VRML In Architectural Construction Documents: A Case Study

Dace A. Campbell, Assoc. AIA

NBBJ Architecture Design Planning

Abstract

The Virtual Reality Modeling Language (VRML) and the World Wide Web (WWW) offer new opportunities to communicate an architect's design intent throughout the design process. We have investigated the use of VRML in the production and communication of construction documents, the final phase of architectural building design. A prototype, experimental Web site was set up and used to disseminate design data as VRML models and HTML text to the design client, contractor, and fabricators. In this paper, we discuss the way our construction documents were developed in VRML, the issues we faced implementing it, and critical feedback from the users of the Web space/site. Finally, we suggest ways to enhance the VRML specification which would enable its widespread use as a communication tool in the design and construction industries.

CR Categories and Subject Descriptors: I.3.5 [Computer Graphics]: Computational Geometry and Object Modeling - Curve, surface, solid, and object representations; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism - Virtual Reality; J.6. [Computer Applications]: Computer-aided Engineering - Computer-aided design (CAD), Computer-aided manufacturing (CAM).

Additional Keywords: architecture, construction, AEC, design, construction documentation, specifications, Internet, extranet, World Wide Web, VRML, virtual worlds, virtual environments

1 INTRODUCTION

The process in which architects labor to design and describe proposed buildings is a complex one, and critical to their role in the Architecture/Engineering/Construction (AEC) industry is their ability to communicate with their design intentions to those who will build them. The communication media architects use to describe their designs is varied, although it is dominated by highly symbolic, orthographic line drawings and text-based specifications. In the past few decades the production of these graphic drawings and written specifications has been aided by Computer Aided Design (CAD), and now recent developments in visualization and network technology promise to give architects new tools to manage and communicate their design intentions.

NBBJ
111 S. Jackson St.
Seattle, WA 98104
phone: (206) 223-5144
fax: (206) 621-2300
dcampbell@nbbj.com

As architects develop their designs from conceptual diagrams and "napkin sketches," through schematic design and development, and on to construction documents, the level of complexity of the design increases. For typical buildings, this development and complexity necessitates an information management structure equally complex. By the time a building design is "complete" and ready to be distributed to contractors who will bid on the design, thousands of hours and hundreds to thousands of drawings describing the building have been generated and distributed for comment, review, and revision. This set of drawings, commonly referred to as construction documents ("CD's" in architectural lingo) is accompanied by a book of specifications ("specs") describing the materials and components in detail. Such CD-sets specs are then interpreted by contractors who distribute them to sub-contractors to construct the building. A complex social and legal infrastructure has evolved around the documentation with these specific communication media, and any mistakes in or changes to the CD's or specs require a host of requests and change orders between the architects and contractors. Historically, the construction of a building has necessitated a large volume of paper with which to document it.

With the Internet, and the WWW which provides it with a graphic interface, architects have been promised a new medium for communicating with other players in the AEC industry. Text, raster-based images, and recently vector-based graphics and models can all be exchanged and distributed widely and instantaneously with the WWW. Developers of VRML and proponents of technology in the AEC industry alike proclaim the benefits of communicating design in three dimensions via the Web. Architects who once used CAD as a drafting tool are now investigating ways to develop their buildings with digital models as their primary design medium. With model-describing languages like VRML, architects are now looking for ways to distribute digital models of their designs electronically, potentially eliminating the need for distribution via printed construction drawings and specifications. While the benefits of moving towards a "paperless" design and construction industry are clear, there are many obstacles -- technical, legal, and infrastructural -- which prevent us from doing so today.

