WEB-BASED VIRTUAL REALITY
FACILITY REPRESENTATION AND SIMULATION
IN CONSTRUCTION PRE-PLANNING

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Abstract: This paper presents a prototype VR (virtual reality) system that allows participants of a construction project to immerse in a vivid 3-D environment via the Internet and effectively review alternative building models. Using the system, engineers, architects and other participants of a construction project can exchange project information. Construction sequences and schedules can be integrated into the 3-D model, and the model can visually simulate construction processes with respect to different alternatives. The prototype system demonstrates that the web-based virtual reality facility representations and simulation can effectively improve the construction pre-planning process.

Keywords: Pre-planning, facility representation, facility simulation, information technology, virtual reality, VRML, web-based virtual reality, World Wide Web.

1. INTRODUCTION

There are many phases involved in the process of project delivery. These phases include feasibility analysis, facility program, conceptual design, detailed design, construction planning, construction, and operation [1]. The first three phases in the early stages of a project are also called pre-planning or preproject planning. It is recognized that the *early planning* efforts have significant influences on a project [2]. The exchanges of information in pre-planning are enormous and critical. The *methods of representing a facility* have significant influences over the quality and efficiency of the information exchanges and therefore the performance of pre-planning. This paper presents how *web-based virtual reality* can be utilized to effectively represent a facility and allow participants to communicate/ collaborate in finding design and construction alternatives.

The following sections explain key components of web-based VR applications in construction and how they can be used to enhance construction pre-planning. A bridge construction example will be given to demonstrate how VR can be used in enhancing construction pre-planning.

2. WEB-BASED VIRTUAL REALITY IN CONSTRUCTION

2.1 Virtual reality, web-based virtual reality and VRML

Virtual Reality (VR) is the technology that integrates computer graphics, electronic, and mechanical engineering for three dimensional (3-D) image presentation that creates an interactive virtual environment. *Web-based virtual reality* (WBVR) integrates the concept of VR and extends the use over the Internet. To implement a WBVR system, *VRML* is almost a standard language and tool nowadays. VRML stands for Virtual Reality Modeling Language. It is a standard for representing the information in a distributed 3-D environment. There are translators that can convert various 3-D file formats including 3-D CAD to VRML format. VRML defines methods of networking through the Internet and the interface between the 3-D models and programming languages such as Java. Current VRML also supports dynamic 3-D model/environment so that objects in the 3-D environment can change its shape or positions, that is, the objects have their own behaviors. It is worth noting that since the dynamic behaviors are realized over "*time*", the VRML model can become *4-D*, 3D

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visualization plus time animation. This is the major reason that VRML can be used for facility representation and simulation simultaneously.

2.2 WBVR in construction pre-planning

Pre-planning provides many benefits in design and construction. Pre-planning not only generates better plans, but also resolves potential constructibility problems before actual construction [2]. Gibson et al. [3] argued that there are three important steps in the pre-planning's "Select alternatives" subprocess: analyze technology, evaluate site, and prepare conceptual scopes and estimates. Also Oglesby et al. [2] argued that *modeling techniques* (physical models and computer based modeling) and *scheduling simulation techniques* serve as an important tool for pre-planning. Therefore, if the WBVR facility representation and simulation can contribute better implementation of "Select alternatives", then it can help achieve successful pre-planning and thus favorable project performance.

Today, there is a growing trend of sharing and managing construction projects' information through the Internet. Many e-business companies offer this type of information services. Among these companies, some are beginning to utilize VRML models to share the facility's geometric information among the participants. This trend shows the need of sharing facility information in a more vivid and dynamic way. Nevertheless, most current applications are limited to static facility representation, and are implemented in a standalone basis. The following sections discuss how VRML can be implemented in a dynamic and integrated manner among project participants.

3. WBVR FACILITY REPRESENTATION

3.1 Facility representation

Architects and engineers use various media to represent their design. They utilize drawings (2D or 3D), specifications, and physical models to convey the design to the owner and the contractors. The more intuitive the representation, the fewer misunderstandings and mistakes during construction.

