

A VIRTUAL REALITY ENVIRONMENT FOR CONSTRUCTION SIMULATION

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Abstract: This paper depicts the approach of constructing a virtual reality environment for simulating building construction operations. The virtual environment is established to demonstrate the constructability of building during the building delivery process. Particularly, the functions such as navigation of construction sites, simulation of construction operations, and evaluation of construction details will be critical to construction operations. The system shell is implemented by JAVA on the web and integrated with VRML 2.0 for supporting the above functions. An office building project is simulated to highlight the above discussion.

Keywords: Virtual reality, computer simulation, office buildings, construction operations

1 INTRODUCTION

Computer simulation technologies are already applied to study the built environment such as architecture and urban landscape for years [1,2,3,4]. The purpose of simulation is to better understand the prospective creation or changes before the physical implementation through various mechanisms. The lately developed virtual reality (VR) technology, known as "a simulated 3D interactive environment," even provides promising characteristics such as immersivity, interactivity, and fidelity [1]. Furthermore, the more profound impact on cyberspace is through internet browsers to surf VR models created by virtual reality modeling language (VRML). It is critical to explore the potential uses of feasibility of VR.

The research question is "how building designers and engineers can utilize VR in the built environment?" Therefore, this paper depicts the approach of constructing a virtual reality environment for simulating building construction operations. The virtual environment is established to demonstrate the constructability of building during the building delivery process. Particularly, the functions such as navigation of construction sites, simulation of construction operations, and evaluation of construction details will be critical to construction operations.

Finally, this paper provides demonstration of construction simulation in an office building project to highlight the usefulness of VR in construction simulation. The operations of tower cranes and

curtain wall installation are also studied in the construction process.

2. MODELING BUILDING OBJECTS AND BEHAVIORS

To develop a VR environment for the design and planning purposes, the following section will describe how to model the building construction-related objects and behaviors for elaborating the above discussion.

2.1 The artifacts in the virtual environment

Traditionally, an artifact such as a building is described by its geometric attributes. Computer simulation of the artifact is primarily modeling the geometry. However, artifacts have their own functional behaviors, including its physical and motional ones. Meanwhile, previous simulation technologies are often limited by the technical and economical factors, and can not demonstrate or represent the completeness of modeling.

In the virtual environment, an artifact is an object with the geometric and behavioral attributes, including the physical characteristics (e.g. visual, acoustic, thermal performance) or dynamic characteristics (e.g. gravity, collision, motion). A more complex artifact can be decomposed into several objects. A top-down process can be used to analyze an artifact such as a building, and can be defined as the building, floors, zones, rooms, parts, and details [3].

Creating a virtual environment primarily depends on the creation of objects and scenes by software, and that requires three steps: (1) establish, arrange the objects in the virtual world, and assign the textures for each object; (2) define objects' attributes; (3) establish the links between objects. According to these steps, a virtual environment can be built as shown in Figure 1. Objects such as doors or windows are linked to a bigger object, a room.

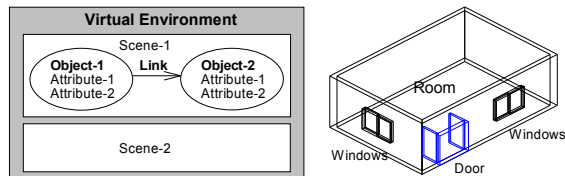


Figure 1. The Virtual Environment

2.2 The objects and scenes

An object is considered as a single artifact, and a scene consists of a group of related objects. Two basic approaches of creating objects or scenes are: (1) to translate from other formats to VR models, or (2) to use existing VR modelers to create objects. In this study, objects are primarily modeled by 3D Studio MAX. VRML is a scene description language. Both the objects and scenes of the virtual environment have to be modeled and converted into .wrl files, which can be interpreted by VRML and linked with the world wide web.

In construction simulation, object behaviors can be exemplified by the operation of a tower crane. The tower crane is a typical construction equipment that facilitates the lifting and moving construction materials around the site, as shown in Figure 2. The basic functions include rotation of arms, horizontal and vertical movements, and position and hang. These functions have to be considered and modeled.

Because VR is real-time rendered without setting path, and is different from computer animation, the complexity of objects is critical to its performance. Most current modelers have limitation of number of polygons that can be used for optimizing the performance [3,4]. The perceived "reality" is subject to the accuracy of objects, the level of details, and the computational performance [4]. Therefore, the key attributes and behaviors of the objects should be modeled essentially.

