SITE

This thesis is published on the World Wide Web, at the URL: http://www.hitl.washington.edu/people/dace/portfoli/thesis/

From this thesis "home page" one can access the following:

- An on-line version of this document, at the URL: http://www.hitl.washington.edu/people/dace/portfoli/thesis/document/

- The design project itself, a gallery of virtual environments, at the URL: http://www.hitl.washington.edu/people/dace/portfoli/thesis/project/

- A record of in-progress text, images, and models from the development of the thesis study and the design project, at the URL: http://www.hitl.washington.edu/people/dace/portfoli/thesis/in-prog/