3.2 WBVR facility representation

Using WBVR, a facility can be presented more realistically in a 3-D environment that allows the participants to visualize the design. Fig. 1 shows a typical configuration of WBVR. Participants of a construction project can access a WBVR facility model on the Internet via a Web browser that has a "plug-in" VRML browser. Either MS Internet Explorer or Netscape can be enhanced with VRML

capabilities. Some VRML browsers provide more advanced VR functions, such as the capability of applying VR hardware for higher degree of *virtual experiences*. Some browsers provide a multi-user interface and the capability of allowing multiple users to communicate and navigate within the VRML facility at the same time. An example is the Sony's "Community Place Browser" (readers can refer to http://community-place.com/).

There are three basic components in WBVR facility models: VRML model, user interface and Java programs.

First, *VRML models*. A VRML model enables the participants to navigate inside a virtual facility interactively. Feedback and opinions can be collected from the virtual experiences and shared via the Internet. The virtual environment provides participants with an intuitive visualization of the facility that facilitates better collaboration during construction pre-planning.

Second, *graphical user interfaces*. Graphical user interfaces are widely used in *windows* environment. It allows the users to easily interact with the WBVR facility. The interfaces communicate with both VRML models and Java programs when the WBVR facility is accessed from the web browser or VRML browser.
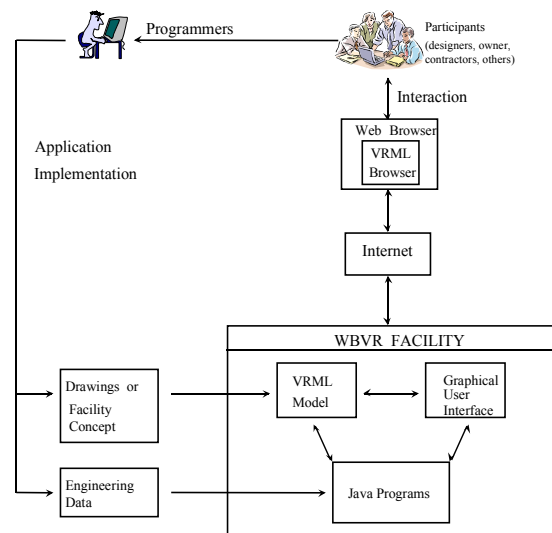

Figure 1. WBVR Facility Representation and Simulation Framework

Third, *Java programs*. Current VRML standards allow VRML models to be integrated with an external language, such as Java, to create additional dynamic integration with other data sources. Through this integration, VRML model could be linked to *engineering data* such as schedules, costs or some other attributes of the components of the model to perform dynamic simulation.

During or after the "walkthrough" of the virtual facility, participants can exchange opinions. Any suggestions or modifications of the model can be communicated to the programmers for refinement and modification. With the help of the programmers, project participants can concentrate on project related improvements while leaving the VR/computer parts to the programmers.

3.3 A prototype of the WBVR bridge representation

A WBVR facility representation prototype has been implemented to demonstrate the construction process of a bridge project that uses a girder system to install the beams on the decks throughout the whole span. Fig. 2 shows the bridge model after the beam installation. The 3-D bridge model is programmed in VRML and Java, and can be accessed via the Internet. The prototype is designed using functions supported by Sony's "Community Place Browser", a free and downloadable shareware.

The WBVR bridge example allows typical virtual reality's *walkthrough* navigation. The walkthrough can be performed by using the browser's standard navigation function. In the prototype, a pre-determined navigation route was programmed to view the facility as if flying by on a helicopter ride. Moreover, users may abort this route at any time and explore the facility from any location. Sound effects are also possible in the model.

Figure 2. The Bridge: After the Beam Installation

Figure 3. User Interface for Facility Representation: navigateGUI

Interactions with the WBVR bridge model are performed by users through the Java *graphical user interface* as shown in Fig. 3, named *navigateGUI*. Note that for this interface to function correctly, the VRML browser needs to support the communications between VRML and Java. The first function in the interface, *On Helicopter*, will transport the user onto a flying helicopter that travels around the bridge in 3-D on a pre-determined route. The second function, *Landing*, allows users to abort from the helicopter at any point of the route and conduct a walkthrough from that location. The third function, *To Control Board*, will send users back to the starting point where they can control other facility scheduling simulations which will be discussed in next section.

