

MANUFACTURING VIRTUAL: APPLICATION IN PROJETES

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The term Virtual Reality (VR) initially referred to the use of immersive technologies like head-mounted displays or CAVE systems for the interactive visualization of three-dimensional environments. Today, the meaning of VR has broadened and includes semi-immersive as well as non-immersive techniques. At the core is always a three-dimensional computer model, often enhanced with functionality and behavior. VRML, the Virtual Reality Modeling Language, is a recent ISO standard that allows for the distribution of such computer models over the World Wide Web and for interactive model viewing within the framework of a regular Web browser. The Virtual Reality Laboratory at the University of Taubaté has explored this revolutionary technology for collaborative applications over the Internet in support of concurrent engineering and distributed work over distances. The underlying principles of Web-based VR via VRML is described and applications in design and manufacturing tasks are illustrated by examples including ship motion simulation, virtual prototyping of sailing yachts, simulation of ship production processes, virtual factory planning, and others.

Keywords: *manufacturing virtual, virtual reality, production processes.*

1. INTRODUCTION

In the late 1980's, Jaron Lanier coined the term Virtual Reality (VR) and his company, VPL Research, developed the first commercially available head-mounted display (HMD), a device that provides its user with an immersive virtual reality experience. In the following years, alternative immersive systems like the BOOM from Fakespace or the CAVE system, developed by the University of Illinois at Chicago, reached the market. These immersive viewing systems present the user with a full scale, stereoscopic representation of a three-dimensional environment that is computer-generated. Head-referenced viewing provides a natural interface for the navigation in three-dimensional space and allows for look-around, walk-around, and fly-through capabilities in virtual environments. Realistic interactions with virtual objects via data glove and similar devices support the manipulation, operation, and control of virtual worlds. Often, sound, haptic devices, and other non-visual technologies are used to enhance the virtual experience significantly. As a basic requirement, viewing, interactions, and other tasks have to be executed with real-time response and, therefore, require often significant computational power. The resulting illusion of being fully immersed in an artificial world can be quite convincing. The benefits of this technology for design and manufacturing tasks were recognized and explored early on as described, for example, in (Beier, 1994).

The term Virtual Reality initially referred to these immersive systems. Alternative terms like Virtual Worlds or Virtual Environments (VE) emerged and reflect more appropriately the wide range of possible applications and the fact that the technology is still far away from simulating "reality." The latter term, Virtual Environments, is preferred by the academic community.

With time, the meaning of VR broadened and, as of today, VR is also being used for semi-immersive systems like large screen projections (with or without stereo) or table projection systems like the Immersadesk and similar devices. Even non-immersive systems, like monitor-based viewing of three-dimensional objects, are called VR systems. The rapid development of the World Wide Web in the recent past has created additional versions of virtual reality as, for example, in Apple's QuickTimeVR or, more importantly, with VRML, the Virtual Reality Modeling Language for the World Wide Web. The boundaries are becoming blurred, but all variations of VR have gained importance and are slowly merging into a very broad spectrum of technologies used to view and interact with three-dimensional worlds in real-time.

2. THE UNDERLYING VIRTUAL MODEL

At the core of most of these VR systems is a computer model that is usually generated using three-dimensional modeling techniques as, for example, supported by many CAD/CAM systems. The model needs to be a polygonal representation of all geometry involved. Only such a representation allows for fast rendering in real-time. If an object

has been created using Constructive Solid Geometry (CSG), it must be first converted into its boundary representation (B-rep). If the boundaries are curved surfaces, a polygonal approximation can be derived using a tessellation algorithm that substitutes the surface by a mesh of polygons (usually triangles). The number of polygons, the so-called polygon count, for the entire model is a critical factor in any VR application since it determines the rendering speed. Real-time rendering requires the generation of at least 20 to 30 frames (perspectives views) per second. A laptop computer can render several thousand polygons in real-time. For the most complex models (up to a million polygons), powerful computer systems with special graphics hardware are required. In general, increasing complexity (higher polygon count) of the model requires more computational power.

To view and interact with the geometry, the computer model needs to be completed with information describing the appearance of objects (color, reflection characteristics, textures), the lighting environment, possible animations, interactions, sound, as well as behavior and functionality. In the following, we will refer to this augmented polygonal representation of a three-dimensional computer model as the "virtual model."

