DESIGN NAVIGATION AND CONSTRUCTION SIMULATION BY VIRTUAL REALITY

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Abstract. This paper depicts the approach of constructing a virtual reality environment for simulating architectural design and construction operations. The virtual environment is established to demonstrate the spatial performance of design and constructability of construction operations. 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 for supporting the above functions. The study focuses on the needs for the system integration and interface design. Four modes of human computer interfaces are proposed, including the user, agent, monitor, and immersion modes. Finally, this paper provides demonstration of construction simulation in an office building project to highlight the above discussion. The operations of crane towers and curtain wall installation are also studied in the construction process. In conclusion, this paper demonstrates the potential uses and limitation of virtual reality in simulation of the built environment.

1. Introduction

Computer simulation technologies are already applied to study the built environment such as architecture and urban space for years [Bertol 1997, Chiu 1997a, UCLA 1996]. 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 interactive environment," even provides promising characteristics such as immersivity, interactivity, and fidelity. 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 VR in architecture.

The research question is "how designers and building engineers can utilize VR in the built environment?" Therefore, a VR environment is developed for the design and construction purposes. The following sections will describe how to model the architectural objects and behaviors, system analysis and design, and demonstrations of an office building project to highlight the usefulness of VR in architecture.

2. Modeling Architectural Objects and Behaviors

2.1 BUILDING DELIVERY PROCESS

The building life cycle or the building delivery process consists of the planning, design, construction, occupancy, and maintenance phases, as shown in Figure 1. Each phase has different needs for design operations and simulation. Design navigation, construction simulation, and design evaluation are particularly needed to ensure the design quality. For example, the spatial quality of a meeting room can be simulated in design navigation, and the dimension of the space can be adjusted if needed. Furthermore, the construction details can be examined and modified in construction simulation, and the quality of space can be assessed and improved in design evaluation.
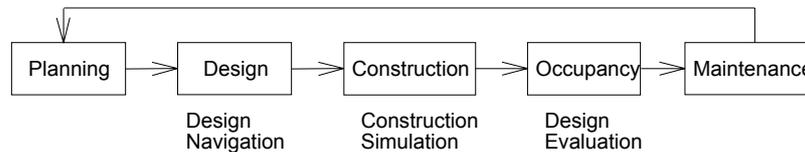

Figure 1. The building delivery process

2.2. THE ARTIFACTS IN THE VIRTUAL ENVIRONMENT

Traditionally, computer simulation of the artifact such as a building is primarily modeling geometric attributes. However, artifacts have their own behaviors, including its physical and dynamic ones. Meanwhile, previous simulation technologies are often constrained by the technical and economical factors, and cannot demonstrate or represent the entire attributes and behaviors of artifacts.

In the virtual environment, an artifact is an object with geometric and behavioral attributes, including 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 partition an artifact such as a building, into components such as floors, zones, rooms, parts, and details.

Creating a virtual environment primarily depends on the creation of objects and scenes by software, and that requires three steps: (1) create and arrange the objects in the virtual world, and assign the textures for each object; (2) define objects' attributes; and (3) establish the links between objects for building hierarchical relationships. According to these steps, a virtual environment can be built as shown in Figure 2. Objects such as doors or windows are linked to a bigger object, a room. A slide window with 2 meters in width and 1.4 meter in height, has two glass panels, and each panel should be able to move parallel to the window frame. Similarly, a swing door has dimensional attributes and action

attributes. Lighting features, light switches, and furniture can also be added to increase the reality of the space.
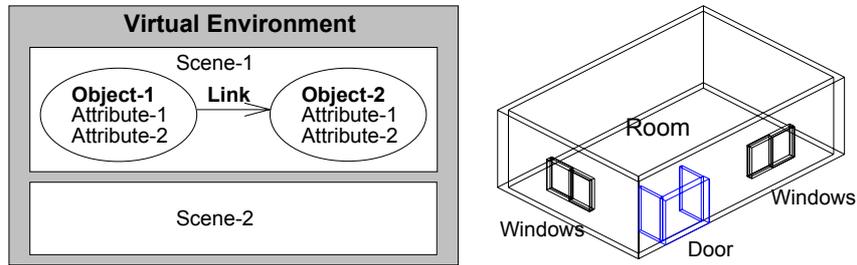

Figure 2. The Virtual Environment

2.3. 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. 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 [Chiu 1997b]. The perceived "reality" is subject to the accuracy of objects, the level of details, and the computational performance [Chiu 1997a].