As mentioned earlier, another important component in the prototype is the Java program. The Java program is responsible for tracking attributes of the entities of the bridge model and translating the commands received from interfaces to the VRML specifications. The VRML browser will then render the bridge model accordingly.

Depending on the objectives of a facility model, the WBVR facility can incorporate other geometric information in the scene such as the site conditions, surrounding environment, or even sound. A preset route can enhance the navigation quality by focusing on some particular spots and angels. Real-time communication can also be implemented when the VRML browser supports multi-user walkthrough and communication capabilities[1].

4. WBVR FACILITY SIMULATION

4.1 What is a facility simulation?

A simulation is to "use computers to *imitate*, or simulate, the operations of various kinds of real-world facilities or processes" [4]. As mentioned before, simulation is an important tool for selecting alternatives. The facility simulation could be used to evaluate various facility alternatives, site layout, construction methods and sequences, and construction schedules. Facility owners can have a vivid and clear perception of the facility before making decisions. Designers and contractors can have fewer misunderstandings regarding construction

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[1] The "Community Place Browser" is one of the advanced browsers.

methods or sequences. Contractors can visually evaluate alternative sequences of construction activities to prevent potential conflicts.

4.2 WBVR facility simulation

In a facility simulation, the user will see the behaviors of the entities in a model. Behaviors in a 3-D model could be specified as the ways of changing the status of the entities within VRML scene [5]. Therefore, the simulation tasks are implemented through the updating of the objects' attributes, such as locations. Java programs are responsible for tracking and updating these attributes. User interfaces let the user select types of simulations or specify how the attributes should be changed. Then the VRML model will be rendered according to the updated attributes.

The rendering and updating of the attributes create an animation of the facility being built step-by-step. Users can experiment with what-if scenarios using WBVR simulation.

4.3 WBVR bridge simulation

Based on the bridge model mentioned in *3.3*, we simulated the construction process. Two types of simulations were implemented in the WBVR bridge prototype system: (1) the sequence of the bridge construction process and (2) construction schedules for installing beams on the decks throughout the whole span. Fig. 4 demonstrates the bridge construction method during a simulation. Fig. 5 shows that a simulation detects an error in schedule where the beam installation is scheduled before deck assembly. The simulation, in this case, help participants visually identify the mistake in the sequence/schedule.
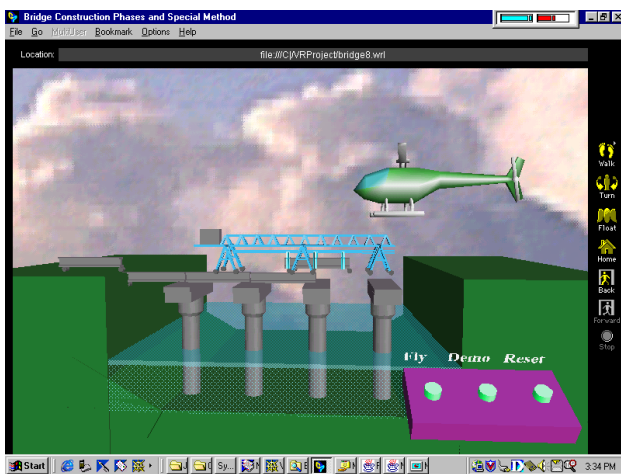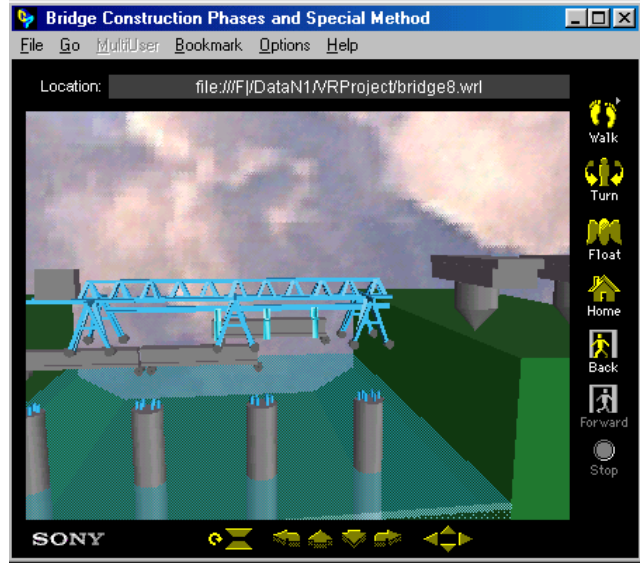