Once the virtual model has been defined, it can be used, at least conceptually, with any of the existing VR systems. Different data formats and missing standards make the transition from one VR system to another still difficult, but this situation is improving rapidly as appropriate tools are being developed. In an ideal situation, a virtual model initially developed on a desktop personal computer can be viewed using the desktop's monitor (non-immersive VR), but can also be utilized using systems involving an HMD or even a CAVE, thereby, providing the features of fully immersive VR, like full scale representation, stereoscopic viewing, and head-referenced navigation.

The creation of a virtual model is still a labor intensive and time consuming task. Even if a three-dimensional model already exists (e.g., as a CAD model), additional efforts are required to derive a polygonal representation with acceptable polygon count and to define supplementary information regarding appearance, lighting, functionality, and other properties. The fast generation of a virtual model, also known as rapid virtual prototyping, is still a topic of ongoing research and development.

3. WEB-BASED VIRTUAL REALITY VIA VRML

A potential solution for a standardized virtual model is the most exciting development of VRML, the Virtual Reality Modeling Language, a new addition to the World Wide Web. While HTML, the HyperText Markup Language, is the current standard for authoring home pages, VRML supports the distribution of three-dimensional models over the Internet. These models have all the characteristics of virtual models (as described above). They are based on a polygonal representation and can be animated, can include functionality and dynamic behavior, and can be interactively controlled by the user. In the future, home pages may be replaced by "home spaces" with hyperlinks to other spaces or pages located on any server within the worldwide Internet.

A VRML model is defined in one or more VRML files. A VRML file is a regular text file that describes a virtual model using a standardized syntax. The content of a VRML file is being viewed interactively through the use of a VRML plug-in available for all common Web browsers (like Netscape or Internet Explorer). These plug-ins can be downloaded from various Web sites and are usually available at no cost for different computer platforms.

When accessing a VRML file on the Web (by clicking on a corresponding link), the file is downloaded on the user's computer and the plug-in is activated and displays an initial view of the virtual model on the computer's monitor. The plug-in provides standard navigational tools like walk-through or fly-over. These tools enable the user to move through the model in an arbitrary way or along a predefined path. Navigation as well as interactions are usually controlled via the mouse input device.

Using VRML on the World Wide Web provides an excellent tool for sharing virtual models with remote users and for supporting collaborative work and concurrent engineering. It is extremely cost effective since the required infrastructure (networked computers) exists almost everywhere and the viewing software (VRML plug-in) is available to everyone. Today's limitations are dictated by network capabilities (download times for large VRML files describing complex virtual models) and the speed of the user's local computer (responsible for real-time rendering and interactions). The current development trend towards high capacity networks like Internet2 and more powerful desktop and laptop computers with 3D graphics acceleration will remove these limitations gradually in the near future.

Viewing a VRML model over the World Wide Web on a monitor provides only a non-immersive VR experience. However, the syntax, data structures, and features of the Virtual Reality Modeling Language are powerful and comprehensive modeling tools that allow for the description of a complete and often sophisticated VR application. This description is in most cases sufficient to run the application on fully immersive systems, if appropriate translators are available.

4. THE VRML STANDARD

The first version of VRML (VRML 1.0) was developed by a consortium of computer graphics professionals and became available on the World Wide Web in 1995. It quickly gained broad support and, after redefining the language, the specifications for VRML 2.0 followed in 1996. This version, with a few minor differences, became an international

standard (ISO/IEC 14772) in 1997 under the name VRML97. For details regarding the interesting development of VRML see (Carson et al., 1999).

Figure 1 illustrates in a simplified form the items and properties that can be defined in a VRML file, the standard use via a Web browser, as well as the possible utilization of a VRML application in various immersive viewing systems.

The building blocks of a VRML model are so-called VRML nodes. Each node is specified using a standardized syntax and describes, for example, a three-dimensional shape, a light source, the path for an animation, the position of a sound source, etc. The nodes are organized within a scene graph, a hierarchical structure commonly used for building and managing complex three-dimensional content.

Geometry and appearance of objects is defined via shape nodes. Simple geometry (box, cylinder, cone, sphere, extrusion, others) can be specified within VRML directly (i.e., manually) using a few parameters. For more complicated geometry, the IndexFaceSet node defines an arbitrary polygonal mesh representing an object's shape. In practice, these objects are usually created using three-dimensional modeling software (like CAD/CAM systems). Most of these software packages allow to export objects in the form of VRML nodes that can be inserted into the VRML file.

