

The Future of Virtual Reality in Simulating Construction Operations

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Abstract

Simulating construction operations is one of the most challenging tasks that many construction and design firms within the US are undergoing today. Two main simulation methodologies are being used, the network-based simulation, and the graphical simulation technique. While the network-based simulation technique, which was originally developed for manufacturing processes, is very tedious, complex, and time consuming, the graphical simulation technique is taking many forms and is gaining more support within the construction industry. It is a fact that the network-based simulation technique has failed to describe three main factors that influence most construction operations, these factors being the construction site **itself**, the building geometry, and the dynamics involved in operating construction equipment.¹ On the other hand, the graphical simulation technique, which was originally derived from what is called the Visual Interactive Simulation (VIS), has taken a new dimension involving the Virtual Reality (VR) technology to model, design, and simulate construction operations, and there are some attempts in that direction.² However, these attempts have either been or are being done within research institutes and large construction companies where expensive computer hardware was purchased and sophisticated software developed. There has been no indication that these attempts were done on non-expensive computer workstations or on the PC platform. Therefore, this paper describes some **state-of-the-art** techniques by which construction operations (such as earth removing operations, material handling, manipulating building components, etc.) can be modeled, visualized, and graphically simulated in real-time 3-D environments and on the PC. This paper shall benefit the construction industry since it introduces new software and hardware technologies that are capable of delivering comparable workstation performance on PCs and with a fraction of the cost.

Introduction

With the complexity involved in large-scale construction operations, there is a continuous need from the construction industry to find a technique which is capable of modeling, visualizing, and simulating construction operations.³ One methodology which has been used is the network-based simulation which was introduced to the construction industry with the development of Micro-CYCLONE, and several other programs.⁴ Although these programs helped construction managers to simulate equipment operations, they failed to include many factors that influence the construction process. These factors are the construction site **itself**, the building geometry, and the dynamics involved in operating construction equipment. It is a fact that these factors play an important role in determining many scheduling and safety related decisions during the construction phase. Another major disadvantage of using such simulation techniques is the complexity and the time required by the user to **under-**



stand simulation languages and their modeling procedure. Using these simulation techniques, a simple crane or earth-removing operation may be modeled in a very complicated simulation network that is very difficult to be interpreted by the user.

With the current advances in the computer software and hardware technologies, the use of **computer-generated** graphics and visual simulation techniques to model, design, and simulate construction operations is increasing day by day. One of the main advantages of using the graphical simulation technique is that the site topography, the building components, and the equipment dynamics are all part of the graphical simulation cycle. The utilization of the object-oriented paradigm allows the user to model the entire construction site as 3-D objects that interact with each other and with the user. These 3-D objects which typically represent the construction site, construction equipment, and building components are represented in what is called a virtual environment. It is called a virtual environment because it represents a real-life universe in 3-D **computer-generated** scenes. This type of visualization methodology shares the same graphical characteristics as that of Virtual Reality (VR) technology.

There are some attempts to utilize the VR technology in modeling, visualizing, and simulating construction operations. One of these attempts was introduced at The Georgia Institute of Technology when **Opdenbosch** and Baker developed the Interactive Visualizer Plus Plus (**IV++**), a real time object-oriented program for visualizing and simulating construction operations.⁵ Although the IV++ opened a new dimension to modeling and simulating construction operations, it was developed on a very expensive computer platform. Most construction and design firms within the US and worldwide are depending on nonexpensive computer workstations to solve their analysis, design, and CAD problems. Even if few design firms have used fast computer workstations (such as SUN, HP, Silicon Graphics, etc.) to solve their CAD problems, they are migrating to the PC platform for major cost effectiveness. The current advances in the computer hardware industry have made the difference between a mid-range computer workstation and a very fast PC quite small.