Design navigation can be viewed as linked by a path with many scenes and objects. This approach constructs a navigation script by adopting objects from scenes and object library. For example, if a person wants to take a trip from the lobby at the first floor to his office (room 303) at the third floor. The path consists of three major scenes and the elevator object, as shown in Figure 3. Therefore, a VR environment can be constructed easily by choosing standardized objects or scenes.
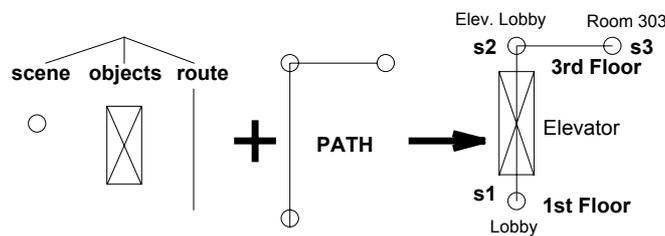

Figure 3. Objects and Scenes in Design Navigation

3. System analysis and design

The above explanation defines the basis of a virtual environment. The system consists of three parts: 1. the shell, 2. the scenes and objects, and 3. the interfaces. There are two approaches for constructing a VR environment, i.e., the image-based and the graph-based VR systems. From the interactive point of views, this study adopts the graph-based VR system approach for better flexibility and future changes. Furthermore, existing computer models can be reused by graph-based VR systems or converted into image-based VR systems. The follows will describe the approaches of system analysis and design for constructing the virtual environment.

3.1. VRML 2.0 AND JAVA

Virtual Reality Modeling Language (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. 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.

The interfaces integrated with VRML and JAVA provide the foundation for VR applications on the web. Meanwhile, an object is modeled by 3D Studio MAX, then converted into .wrl file. The file has to be redefined and connected with interfaces such as Proto, Route and Script nodes defined by VRML, as shown in Figure 4. Once the geometric and action attributes are defined, the simulation module is completed. For example, a door object is created and linked with the behavioral interface such as rotation. The rotation class (TurnDoor.class) by JAVA is connected to the .wrl as external reference, then the door can initiate open and close action.
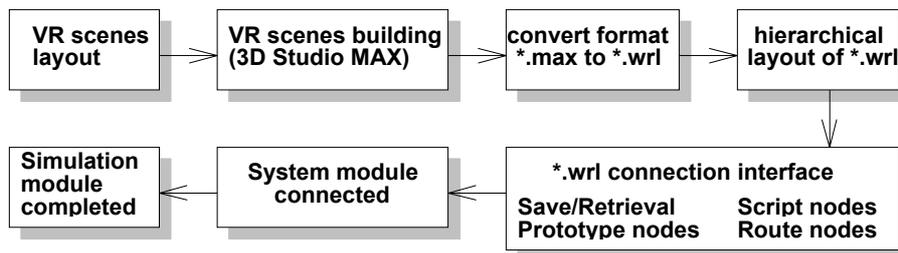

Figure 4. The modeling process

Currently, VRML and JAVA are not as well developed as the other 3D descriptive languages such as Open Inventor and C++. For example, the object behavior descriptions of VRML are not completed, and VRML does not fully support rendering ability. Similarly, the function and computational performance of JAVA are not as effective as other close VR systems. However, these shortcomings are under development and should be resolved in the near future.