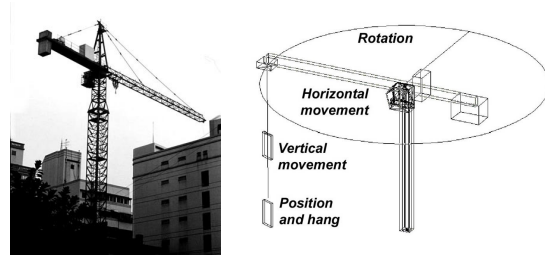


Figure 2. Construction Objects and Behaviors

3. A VR ENVIRONMENT

The above explanation defines the basis of a virtual environment, that basically consists of three parts: 1. the shell, 2. the scenes and objects, and 3. the interfaces. The follows will describe the approaches of system analysis and design for constructing the virtual environment.

3.1 System framework and shell

The building life cycle or the building delivery process consists of the planning, design, construction, occupancy, and maintenance phases. Each phase has different needs for design operations and simulation. Navigation, simulation, and evaluation of construction operations are particularly needed to ensure the building quality. Therefore, the system is modularized for allowing models shared among different applications. The system currently consists of three subsystems or applications, i.e., design navigation, construction simulation, and design evaluation, as shown in Figure 3. However, the system can be expanded horizontally. In the construction simulation module, the functions include construction operations, procedures and environments to activate control objects and related behaviors.

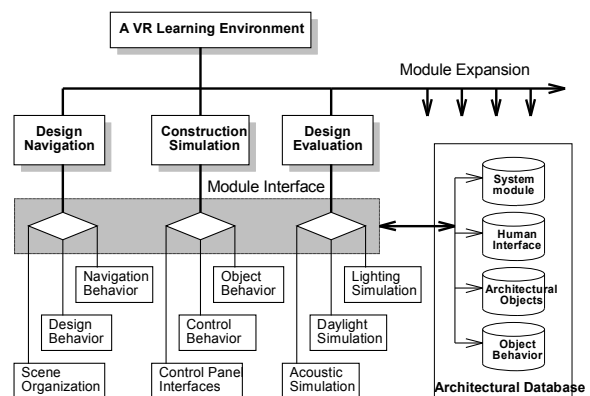


Figure 3. The System Framework

The system shell is implemented by JAVA on the web and integrated with VRML 2.0 for supporting the above functions. The system consists of three

parts: 1. the shell, 2. the scenes and objects, and 3. user interfaces. The study focuses on the needs for the system integration and user interface design.

Because there is no integrated VR world builders, the system shell is implemented by several programs such as Visual J++ and SONY Conductor, and integrated by JAVA for creating the interfaces. The input of VR models of VRML 2.0 format is primarily created by 3D Studio MAX 2.0 and partially by other model builders. The output files can be viewed by the SONY Community Place Browser 2.0.

3.2 Scenes and objects

Currently, VRML 2.0 is enhanced with interactive and sound specifications, and can be used by multi-persons on the net. However, VRML 2.0 currently neither defines the object relations nor supports the control sensing function. VRML has to integrate with other programming language to enable the detection of objects and interaction. JAVA is an object-oriented language which can be executed cross various platforms and generate actions and link to the objects. Therefore, JAVA provides the mechanism for enabling objects to perform certain behaviors.

Meanwhile, an object file (.wrl) has to be redefined and connected with interfaces such as Proto, Route and Script nodes defined by VRML. Once the geometric and action attributes are defined, the simulation module is completed. For example, if the rotation class (TurnDoor.class) by JAVA is connected to the .wrl as external reference, then the door can initiate open and close action. Similarly, a tower crane object is created as a main object (CraneTower.wrl) consisting of at least six sub-objects and linked with various behavioral interface, as shown in Table 1.

Table 1. Specification of a Tower Crane

Sub-objects	Interfaces
1. MainControlPanelProto.wrl : Define control panel	1. CraneMotion.java
2. Frontpanel.wrl : Define control panels	2. ScaleValueChange.java
3. SliderProto.wrl : Define adjustment	3. ToggleSwitch.java
4. ButtonProto.wrl : Define control buttons	4. Warningflash.java
5. ToggleProto.wrl : Define control switches	
6. FlashLightProto.wrl : Define warning signs	

3.3 User interfaces

Shneiderman (1992) indicates that effective human-computer interactions can be achieved by

designing suitable user interfaces [5]. Particularly, the relationship between physical and virtual world should be carefully defined [6]. Because different kinds of tasks may cause different human computer interactions, four modes of user interface are proposed, including the user, agent, monitor, and immersion modes [2,3]. These modes define the users' role in virtual reality and the ability to control objects or scenes directly or indirectly.

The interfaces integrated with VRML and JAVA provide the foundation for VR applications on the web. For example, the user interfaces in tower cranes and control panels as shown in Figure 4 and Figure 5. The command list or adjustment of operations can be recorded. Users such as tower crane operators can either directly control or monitor the process, while other users can also coordinate and facilitate the process through remote windows via the internet.