2 PREVIOUS AND RELATED WORK

In recent years, a number of researchers and academics have been investigating the use of digital models as a way to communicate design ideas. Before VRML was developed, researchers at the University of Washington described a need for a modeling language which could offer hyper-geometry links and multiple levels of detail for architectural representation [1]. Such hyperlinks and multiple levels of detail were eventually implemented in the first VRML specification. Academics have also investigated the use of immersive, distributed virtual environments along with other electronic media as a means to communicate and critique design intentions [2, 3]. Hyperlinks and multiple representations of a design have been found valuable to understanding a proposed building. It has also been noted that the hyperlinked geometry offered by VRML is quite similar to the use of architects' "detail bugs," a symbolic system which references detailed drawings in construction documents [4].

Professionals outside of the AEC industry have already begun to advance the notion of communicating graphic and model data electronically to automate the construction process. Perhaps the most famous project is the design and production of the Boeing 777. Digital models of the airplane were used to design and optimize the plane, and then all of its components were manufactured directly from digital data which was extracted from the model and communicated to fabricators. In fact, entire systems have been implemented which enable manufacturers and suppliers can partner with designers electronically [5]. The AEC industry has lagged behind the academics, researchers, and related design/manufacturing disciplines. The legal and social implications of a paperless design and construction process for buildings are not yet completely understood by the industry as a whole, although VRML shows promise as a medium for communicating building design in construction documents.

3 THE EXPERIMENT AND METHODS

To investigate VRML's usefulness in the AEC industry, we have implemented a test project within our architectural firm. To design a research facility for a client in the health care industry, we have set up an Extranet between our firm, the client, the contractor, and a fabricator. Because of the scale and complexity of the building, only a portion of it was used to test our ideas: the architectural "feature" stairs which involve a significant amount of custom metal work. In addition to documenting these stairs in traditional, two-dimensional line drawings with notes and specifications, the stairs were also documented on the Web with VRML and HTML.

The Web site for the project consists of several frames (see Figure 1). These frames feature the project title, and index to the "drawing" (model) set, a link to a record of related issues, a main graphic display, and related notes.

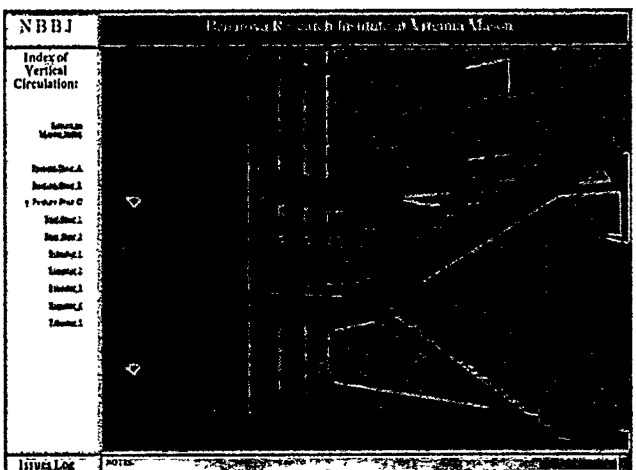

Figure 1. Web site, featuring project index and graphic display.

The main graphic display is used to show the stairs as they were developed throughout the project. By rendering a model of the stairs with radiosity algorithms (using Lightscape), we were able to show design alternatives as photorealistic VRML models during schematic design and design development (see Figure 2). The client and the fabricator were able to visualize and understand the designs with VRML in ways that were not possible in other media.

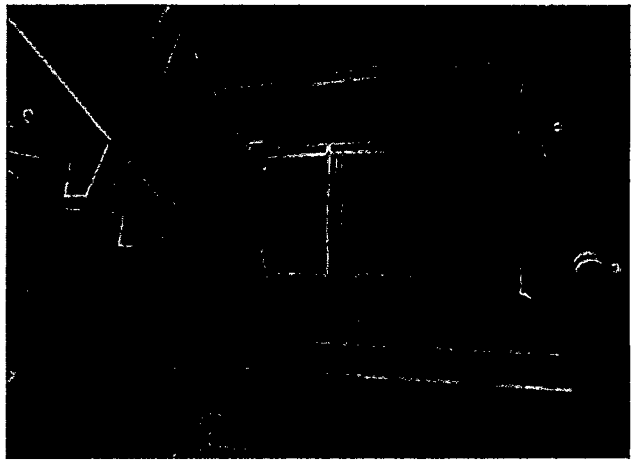

Figure 2. Design alternative of project in design development.