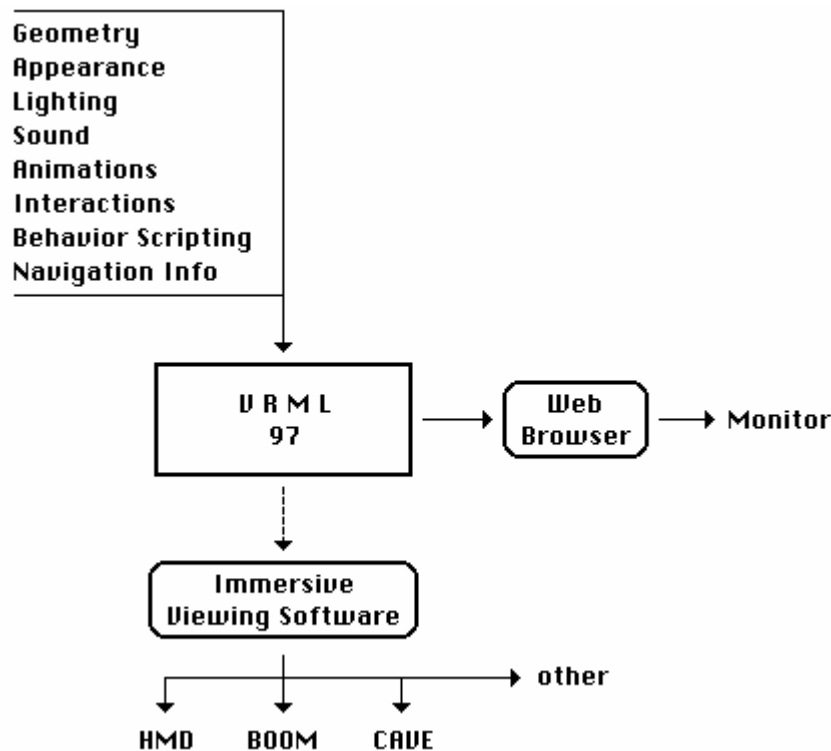


Figure 1. Definition and use of a VRML file

The main tool for the definition of interactions are sensor nodes that track the user's position within the VRML world or the position of the user's input device (usually a mouse). When entering a specified area of the world or clicking on a shape, predefined events will be triggered through a routing mechanism (e.g., starting an animation, changing the light, rotating an object, modifying a color, or adding fog to the scene).

The Script node provides additional flexibility for creating a VRML application. Within this node, customized behavior and functionality can be "programmed" using, e.g., JavaScript. It should be noted, however, that VRML is not a programming language per se. For example, scripts are not compiled and, therefore, complicated interactions and sophisticated scripts may slow down the execution.

A comprehensive description of VRML is outside the scope of this paper. The reader interested in learning VRML may refer to overview articles like (Nadeau, 1999) or to a list of excellent books on VRML like (Ames et al., 1997, Carey and Bell, 1997, Hartman and Wernecke, 1996, Tittel et al., 1997).

In addition, the World Wide Web is a great resource for information about VRML. The Web 3D Consortium (www.web3d.org) is an open consortium focused on all aspects of 3D technology on the Internet and the promotion of VRML. The site provides links to many VRML sites and includes the official and complete specification of VRML97. The Web 3D Consortium also maintains the VRML Repository (www.web3d.org/vrml), a community resource for the dissemination of information relating to VRML.

5. APPLICATIONS IN DESIGN AND MANUFACTURING

The Virtual Reality has been involved in research and development regarding the application of VR in industrial problems and other areas since 1993. Besides the use of HMD, BOOM, and CAVE systems for immersive applications, non-immersive VR and Web-based VR via VRML has become an area of high interest. The laboratory has explored the usefulness of VRML in design and manufacturing through a variety of studies and projects. Some of the results are presented in the following.

When using VRML for engineering tasks, one has to keep in mind that VRML was not specifically designed for engineers. The generic concept of VRML has resulted in a wide-spread use including such diverse areas as architecture, archeology, medicine, scientific visualization, human animation, multimedia presentations, entertainment, education, or even 3D cartoons.