3.2. THE SYSTEM SHELL

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. Figure 5 demonstrates the system shell. 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.
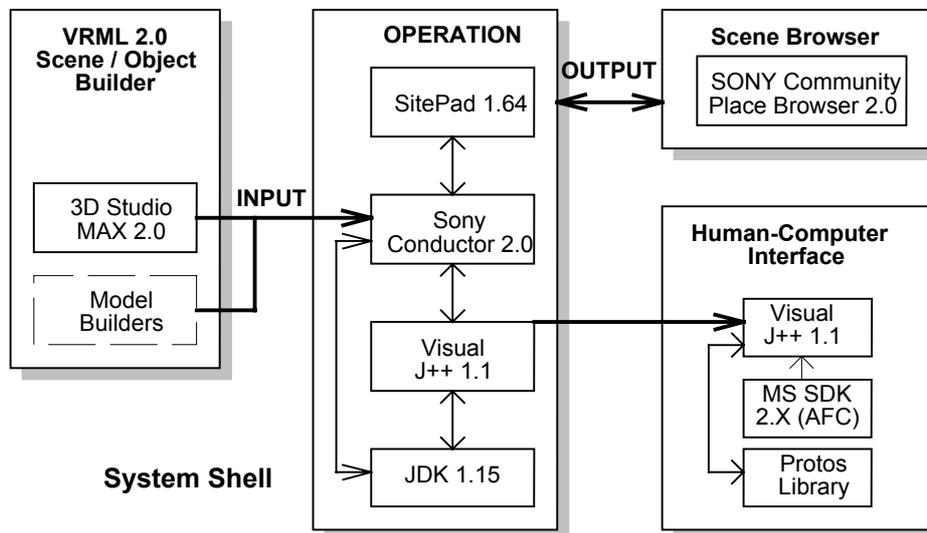
Figure 5. The system shell

3.3. THE SYSTEM FRAMEWORK AND FUNCTIONS

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 6. However, the system can be expanded horizontally.
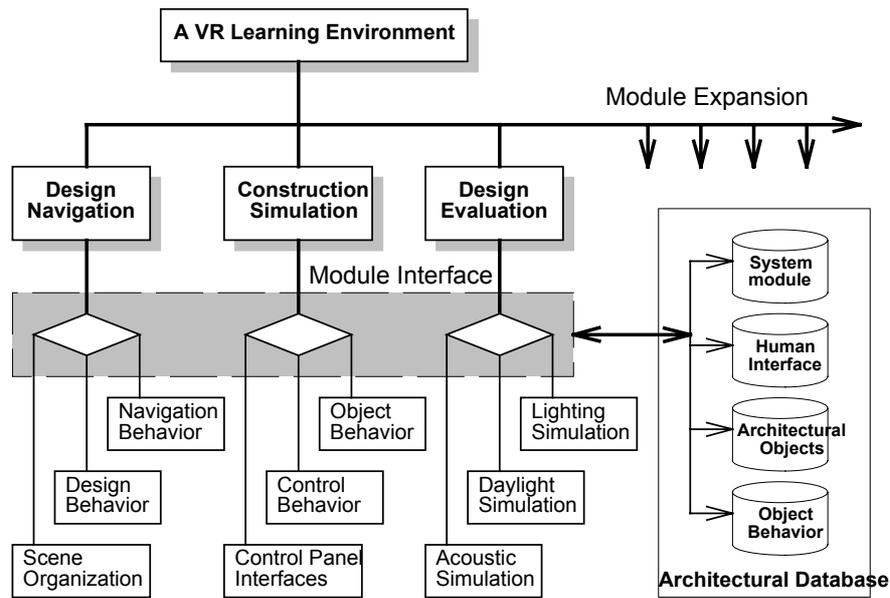
Figure 6. The system framework and functions

The function and module units of the subsystems are shown in Table 1. The operations can be used to examine the relationship among objects, the interaction between human and object, object behaviors, and control behaviors. The module interface is linked with the architectural database which also has four modules, i.e., the system module, human interface, architectural objects, and object behavior. For example, in the design navigation, the basic functions include space browser, design behavior, and space navigation. The details are described in the next section.

Table 1. Sub-system and Functions

Sub-systems	Functions	Module units
Design Navigation	Space Browser Design Behavior Space Navigation	Navigation Behavior Design Behavior Scene Organization
Construction Simulation	Construction operation Construction procedure Construction environment	Control panels Object behaviors Control behavior

3.4 USER INTERFACES

Shneiderman (1992) indicates that effective human-computer interactions can be achieved by designing suitable user interfaces. Because different kinds of tasks may cause different human computer interactions, four modes of human

computer interface are proposed, including the user, agent, monitor, and immersion modes. These modes define the users' role in virtual reality and the ability to control objects or scenes directly or indirectly.