Virtual Construction Environments

The simplest way to describe a virtual environment is to imagine a set of 3-D objects drawn on a computer screen and the user having some sort of control on the viewing conditions such as location and **orientation**.¹ Similarly, a virtual construction environment is a 3-D graphical scene where the objects in that scene are representing the construction metaphor. The 3-D objects in such environments may represent a building structure, people, terrain, or construction equipment, etc. With the recent advances in computer software and hardware technologies, the user is able to navigate through that computer generated 3-D environment at very fast speeds. In addition, the user can control the viewing point inside the generated environment by using Head Mount Displays (**HMDs**) and tracking devices. The purpose of such hardware devices is to match the user's rotation and orientation with the rotation and the orientation within the generated environment when the user wears **them**.⁶ The use of a HMD device provides a closer look at the computer-generated environment so that the user feels as if inside the environment and the simulation cycle turns into virtual reality. This unmatched level of interaction between the user and the generated virtual environment is what is referred to as immersion. **The** next section presents the main building blocks that are required by VR technology in modeling, visualizing, and simulating construction operations.

What Do We Need to Utilize the VR Technology in Construction Simulation?

With the recent advances in computer software and hardware technologies, VR technology is gaining more recognition day by day since it provides relatively more economic solutions in training and other **engineer-**



ing applications. This section describes the basic building blocks that are required to apply the VR technology in simulating construction operations on nonexpensive personal computers without programming. This section suggests the operating system, hardware, and software required to simulate construction operations as real-time rendered images. These real-time images are what is referred to as virtual environments.⁶

The Operating System

As mentioned earlier, this paper targets the PC based platform to demonstrate some of the techniques by which construction operations can be simulated in virtual environments. There are many software development companies in the area of computer graphics and graphical simulation starting to release what is called Virtual Reality Authoring programs. These VR programs are the software tools which are required to create virtual worlds without programming. Most of these new VR authoring programs are being developed to operate on both the Windows 95, and the Windows NT operating systems (from Microsoft Corporation). Since the cost of both operating systems is relatively negligible, either one maybe used. However, it is advisable to utilize the Windows NT operating system for performance-related issues and because it is a true 32-bit operating system. The Windows 95 operating system still contains some embedded 16-bit code for backward compatibility. Furthermore, both operating systems have an easy-to-use Graphical User Interface (GUI), and provide many features such as Dynamic Linking (DLL), Object Linking and Embedding (OLE), Dynamic Data Exchange (DDE), and Open Data Base Connectivity (ODBC). These features allow great flexibility in operating any Windows-based application. For the sake of this paper the author refers the reader to any of several books which describe these features in more detail.

The Hardware

The recent advances in computer hardware technology made the performance of mid-range computer workstations (such as SUN or Silicon Graphics) available on very fast PC stations (such as the new Pentium Pro or P6) for a fraction of the cost. In addition, several nonexpensive HMDs including tracking controls are becoming available in the market for less than \$800 (such as the i-glasses from Virtual i O, Inc.). Moreover, several companies are providing special graphics accelerator boards (such as the GLZ5 from Intergraph, Sapphire 2SX from Fujitsu Corporation, etc.) which boost the graphics display performance to a level comparable to a mid-range graphics workstation. As prices drop on a monthly basis, a high performance virtual reality system consisting of a Pentium Pro PC station, a navigation device (similar to a joystick), a HMD with a tracking device, and a graphics accelerator board can cost about \$7,000 which is still nonexpensive compared to a computer workstation which would cost between \$35,000 and \$200,000.

The Software

In early 1996, VR users will be impressed since many software development companies are releasing what is called VR authoring programs (such as VRCreator by VREAM Inc.⁷, WorldUp by Sense8 Corporation⁸, and Virtus Walkthrough from Virtus Corporation). These VR programs are simply the software tool by which virtual worlds can be developed and distributed among users and without the hassle of computer programming. Elements of a construction operation can be modeled using existing CAD programs (such as AutoCAD, or Micro Station, etc.), imported from a graphics library, or simply created using the VR authoring program itself. Cause and effect relations between objects within the virtual environment can then be created based on their roles on the construction site. The user has full control of the displayed objects and the viewing parameters such as shading, color, background, light, orientation, and location, The level of interaction between the user and the generated virtual environment can be achieved using a head mount display and a tracking device. Thus, the user



can experience the generated environment as an observer, a truck driver, from the driver's side of an excavator, or even as a crane operator and the user turns into virtual reality. The illusion of immersion is extremely beneficial if the generated virtual environment is used for training purposes, or safety enhancements.