In the area of Computer-Aided Design and Manufacturing, the CAD model is of overall importance as the computer-internal description of a product or process. It is used for a variety of tasks in design, engineering analysis, operational simulations, production, maintenance, and others. In addition, it can also serve as the basic source for creating a virtual model of a product or process.

A VRML representation of a product or process is a polygonal approximation of the original CAD model. It is less precise and, often, less detailed. As a virtual model, its purpose is to allow for viewing and interactions with real-time response. The VRML model cannot replace the CAD model. Fig. 2 illustrates that a VRML model can be created from a CAD model (using existing export functions of CAD/CAM systems) and, with additional information, used as a VR application. However, the path is only one-way. Interactive changes in the VRML model cannot easily be propagated back into the CAD model. This current drawback is a topic of ongoing research and will find appropriate solutions in the future.

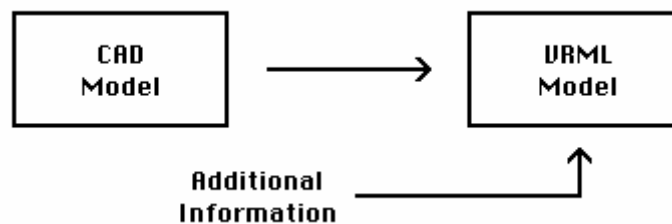


Figure 2. Creation of a VRML application from CAD data

5.1. Ship Motion Simulation

This early study was involved the creation of a virtual model of a sailing yacht. The yacht designer provided only blueprints and a lines plan. The students created first a three-dimensional CAD model using AutoCad. The final polygonal approximation for the virtual model was derived from the AutoCad model and, at that time, involved significant manual work since software for reducing and editing polygonal models was not yet readily available.

Figure 3 shows a view of the deck seen from the helm and a snapshot from a walk through the yacht's interior. Intensive use of texture maps (e.g., wood grain on furniture) resulted in a realistic appearance of interior objects.



Figure 3. Creation of a VRML application from CAD data

This application illustrates how a yacht designer can place the virtual model of an ongoing design on the World Wide Web and, thereby, allow a remote customer to inspect the design in detail using fly-over and walk-through navigation. Deck layout, interior arrangement, and other features can be evaluated easily. For the customer, a three-dimensional model is much more intuitive than a blueprint and he or she can comment and ask for design modifications by referring to the model. Resulting design changes can be placed on the Web for customer approval quickly and the process of negotiating the final version before the yacht is being built becomes very time and cost effective.

In this study, the yacht designer did not allow us to place a VRML model of the yacht on the Web for public access. Since a VRML file is a readable text file, details about the underwater hull form could be extracted from the VRML file by anybody. In such situations, a password protected Web site or even the use of encryption technology are common tools that allow for the protection of proprietary information on the Internet.

If these concerns do not exist, the designer may place virtual models of sailing yachts on the company's public Web site to advertise the company's products and attract customers.

The virtual model developed in this study contains only "passive geometry," i.e., no interaction or functionality has been defined. This makes it extremely easy to use the model in immersive VR. Viewing the model in stereo and full scale in a CAVE system is not only very impressive, but also conveys the narrowness of the interior spaces and the effect of three-dimensional arrangements more convincingly. Studies that relate to reachability, accessibility, visibility, and operational task can be performed in a more realistic way.

Overall, this virtual prototype of a sailing yacht illustrates the benefits of distributing virtual models over the Web and, at the same time, the utilization of the identical model for evaluations in fully immersive VR.

5.2. Ship Motion Simulation

In this application, the motion of a high speed container ship traveling in head seas was pre-calculated by a linear analysis algorithm. The results were then used to animate a VRML model consisting of three object groups: Animated wave surface, ship hull with superstructure, and bending moment indicator displayed as a background graph. The application demonstrates the capabilities of VRML for the three-dimensional visualization of engineering analysis results.