Figure 7 demonstrates these four modes of interfaces. (1) The user mode is a hidden interface and it will appear only when needed. The user can interact with the environment directly, such as a person sits in the control room of a crane tower and operates the control panels based on his views. (2) Instead of the users directly operate the interface, a created "agent" can operate the interface in real time. In the agent mode, individuals can turn on light switches from the panel outside the scenes. (3) The monitor mode allows users operate the objects from monitors by adjusting the numerical or orientation settings. (4) The last mode is the immersion mode in which users can directly control the real environment by activating the objects in VR. While each has different architectural implications, these interface modes will be applied to the subsystems to examine the control behaviors.
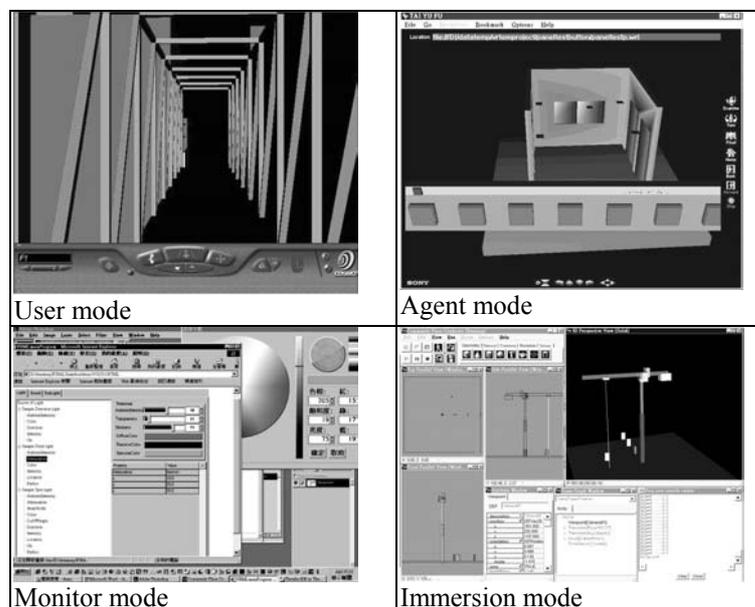

Figure 7. Four Human Computer Interface Modes

4. The Virtual Reality Environment

The virtual reality environment is established based on the above system analysis and design. The potential users of the system are designers at the conceptual design stage and students at the learning process to understand the interactions between users and the design environment. The follows describe

how the subsystems function.

4.1 DESIGN NAVIGATION

The purpose of design navigation is to observe and understand spatial relationship. Typically, users' perception is getting from the orientation, the shape, and size of space. Figure 8 demonstrates the door and walls can be reviewed under different browsers such as the Cosmo Player and SONY Community Place Browser, where one can activate actions such as door sliding and rotation. Figure 9 demonstrates that users can access the created space and navigate in a room. Users can walkthrough spaces by moving mouse cursors.
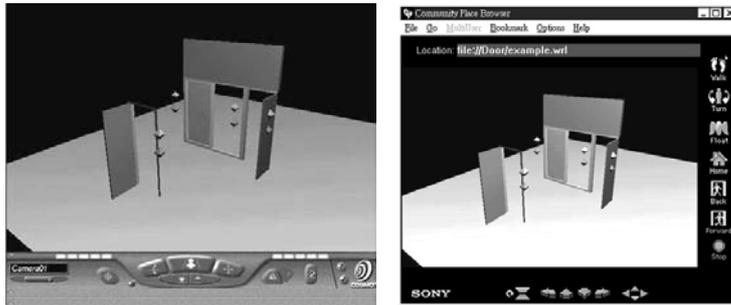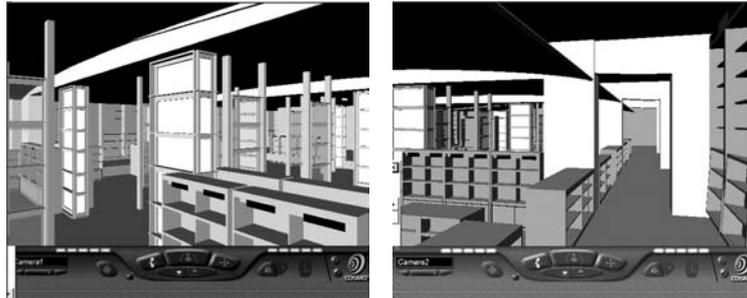