As the design was developed to its final form in the construction document phase, it became clear that there was too much detail in the design to show photorealistically using just one VRML model. Use of VRML's Level-of-Detail strategy was considered, but the time required to author multiple representations of each component was cost prohibitive. Rather, a simple diagrammatic model of the stairs was built to behave as an interface to more complex, detailed models and images. This follows the standard of traditional architectural representation of line drawings, in which low detail is shown in drawings at a smaller scale. These typical representations use "detail bugs" throughout a lesser developed drawing and refer to other, more detailed drawings of typical and particular construction assemblies (see Figure 3). It was thought that since professionals in the AEC industry are accustomed to this model of interaction, in which a single building system like the stairs may be traditionally described in several plan and section drawings on multiple pages of the CD set, a hyperlinked model would be an appropriate and much simpler interface for accessing detailed information. Thus, the low-detailed model has three-dimensional "detail bugs" which surround areas of the model and refer to higher-detailed models. These linked "bugs" are shown as orange wire-frame boxes in the model (see Figure 4).

The simple model is not only an interface for accessing more detailed models of the stairs, but also is meant to contain basic textual information necessary to the description of the stairs. Traditional plans and sections use dimensions to relate distances between points on objects (to measure objects or the spaces between them) and notes to describe the qualities of the objects. Using this precedent we added three-dimensional dimensions and notes to the VRML model to describe basic measurements (see Figure 5).

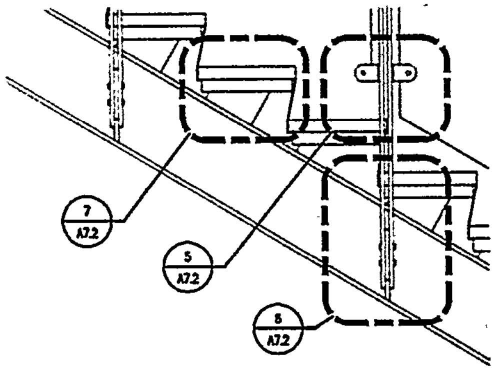

Figure 3. Traditional detail-referencing in a drawing.

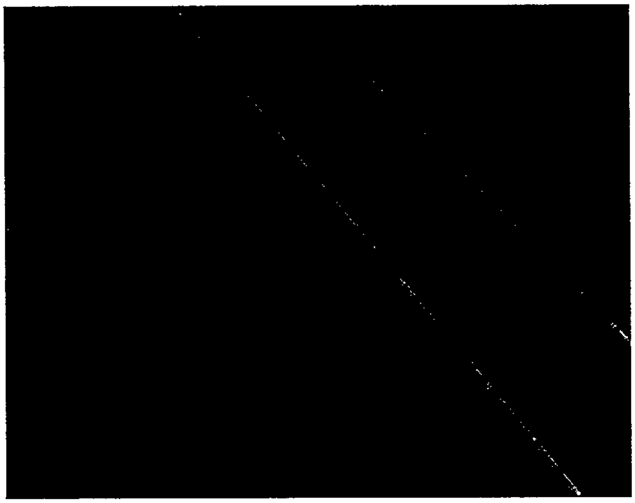

Figure 4. Experimental referencing technique in a VRML model.