As the ship travels through the waves (with animated pitch), a moving red line on the background graph indicates the current bending moment. Buttons on top of the graph provide interactive control of the VRML animation. Time controls for forward, rewind, and freeze allow to study any situation of interest in detail. The user can jump to several pre-defined viewpoints (including a viewpoint attached to the ship) or can freely navigate around the environment Fig.4:

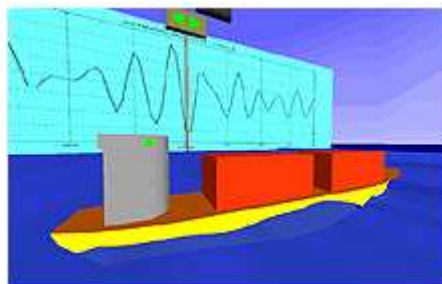


Figure 4. Creation VRML animation of ship motion simulation

The focus of this application is on the modeling of dynamic behavior and correct motion visualization. A realistic looking environment is not important. Colors may have a symbolic meaning or are chosen to improve the visual perception of motion. Immersive viewing will bring no advantages in this application, but sharing the animated model over the Web with other engineers or researchers supports collaborative work and is highly cost effective. For the future, we plan to extend the frequently used dynamic analysis program with an output option that automatically creates a VRML file showing the animated results of a particular calculation.

When evaluating the animation, insight into the dynamic behavior of a design can be gained. But, as in many engineering analysis calculations, a critical mind will always look at the suitability of the algorithms for a given situation. In this VRML model, the system shows extreme responses. At a certain point in time, the ship's afterbody comes completely out of the water indicating that the linear theory used in the underlying algorithm may not be appropriate. A three-dimensional VRML animation can reveal the limits of an underlying theory.

5.3. Simulation of Ship Production Processes

The design of a double bottom section for a navy cargo ship was provided as an AutoCad model and converted into a virtual model (Fig. 5) for analysis in immersive and non-immersive VR. Subsequently, the assembly sequence for this section was simulated based on standard practice procedures of a given shipyard.

A walk through the VRML model revealed several design errors typical found in initial CAD models created at an early design stage. Often, these errors are quite embarrassing and, if not found, can result in costly time delays during the manufacturing process. In this case, several compartments of the double bottom section are not accessible at all and it would not be possible to weld the section together. Simply adding more manholes proved not to be a solution since

longitudinal stiffeners on the bounding plates of these compartments needed to be cut in order to create access. These stiffeners contribute to the structural integrity of the section and, therefore, can not be removed. As a result of the analysis using VRML, the entire design needed to be changed.

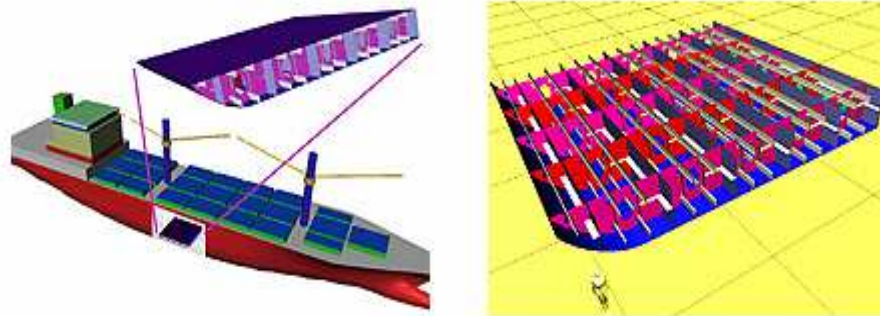


Figure 5. Location of section left and interior structure with top plate removed right

The animation of the proposed assembly sequence in VRML in Fig. 6 illustrates this process clearly for the manufacturing department, but also allows for the study of clearances, possible collisions during this process, required welding operations at various stages, necessary crane operations, and other production aspects.

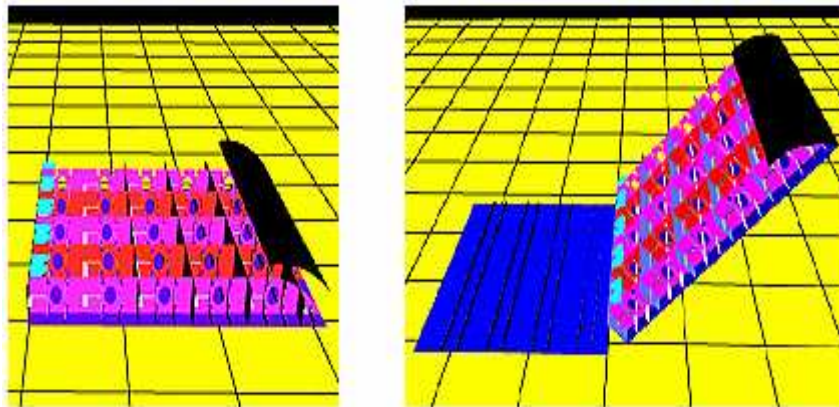


Figure 6. Stages of animated assembly sequence

This applications shows one of the major benefits resulting from using VR: The early detection of design errors. These errors can be communicated vividly over the Web to all parties involved. In a similar way, the design of processes like the assembly sequence can be shared with other departments at an early stage, thereby, supporting concurrent engineering.