Figure 8. Doors and walls in two browsers

Figure 9. Design Navigation of A Library Room

4.2 CONSTRUCTION SIMULATION

Constructability is one of the major concerns in design [ASCE 1991]. In the construction simulation subsystem, object behaviors are exemplified by the operation of a crane tower. The crane tower is the typical construction equipment that facilitates the lifting and moving construction materials around the site. Figure 10 demonstrates a crane tower in the construction site and the simulation of the object and scene, and the VR environment.
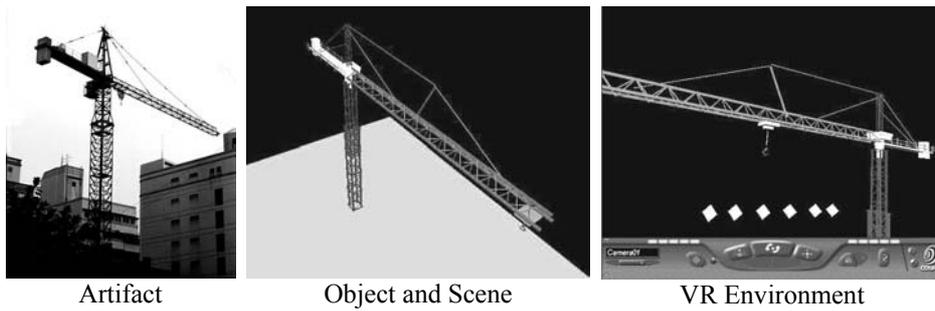
Artifact   Object and Scene   VR Environment

Figure 10. Simulation of A Crane Tower

The operation of the crane tower object is demonstrated in Figure 11. The crane tower can perform basic tasks such as lifting, rotation, hanging, and release of objects. Users can examine the operations from multi-windows simultaneously, or change the locations of the crane tower to examine the effectiveness of a scheduled construction plan. On the other hand, construction simulation can be used to prevent construction or transportation problems. The control panel is designated to perform actions such as pushing buttons or dragging the handlers according to corresponded requirements as shown in Figure 12.
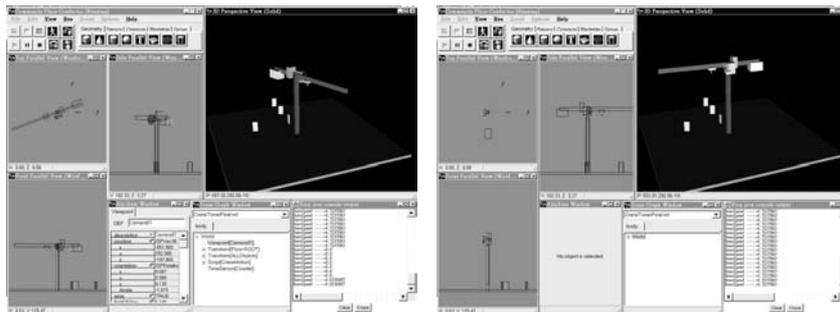

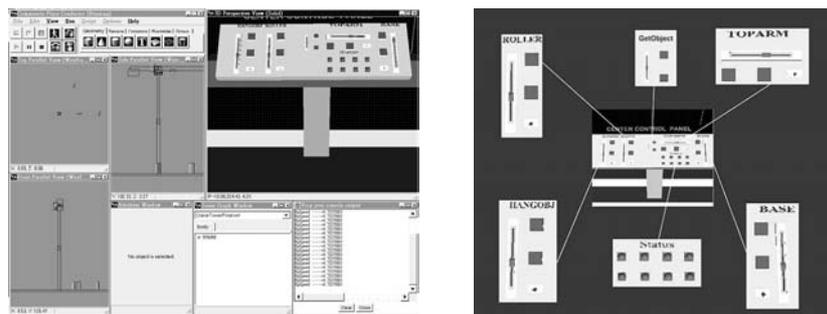*Figure 11.* Operations of A Crane Tower

Figure 12. Control Panel Interfaces of A Crane Tower

4.3. PRELIMINARY EVALUATION

The above illustrations demonstrate the possibility and potential uses of VR in architecture. 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 students. The implications for architecture 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 level of details in modeling, and the numbers of polygons [Chiu 1997a]. 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

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 [Webster et.al. 1996]. 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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