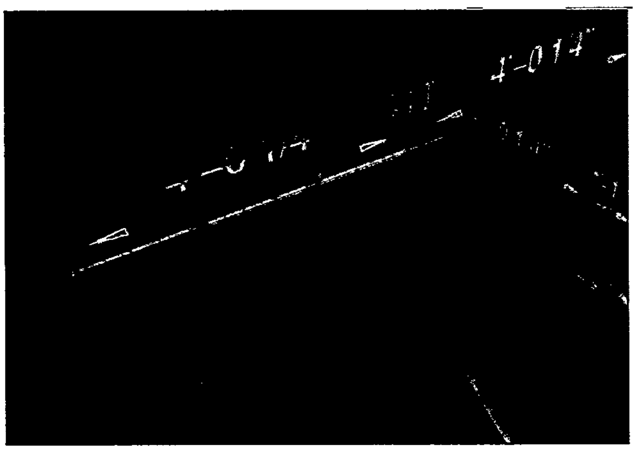

Figure 5. 3-D dimensioning and notes in a VRML model.

As an alternative to placing the notes in space around the model, we also investigated a new strategy in the detailed models which takes advantage of unique characteristics of frames. Rather than having notes with leaders to describe the objects as traditionally done in line drawings (see Figure 6), we defined each object in the model as an anchor. Clicking on any object in the model would then call up a description of that object in the notes frame (see Figure 7). This strategy did not to work for dimensions which measure the relationship or space between objects, but was very successful when describing individual objects and components.

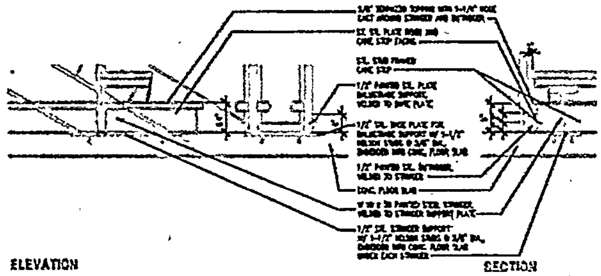

Figure 6. Traditional notes with leaders to annotate a drawing.

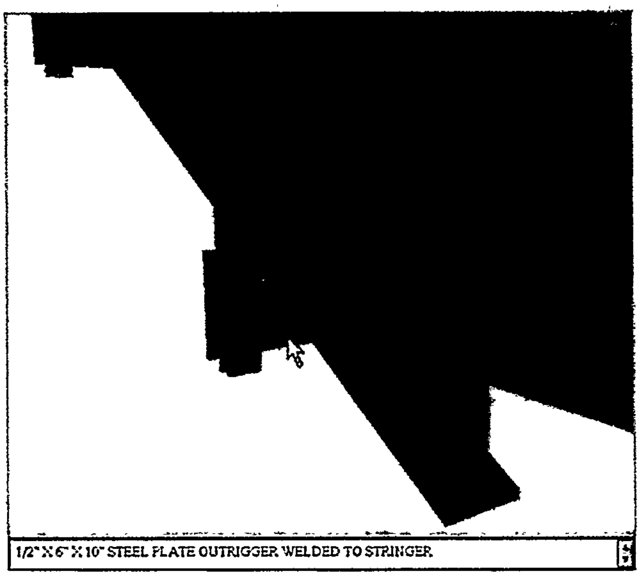

Figure 7. Experimental anchored notes in a VRML model.

Lastly, the objects in the detailed models were linked to related specifications on-line. Traditionally, the specifications are printed in a book that is used as a reference, hand-in-hand with the construction document drawing set to describe specific qualities that the object should have when being selected, manufactured, or assembled. Rather than provide the specs in a separate medium, our approach enabled the user to read detailed text associated with that object in the same medium (the Web) in a frame next to the graphic display (see Figure 8).