Another advantage that users can expect from the new VR authoring programs is the ability to have a multiple participant option allowing more than one user to share the same virtual environment at the same time and across the Internet. Therefore, a user in one place can put himself in a crane while another user can put herself in a truck and then observe each other within the virtual environment. This level of multiple interaction is extremely effective in training applications.

The cost of such VR authoring programs ranges between \$500 and \$3000 depending on the level of features that each program offers. The future competition between VR companies and the increasing popularity of the VR technology will force these prices to decrease sharply. It should be noted that the two VR authoring programs mentioned earlier in this paper (VRCreator and WorldUp) were chosen since they utilize fast graphics rendering software engines. Those two software rendering engines are the RealityLab and OpenGL from Microsoft Corp. The VRCreator program uses the RealityLab rendering engine which is a very fast graphics rendering software engine developed originally by a British company called RenderMorphics on Silicon Graphics workstations and ported to the PC platform by Microsoft. This graphics engine is supported by the Windows 95 operating system. Furthermore, WorldUp uses the OpenGL graphics software rendering engine which was originally developed on the Silicon Graphics and ported to the PC platform by Microsoft. One of the features of using the OpenGL graphics software rendering engine for developing simulation programs is that it is very easy to use. In addition, the OpenGL graphics engine is supported by many graphics accelerator boards. This graphics engine is supported by the Microsoft's Windows NT operating system and in the very near future will be supported by the Windows 95 operating system as well. The next section provides an illustrative example in creating a virtual environment for a crane operation using the VREAM approach.

Example Using The VREAM Approach

VREAM, Incorporated, is one of many software development companies specializing in developing programs for visual simulation and virtual reality. The company was founded in Chicago, Illinois, in 1990 to provide virtual reality solutions without programming for PC users. The company's first achievement was the development of the VRCreator program under the DOS operating system, which has gained good reputation among virtual reality users. One of the main features of the VRCreator software was its graphical user interface which includes a modeler and a run-time engine. The company has started to migrate its program to the Windows operating system about two years ago taking the advantages offered by such a graphical user operating system (such OLE, DDE, ODBC, etc.). The following example was created using a prerelease version of the VRCreator program under the Windows 95 operating system.

Step-1: The Modeling Process

The first step required in creating any virtual environment which represent any real-life operation is to graphically model all of the objects participating in that operation. In this case, AutoCAD R. 12 was used to model the construction site topography, the crane prototype, and the building geometry. The site topography was modeled as a 3-D flat terrain where the building geometry was represented as a set of beams and columns. The crane prototype was imported as a DXF file format using an older graphics library downloaded from the Internet and modified inside AutoCAD. VRCreator offers an integrated intelligent and easy-to-use modeler; however, it was not available with the prerelease version.