Figure 5. The Bridge Simulation: A Sequence/Schedule Error is Detected

Two graphical user interfaces for simulations are programmed in VRML and Java. The VRML interface is a "*Control Board*" located at the front of the scene in Fig. 4 with three simulation command buttons. The Java interface is shown in Fig. 6, named *planGUI*. This sequence/schedule interface allows the user to specify each activity's duration and starting/ending dates. These settings allow users to experiment with what-if scenarios in terms of construction schedules.
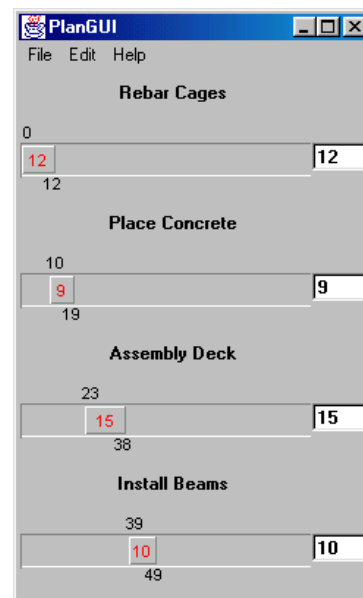

Figure 4. Bridge Construction During a Simulation

Figure 6. User Interface for Facility Simulation: planGUI

5. AN AUTOMATED INTEGRATED SYSTEM

The prototype system demonstrates the capabilities and potentials of VR. We believe that the future of WBVR will include the following functions:

Multi-user Virtual Environment and Shared Scenes: In WBVR facility representation and simulation, the participants should be able to visit a site together, have discussions on-line, and activate a scene simulation which can be shared by all participants.

Multi-media Integration: Delivery of multimedia information is also a trend in VRML. Current VRML browsers seldom provide this capability. With the integration of audio and video information into VRML scenes, it is possible to *monitor* a job site or share job site information in the 3-D scene and in real time via the Internet.

Integration with CAD: One essential research area is to create symbolic object models linked to 3D CAD models [1]. This subject includes the standardization for object libraries instead of drawing based modeling. Through the improvement of CAD technologies, behaviors and simulations of VR objects and models could have more *intelligent* ways of representing a facility and associated construction information.

Database Integration: Many applications of WBVR are data intensive. For a complicated and large-scale facility model, a database to manipulate these data may be essential. The approach of designing the database for WBVR facility representation and simulation will be the key to the success of WBVR.

Interface Design: In our prototype, Java programs serve as an internal interface which is "running *internally* to the browser" [5]. It offers only the ability for simple interaction with the pre-defined model and behaviors. Users can not go beyond this and modify the model or simulation. However, in the future, we expect that an *external* interface can be implemented to directly edit the VRML model within the VRML browser. With this ability, users can dynamically add or delete the objects inside the VRML scene. This integration is critical for extending the utility of a WBVR model to its maximum since the model or simulation refinements can be performed by the *users* instead of the programmers.

6. CONCLUSIONS

Web-based virtual reality can serve as a new modeling and communication tool for construction planning and control. Our experience with the prototype system suggested that VRML model, graphical user interfaces and Java programs can be integrated to work seamlessly through the Internet. The WBVR facility representation and simulation provide a means for evaluating alternatives and enhancing constructibility of a project. Various project participants can effectively investigate the facility via the Internet. They can also identify potential problems or select alternatives by performing 3-D simulations. Opinions and information can be shared more effectively and efficiently to prevent potential misunderstandings.

The future of web-based VR applications in construction seems promising with the advances in computer hardware and software. An ideal system which integrates multi-user environment, multi-media, 3-D CAD, and databases may not be so far after all from becoming a reality for the Architecture/Engineering/Construction industry.

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