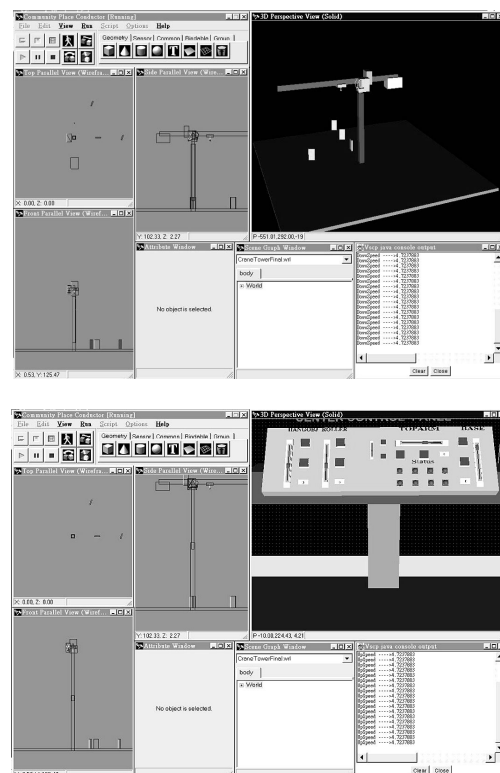


Figure 4. User Interface of Tower Cranes

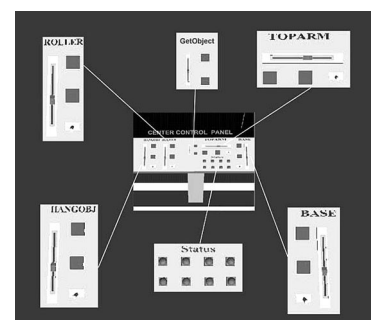


Figure 5. User Interface of Crane Control Panels

Similarly, working lifts or elevators are also studied and modeled, as shown in Figure 6. The basic functions consist of activating vertical movements (e.g. up, down, and stop), the speed of movement, and door status (e.g. open/close).

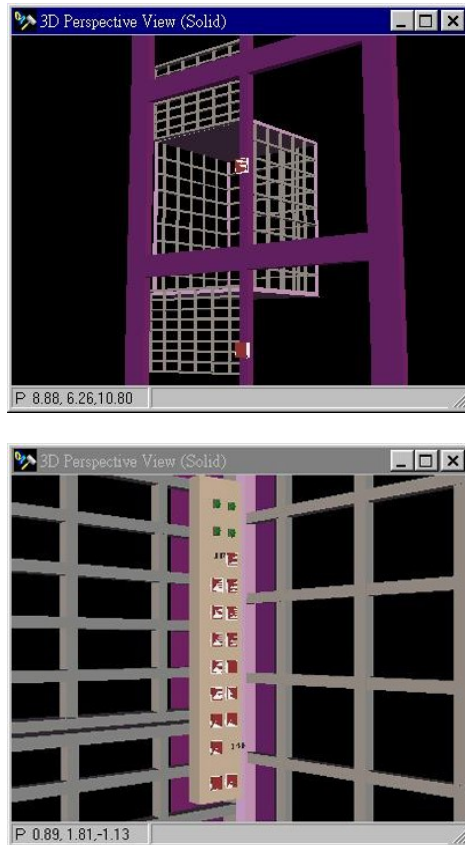


Figure 6. User Interface of Working Lifts

4. CONSTRUCTION SIMULATION

Constructability is one of the major concerns in building design and construction management [7]. In construction processes, the construction objects, activities and schedule can be simulated for planning, inspection, or examining the feasibility of details [8]. The simulation can also be used for job coordination and resolve some conflicts in a large-scale construction site or detect pitfalls.

4.1 Construction operations and processes

Construction operations and processes can be simulated and studied in accordance with the scale of building and importance of activities. The construction simulation can be categorized into two kinds of simulation:

a. Static simulation: Static simulation generally focuses on the result of activities by visualizing the physical form or position of building parts.

Visualization can assist communication among various working groups. The process can be exemplified by the steel erection or curtain wall installation in an office building as shown in Figure 7.

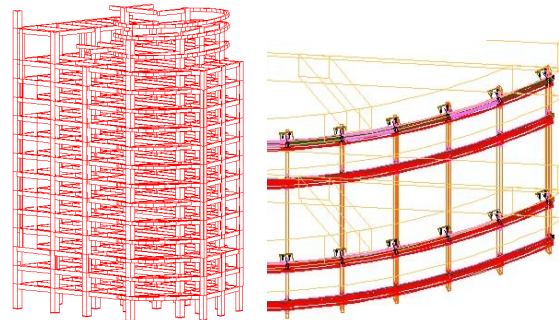


Figure 7. Simulation of Construction Assembly

b. Dynamic simulation: Dynamic simulation focuses on the continuity of activities by visualizing the process. For example, a crane tower is employed for lifting and moving construction materials around the site. Figure 8 highlights the key steps in the process of . Figure 9 demonstrates the simulation of a tower crane operating in the construction site and snapshots from different viewpoints.