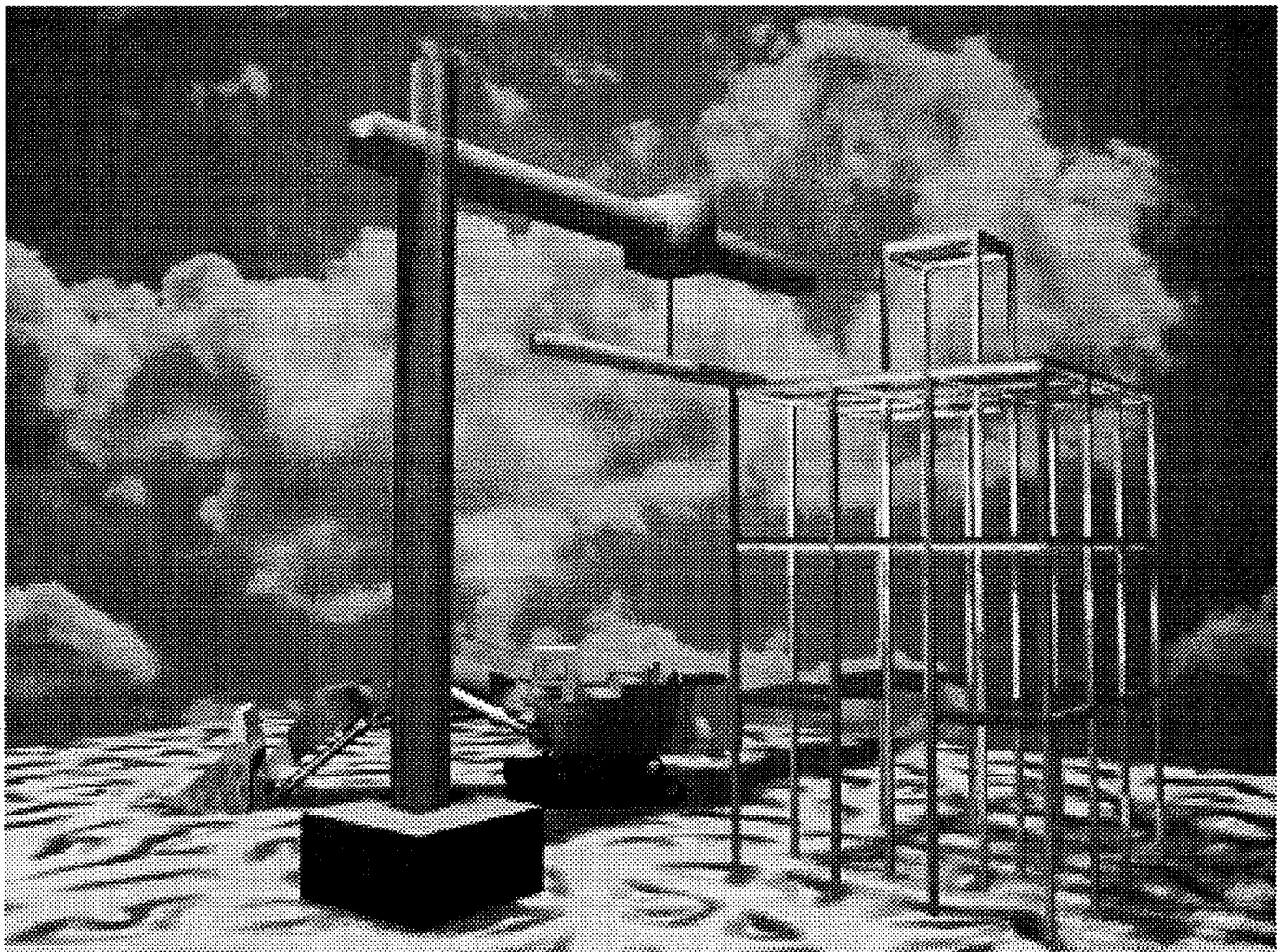


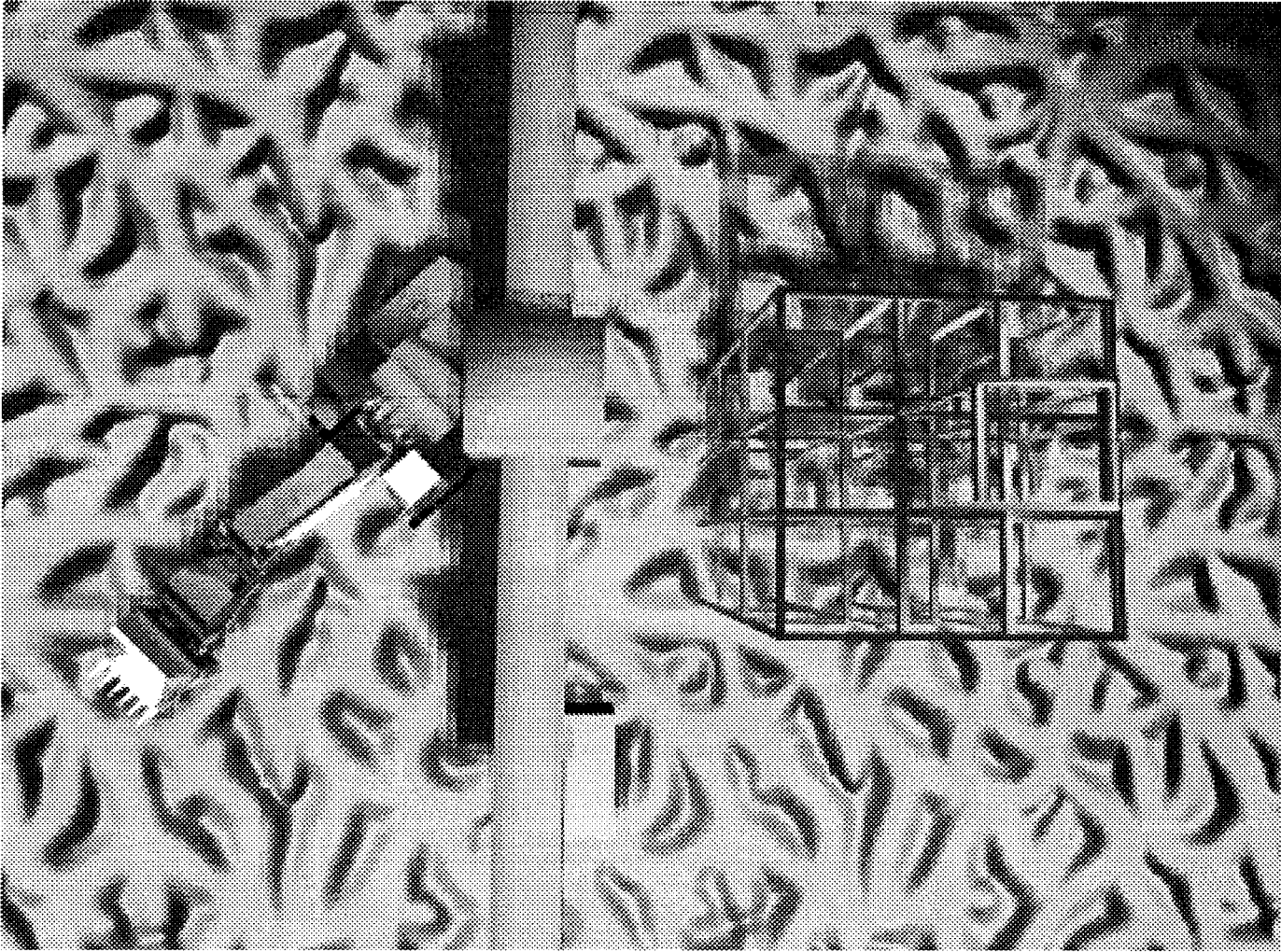
Step-2: Adding Realism to The Created Models

The next step in this example involved the utilization of the VRCreator program itself in order to add realism to the created drawing models (objects). VRCreator offers many features which can add more realism to the generated virtual environment such as different shading modes, different texture mapping modes, different light sources, colors, sounds, etc. For example, a sand texture (via a bitmap file which can be mapped onto the object) has been applied to the 3-D terrain in the virtual environment. In addition, two light sources have been added to the virtual environment. Finally, a background image was added to illustrate the virtual environment as if it is being visualized during the day.

Step-3: Adding Behavior to The Graphical Objects

In this step, behavior is attached to objects within the virtual environment in order to simulate the crane operation. The rotations of the crane's boom are assigned as well as the vertical movements. When the simulation cycle begins, the crane object moves each of the building components (such as beams and columns) from the material patch location to the proper location in the building frame. This assembly process has been done according to a script file which can be written by the user or graphically defined within the VRCreator program. Figure 1 represents the crane operation from a viewer's point of view. Figure 2 illustrates the virtual construction environment (construction site, equipment, and the building components) from an elevated camera.





Performance Related Issues

The example presented in this paper was done using a standard Pentium PC running at a 90 MHZ processing speed with a special graphics accelerator board (Sapphire 2SX from Fujitsu Corporation) The graphics board boosts the graphics performance up to 12 to 14 times that of a standard SVGA display board. In addition, it helped to boost the rendering performance (colors and shades) to about 6 to 8 times a standard SVGA display board. This is due to the fact that all of the drawing and the rendering processes are done by the graphics board hardware instead of using a software driver with a standard SVGA board.