5.4. Robots in Virtual Manufacturing

In this study for Manufacturing, we investigated the use of VRML for the modeling of robot operations in a virtual factory. Functional robots can be modeled using VRML's scripting capability. This paves the way for a future Web environment where robots (or other machinery). Ultimately, the downloaded equipment would be fully functional and would allow for the simulation of a production process before any hardware is being bought and installed.

Libraries of industrial robots are already available on the World Wide Web. Some of these libraries provide three-dimensional models of these robots in VRML format. The models are passive (not functional), but one can envision intelligent robot models on a supplier's Web site that can be downloaded and fed with a robot control program developed for a specific task by the user.

We downloaded one of these passive robots and added interactive features to the VRML description that enable a user to program the robot in a simplified way. The interactive buttons in Fig. 7 operate the individual robot links. The "Animate" button executes a predefined robot control program. In the future, we would like to operate the VRML robot by an externally provided robot control program, the same program used to control the real robot.



Figure 7. Interactive VRML interface for simplified robot programming

After several copies of the robot have been programmed for individual tasks, they can be placed into a VRML factory (a simplified version shown in Fig. 8). The resulting simulation with animated robots allows to check for layout efficiency, correctness of robot programming, robot reach, clearances, interferences, collision events, and other aspects.



Figure 8. Animated robots at work in a simplified virtual factory

This study, although based on a simple environment, indicates the future potential of using three-dimensional models over the World Wide Web. If standards can be defined that allow to pull functional objects from various Web sites and combine these objects into a larger, functional system, a complete virtual factory or, to use another example, a functional engine room of a ship could be created and evaluated by using virtual product models from various suppliers.

6. CONCLUSION

The field of virtual reality, initially focused on immersive viewing via expensive equipment, is rapidly expanding and includes a growing variety of systems for interacting with three-dimensional computer models in real-time. Conceptually, a virtual model can be utilized by a wide range of technologies including personal computers as well as Web-based distribution of VR applications.

The Virtual Reality Modeling Language, an ISO standard known as VRML for the World Wide Web, opened the door for collaborative work over the Internet involving functional, three-dimensional models. Sophisticated VR applications can be shared over distances as the given engineering examples demonstrate. In addition, VRML adds a new, three-dimensional information resource type to the Web and allows for the creation of libraries of virtual models. This paves the way for a networked environment where items from such libraries can be downloaded and used as modules in the development of complex virtual simulations.

Thousands of VRML worlds are already available on the Web and the number is increasing daily. This rapid propagation is based on a network environment that has become a standard infrastructure and that supports an exchange standard for virtual models on almost any computer platform and virtually at no additional cost.

These appealing benefits can already be utilized in selected design and manufacturing applications. The complexity of Web-based VR applications will increase as future developments will bring faster networks, more powerful local computers, and improved standards.

7. REFERENCES

Ames, A.L., Nadeau, D.R., Moreland, J.L., *VRML 2.0 Sourcebook*, John Wiley & Sons, 1997.

Beier, K.-P., "Virtual Reality in Design and Manufacturing," *Proceedings Convergence '94*, SAE (Society of Automotive Engineers), pp. 241-247, October 1994.

Carey, R., Bell, G., *The Annotated VRML 2.0 Reference Manual*, Addison-Wesley, 1997.

Carson, G.S., Puk, R.F., Carey, R., "Developing the VRML 97 International Standard," *IEEE Computer Graphics and Applications*, Vol. 19, No. 2, pp. 52-58, March/April 1999.

Hartman, J., Wernecke, J., *The VRML 2.0 Handbook - Building Moving Worlds on the Web*, Addison-Wesley, 1996.

Nadeau, D.R., "Building Virtual Worlds with VRML," *IEEE Computer Graphics and Applications*, Vol. 19, No. 2, pp. 18-29, March/April 1999.

Tittel, E., Sanders, C., Scott, C., Wolfe, P., *Building VRML Worlds*, McGraw-Hill, 1997.

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