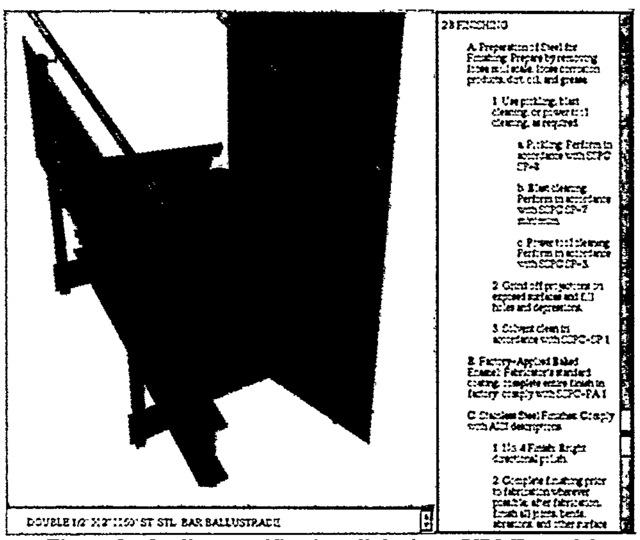

Figure 8. On-line specifications linked to a VRML model.

4 RESULTS AND DISCUSSION

Once the Web site was developed, it was tested and critiqued in a series of trials and interviews with the client, the fabricator, and the contractor. Since it is their position to interpret and act on the intentions of the design team, it proved to be a valuable test group for analyzing the usefulness of the Web site. Their critique and comments are presented here, as well as our own.

During the construction of the Web site, we found several advantages and limitations to using VRML as our primary communication medium. As could be expected, the model was able to convey information in ways not possible with two-dimensional drawing media. The design team was able to spot errors sooner, and to resolve conflicts with more conviction based on the real-time visualization of the VRML files. However, we also found several disadvantages to the construction and use of the Web site as a way to communicate with our client, contractor, and fabricator. These limitations ranged from technical, to social, to infrastructural. We discuss some of these issues below, and follow the discussion with several specific recommendations for further development of VRML.

4.1 Authoring and Publication Issues

The VRML files took more than twice as long to "author" as it took to draw a comparable amount of data using a standard CAD package. In part, this can be attributed to the lack of modeling capabilities of the software we used to author the models. However, it should also be noted that in general there is a lack of sophisticated VRML modeling packages/authoring tools available on today's market with the capabilities one expects from CAD software. VRML authoring tools have to become more sophisticated if designers are expected to take them as serious development media.

Another option for creating VRML models was to use CAD packages which support an export or translation feature to create VRML files. However, while this method often creates accurate polygonal and texture data, we found it largely incapable of translating some primitives critical to the description of architectural design. Text and line sets necessary for creating dimensions in the VRML model are not readily produced by export from CAD packages.

In addition to recognizing the limitations of today's authoring tools and software, we found several other obstacles which prevent architects from using VRML as a primary medium for design communication. To publish design documentation at an architecture firm requires that all other parties must have access to computer technology sophisticated enough to read the files. Clients, fabricators, and contractors must all have high-end Pentium PC's with Windows 95 or NT in order to use the most common VRML plug-ins, and this can be cost prohibitive for jobs of almost any size. Also, for VRML to be useful at the fabricator's shop or on the construction site, the computers used for rendering the VRML models must be portable and durable.

4.2 Critique Of Use Of VRML

Despite these potential setbacks to use of VRML to communicate our design ideas for construction, we were able to provide access to the appropriate parties at the appropriate times. When the VRML models were presented to and shared with the client, contractor, and fabricator, their reactions were largely in favor of its use for this application. Their optimism about the potential of VRML is rooted in its enabling the publication and communication of 3-D spatial design data. However, this optimism is also tempered with a host of concerns and criticisms about the medium. Their comments about the benefits and shortcomings of our use of VRML are described here:

4.2.1 Benefits

- The use of the diagrammatic model as an interface to access detailed models is an appropriate metaphor for a construction industry accustomed to reading drawings of varying level-of-detail at multiple scales.
- With the three-dimensional model available on-line, there is less need to show multiple views of a given space, which means less need for printing out documentation to distribute to subcontractors.
- It is much easier to check for construction or lay-out conflicts with an on-line model than with a set of two-dimensional drawings describing complex building systems.
- The links between graphic information in VRML and construction specifications in HTML are a clear advantage to the Web site as a communication medium.