Current Research

Using the VREAM visualization and simulation approach, research was initiated at the Department of Civil Engineering at the University of Florida to develop a real-time object oriented graphical user interface that can be used to model, visualize, and simulate construction operations in virtual environments. The research uses the VREAM Application Programming Interface (API) and its run-time graphics engine to develop a visualization and simulation program that can be used within the construction industry. The VREAM's API is a sophisticated programming library (based on the C programming language) which can be linked to a program in order to facilitate the drawing and the rendering of algorithms. Furthermore, this research utilizes the object-oriented



programming methodology and the visual programming techniques (such as **Microsoft** Visual Basic and Visual C++) to develop a **fully Windows 95 and NT visualization and simulation interface**. The research **will** benefit the construction industry since it will provide a nonexpensive, and an easy-to-use visualization and simulation program that can be used on standard PC. One of the main features of the program will be its ability to allow multiple users to share the same virtual environment across the Internet. The program will be developed so that simulation files can be distributed and shared across the World Wide Web as a standard VRML file (**Virtual Reality Modeling Language**). This level of compatibility with the Internet will allow designers at one location to share ideas with construction managers at a different location at the same time.

Conclusion

This paper describes some state-of-the-art-techniques by which virtual reality was used to model, visualize, and simulate construction operations on the PC. The example presented in this paper was experienced using the i-glasses **HMD** from **Virtual i-O** to provide an **immersive** user experience to the generated virtual environment. The navigation within the virtual environment was much faster than expected. Thanks to the **Sapphire 2SX** board which accelerated the graphics performance very much. The graphics performance was less than fluid when the same virtual environment was tested on a standard Pentium PC with standard SVGA graphics board.

The same virtual environment was experienced using the latest Intel's 180 MHZ Pentium Pro (**P6**) with a 32 MB of RAM, and the **Sapphire 2SX** graphics board installed in the system. Real time rendering performance which was measured by navigating through the generated virtual environment was extremely fast even when complex terrain texture was applied to the environment. Table 1 presents the cost of the hardware system which was used in this example.

Table 1. Hardware Cost of PC-based VR System

Device	cost
180 MHZ P6 Magnum Workstation (Micron), with 32 MB RAM	\$4,300
i-glasses, Virtual I-O Inc.	\$ 900
Sapphire 2SX, Fujitsu Corp.	\$1,700
Total Cost	\$6,900

Even though the graphics performance in this PC-based VR system was very fast, more complex virtual environments can be tested on faster machines. Intergraph provides a unique solution for ultimate workstation performance on a PC-based system with a graphics accelerator board similar to the **Sapphire 2SX**, which is called the **GLZ5**. The **GLZ5** includes three graphics boards from Intergraph for performance, texture, and geometric acceleration of any program that utilizes the **OpenGL** graphics engine. Although the example demonstrated in this paper was done using the **VRCreator** program which uses the **RealityLab** rendering engine, the same example can be demonstrated using the **WorldUp** program. The only major difference between **VRCreator** and **WorldUp** is that the behavior in **WorldUp** can be assigned using a **Visual Basic**-like scripting language. As mentioned earlier, **WorldUp** uses the **OpenGL** software graphics rendering engine, which is supported by the



GLZ5 graphics boards from Intergraph that deliver a graphics performance up to about 7 times that of the Sapphire 2SX board.

It is hoped that the techniques described in this paper will be used as guidelines for **future** research in utilizing VR technology in simulating construction operations. The flexibility of current visualization, and 3-D graphical simulation programs available on the PC platform will allow researchers to link these programs to scheduling, expert systems, and other programs.

References

1. Opdenbosch, A. *Design/Construction Processes Simulation in Real-Time Object-Oriented Environments*. Ph.D. Thesis. Georgia Institute of Technology, 1994.
2. O'Keefe, M. Robert. "What is Visual Interactive Simulation?" *Proceedings*. Winter Simulation Conference. 1987.
3. Oloufa, A. A., "Feedback Mechanisms for Operational Simulation." *Journal of Computing in Civil Engineering*. 6: no.2, 1992, 161-177.
4. Halpin, D. W. *An Investigation of the Use of Simulation Networks for Modeling Construction Operations*. Ph.D. Thesis. The University of Illinois. Urbana Champaign, 1973.
5. Opdenbosch A., and N. Baker. "Simulation of Construction Operations in Virtual Interactive Environments" *Journal of Computing in Civil Engineering*. 1994, 1435-1442.
6. Pimentel K., and K. Teixeira. *Virtual Reality: Through the New Looking Glass*. 2nd. Ed.. McGraw-Hill. New York, 1995.
7. VREAM, Incorporated. *VRCreator Reference Manual*. 1995.
8. Sense8 Corporation. *WorldUp Reference Manual*. 1995.

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