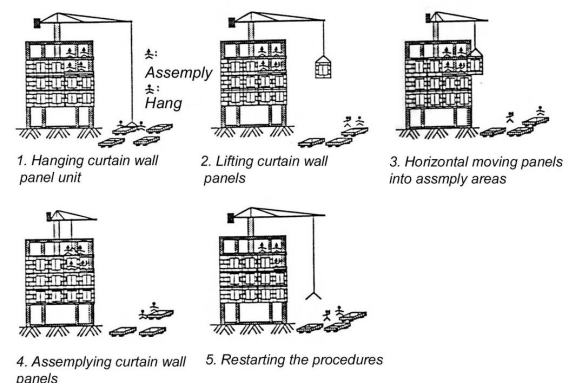


Figure 8. The Construction Process

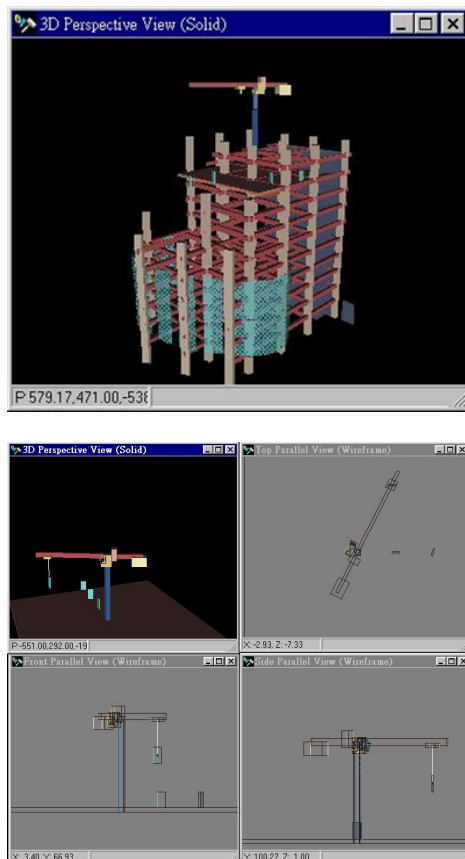


Figure 9. The Construction Simulation

The above simulation is implemented on a Pentium-II-350-based PC that can be operated as a stand-alone machine or on the internet. While environmental information will enhance the reality of simulation, only necessary information is considered. For example, while the sound effect can be incorporated into the simulation, spatial awareness is largely based on visual information. It is found that the physical conditions of construction operations and process will be better simplified and modeled in accordance with the needs. Therefore, weather conditions and gravity is not considered in the study due to the complexity of reality.

4.2 Preliminary evaluation

The above illustrations demonstrate the possibility and potential uses of VR in construction simulation. While the system is still a prototype of the VR environment, both system modules and the object library can be expanded. The preliminary evaluation indicates that the interactive and control characters of VR are promising for designers and engineers. The implications for building design and planning are the ability to examine the space with the control ability and interactive behaviors, improve the design quality, and prevent problems that may be occurred.

However, the operational performance of VRML is subject to two factors: the hardware and the integrity of VRML. The computation performance is subject to the accuracy and the numbers of polygons [3]. Because large-scale visualization are critical to real-time operations, the level of details in object modeling can be as abstract as possible. Currently, VRML 2.0 is very primitive, and even the same object or scene file can often generate different outputs and cause incompatibility problems among different browsers. Furthermore, there is no definition of rendering in VRML and consequently no shadows behind objects. Therefore, the visual perception of VR is still different from the reality.

5. CONCLUSION

In conclusion, this paper demonstrates the potential uses and limitation of virtual reality in construction simulation, the needs for defining user interfaces in VR, and how the process of planning, design, and construction can be affected by the VR technology.

The study indicates that an integrated VR world builder and environment is critical to the VR development. To combine the behaviors with geometry of an artifact can create interactive relationships between users and the design environment. The study demonstrates the feasibility of using VR for the architectural applications, such as design navigation and construction simulation. Future research directions will include extension of system modules and development of an architectural object and scene library.

The current VR systems vary in hardware and software. While augmented reality in architectural construction, inspection, and renovation are feasible, the effectiveness of VR to the field is still under investigation [9]. The major weakness of VR is related to the "visual acuity" because human beings are sensitive to the difference between "the reality" and "virtual reality". However, each will be complement to the other in the future. While the current VR hardware and interfaces are still far behind the acceptable level, the future improvement is promising. The balance between the quality of simulation and economics is critical to the uses of VR.

Acknowledgments

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