4.2.2 Shortcomings

- The navigation around and between the multiple 3-D models would be aided by standard 2-D and 3-D icons as a way to go into or out of details and to see orthographic views.
- Links to two-dimensional information are critical to convey analytical and descriptive data about how to build or lay out systems and components. The qualitative information provided in the three-dimensional model is not adequate to fully describe architecture.
- It is necessary to be able to query spatial relations between objects, like dimensions. The mimicking of traditional 2-D dimensions in 3-D space is inappropriate and illegible.

4.3 Recommended Features For The VRML Specification

From these comments, and from our own experiences in authoring the VRML models, we have discovered several opportunities to make the VRML specification more sympathetic to the documentation of a building design for construction. Thus, there are several nodes, fields, and features which we recommend be incorporated into future iterations of the VRML specification. Such features would enhance the specification to the point where VRML could be come to widespread use to communicate design intentions in the AEC industry. Some of these features are noted here:

4.3.1 Dimensions

Dimensions are needed when describing architectural design intentions as a way to measure spatial relationships between objects. Traditional dimensioning with text, lines, and arrowheads was developed for line drawings in two dimensional media. A similar primitive or construct of primitives is necessary for being able to display dimensional information and spatial relationships in 3-D VRML models.

4.3.2 "Text2"

In order to place text in the models which face the view at all times, such primitives must be "billboarded"individually when authoring. An earlier specification for the SGI Inventor scene graph included a "Text2" node which automatically placed non-polygonal, consistent-height, billboarded text in space around the model. This is critical to enabling the reading of text information in complex 3-D models in should be implemented in VRML as well.

4.3.3 Advanced Line Sets

Designers use a variety of line types and thicknesses to convey different kinds of information about their proposed creations. Center lines, property lines, dashed lines, and strings of dots are just a few examples. The IndexedLineSet should be expanded to allow VRML models to display different line thinknesses and patterns, or types.

4.3.4 Orthographic Projection Viewpoints

Central to the understanding of spatial relationships is the ability to convey graphic information in two dimensions. While the benefits of a three-dimensional model as afforded by VRML are quite clear, there are times when complex spaces are best analyzed in plan or sectional view. Just as there are perspective cameras in the VRML spec, we should be given the opportunity to create true orthographic views for plans and sections. This feature was dropped from the VRML specification and should be brought back.

4.3.5 Roll-Overs

One clear advantage of digital media is the ability to display context-sensitive information when it is requested by the user, and only at that time. Advanced HTML specifications enable "roll-over" actions to modify the display of information when the user drags a mouse/cursor over a specified location. While a similar feature, the "IsOver" field of the "TouchSensor" node, exists in VRML, it we found that we could not use it to display text in the view (or any other frame) using VRML alone. A "roll-over" feature, perhaps a way to route an "isOver" to an "Anchor," should be considered.

4.3.6 Mark-Ups

Critical to any communication or exchange of architectural ideas is the ability to make graphic notes during such discussions and critiques. VRML developers should consider ways to enable designers and users to "mark up" or "sketch" in VRML models and be able to save such changes as notes of a design discussion. Such notations of design revisions in 3-D models are central to making VRML a valid medium for representing and communicating construction documents.

5 CONCLUSIONS

This project took place as an experiment to test the validity of VRML as the primary communication media of building design for construction. In general, the feedback from the various users was positive and encouraging. Having tried this as a proof-of-concept exercise with just a portion of a much more complex building, the feature stairs, it is now time to attempt a similar project with a full building from the very beginning of the design process. Only then can we understand the full implications, advantages, and limitations of using VRML to describe building designs to our clients and to those who will construct these buildings and components.

Until such a larger project is implemented, however, the results from this study indicate that there are already some places, technical or otherwise, where the infrastructure must develop to use this technology. The VRML specification and the tools used to implement it need to mature for it to be used for the specific purpose of documenting a building design. Many new nodes, fields, and features can go a long way to making VRML more useful in the design process. Furthermore, this technology will not likely be adopted by the AEC industry at-large until it can be proven to be cost effective both in the design office and on the construction site. However, this technology cannot and will not become cost effective until the industry embraces new means of communication in the digital information age.

6 FUTURE WORK

In addition to the specific recommendations for developing the VRML specification noted above, there are several topics of research and development which could be undertaken based what we have discovered. We suggest the following topics for further discussion and investigation:

6.1 Four-Dimensional Simulation Of Building Construction

An important feature of digital technologies is their ability to describe changes to space over time. This capability can be harnessed to automate and to animate construction sequences of buildings with VRML. In this way, conflicts in the choreography of a complex building's construction can be optimized and potential conflicts leading to expensive delays can be reduced.

6.2 Navigation And Transition Between Data Types

There is a need for intuitive, natural movement between models, drawings, and text on the World Wide Web. Transitions between perspective views, orthographic views, alpha-numeric, and tabular data must take place seamlessly when integrating these media into the description of a complex building design. It is not enough to have links and anchors between models, images, and text in various frames. Rather, ways should be investigated to develop VRML as an overarching spatial interface to access other kinds types of data.

6.3 3-D Symbols And Conventions

There is a need to create new paradigms for the description of analytical data in electronic three-dimensional documentation. It is not sufficient to copy or modify only slightly the two-dimensional drafting and drawing conventions we traditionally use to describe architectural design. Rather, new spatial metaphors need to be explored which are uniquely suited to the hyperlinked spatial nature of the VRML specification.

6.4 On-Site Implementation

The fully-enabled use of VRML (or similar technologies) will probably not take place in the AEC industry for many years to come. The resolution of this matter certainly involves issues relating to access or infrastructure, but also centers around the fact that at a certain point in the process the building and its components must be built. It is unclear just how VRML can be used on the construction site or at the fabricator's shop, as construction methods are rarely sympathetic to the relative fragility of the technology used to render VRML models. Ways need to be investigated to display VRML models in full-size on the job site, with robust technology that is accessible and manageable by the personnel who need to use it.

7 ACKNOWLEDGMENTS

We would like to acknowledge our client, Virginia Mason, for their willingness to explore new methods of communication during the design of the Benaroya Research Institute. We would also like to thank Al Wirta of Associated Metals and Fabrication, Inc, and the project team at Baugh Construction for their advice, criticisms, and insight.

We would like to extend our thanks to Bruce Campbell of the Human Interface Technology Laboratory at the University of Washington for his help with the ins and outs of the VRML 2 specification. Finally, we would like to thank the project team members for their patience, understanding, and their willingness to explore new frontiers of representation: Richard Dallam, AIA, Allen Whitaker, Grant Gustafson, AIA, Reidar Dittmann, and Stephen Glen.

References

[1] Campbell, Dace A. and Wells, Maxwell. "A Critique Of Virtual Reality In The Architectural Design Process." HITL Report No. R-94-3, 1994.

[2] Davidson, James N. "Aspects Of Asynchronous And Distributed Design Collaboration" and "Digital Pinup Board - The Story Of The Virtual Village Project." *Virtual Design Studio.* Ed. Jerzy Wojtowicz. Hong Kong: Hong Kong U P, 1995.

[3] Mandeville, Jon et al. "GreenSpace: Creating A Distributed Virtual Environment For Global Applications." *Proceedings of IEEE Networked Virtual Reality Workshop*, 1995.

[4] Mitchell, William. Comments from Wrap-Up Session of "Virtual Design Studio 1995." http://www.hitl.washington.edu/people/dace/vdswrap.html.

[5] Varney, S. H. and McCarthy, V. "E-commerce: Wired for Profits." *Datamation.* vol.42, no.16. pp. 42-5, 48-50. Oct. 1996.