WEB-BASED 4D VISUALIZATION
FOR REAL-TIME CONSTRUCTION SIMULATION

Julian H. Kang
Assistant Professor, Texas A&M University, College Station, Texas, USA

Stuart D. Anderson
Associate Professor, Texas A&M University, College Station, Texas, USA

Mark J. Clayton
Associate Professor, Texas A&M University, College Station, Texas, USA

ABSTRACT

Four-dimensional CAD (4D CAD) has been considered an effective tool to improve collaborative decision-making in construction scheduling. However, updating the 4D CAD model requires re-linking all activities to their corresponding CAD elements and re-distributing the revised model. If the 4D visualization of the updated schedule can be created automatically and displayed on the Web browser, the revision process of the 4D CAD model can be expedited.

A new way to build a 4D model is proposed and a Java applet is developed using Java 3D API and Java JDBC to display this 4D model on the Web browser. This Java applet allows users to retrieve the 4D model at the appropriate level of completion to create 3D computer graphics on the Web browser. Users then can navigate around 3D computer graphics. The construction schedule of the 4D model can be updated over the Internet, and the revised 4D model can be displayed on the Web browser immediately.

KEYWORDS
Web-based 4D Visualization, Web-based Project Management, 4D CAD, Construction Scheduling

1. INTRODUCTION

The planning and scheduling process has three distinguishable steps. Given a project description, the scheduler interprets the information to determine what to build. The scheduler then needs to address how to build it, i.e., select appropriate construction methods and generate corresponding activities and their sequence relations. Finally, the scheduler determines when activities will take place by calculating activity and project durations (Fischer and Alalmi, 1995). Current planning and scheduling process abstracts these processes and reduces a complex building cycle to a Gantt chart or Critical Path Method (CPM) schedule (McKinney, et al. 1996).

Abstractive description is sometimes more effective to portray multi-dimensional information when it is illustrated on one sheet. A graphic timetable for Java railroad line, drawn in 1937, is a good example that explains the merit of abstractness in describing multi-dimensional information (Tufte, 1990). The time table shows six different types of information on one sheet using station title and inclined lines: the location of a train between towns; time of that position; direction; train type; relative speed; and yearly pattern of operation. Similarly, the bar chart can show the

entire construction schedule and progress at once using the conceptual expression of a work package and its duration.

However, in order to understand the construction schedule described in the bar chart, viewers need to develop the construction sequence in their minds by associating the components in the 2D drawings together with the activities in the schedule (Koo and Fischer, 1998). This process requires many years of practices and it is often a challenge to develop realistic and practical schedules using the bar chart. In addition, the increasing complexity of the constructed product, combined with intense project schedule pressure, has created the need for more sophisticated tools to help project participants plan and manage their projects more effectively (Williams 1996).

Research has attempted to show the sequence of construction using 3D computer model. Bechtel Corporation developed 4D-Planner that is a graphical simulation tool to help project managers, construction planners, and field engineers plan and manage their projects effectively. 4D-Planner allows the user to electronically relate the 3D CAD model and the project schedule to create a unique simulation file that can be reviewed interactively. When a simulation file is played back, the various components or groups of components are turned on in the model at the appropriate time (Williams, 1996).

The Center for Integrated Facility Engineering (CIFE) at Stanford University developed 4D CAD that connects 3D CAD objects with the construction schedule to show the construction sequence visually (Collier and Fischer, 1995). CIFE and Dillingham Construction demonstrated in the San Mateo County Rehabilitation Center campus expansion project that 4D CAD was a valuable tool to help people understand a construction schedule intuitively. The hospital management, doctors, nurses, and technical staffs were able to understand the impact of planned construction on their department, office, and daily operations (Collier and Fischer, 1996). Walt Disney Imagineering Research and Development and CIFE utilize a 4D CAD model for better understanding of the construction of a new Walt Disney Concert Hall. Using 4D models, the project team was able to visualize several what-if scenarios to detect conflicts before the project began. The 4D models also helped subcontractors comprehend access issues. Since the construction site is in downtown LA and streets must remain open, lay-down areas were modeled to ensure efficient and unfettered access paths (Goldstein, 2001).

4D visualization of construction simulation has a great potential to improve the construction management process. It expected to enable construction professionals to 1) easily understand the impact of changes in the schedule, 2) anticipate time-space conflicts and safety hazard situations, and 3) promote interaction with others (Koo and Fischer, 1998).

2. MOTIVATION

The San Mateo project elucidated several important points about the limitations of the 4D CAD tool. One of restrictions is the revision process of the 4D CAD model. Implementing local changes to the schedule required that the user re-link all activities to their corresponding CAD elements. This revision process could require an extensive time commitment (McKinney, et al. 1996). This restriction may reduce the desirability of 4D CAD in actual construction projects where modification of the construction schedule is an unavoidable practice. McKinney, et al. (1996) suggested that future improvements of 4D CAD should consider how a 4D CAD model is built with input from several professionals and how evaluation for multiple perspectives can take place across a network.

If multiple users can modify the construction schedule over the Internet, and if the animation of the construction sequence can be created automatically and displayed on the Web browser, then the project participants could expedite the revision process of the 4D model and access up-to-the-minute 4D visualization. This process would not only provide the visual benefit of using a 3D model but also provide the necessary immediacy required for effective scheduling. Project participants could communicate with each other in cyberspace synchronously or asynchronously to discuss current construction progress verses scheduled progress, and could make a plan proactively for future construction.

The current 3D technologies such as VRML and Java3D provide interactive 3D graphics on the Internet. These technologies should provide the possibility to display 4D CAD on the Web. Active Server Page (ASP) of Microsoft enables users to access a database of the Web server over the Internet. This should provide the possibility to update the construction schedule over the Internet. Therefore, it is reasonable to develop a prototype application that

implements 4D CAD on the Web. This development may improve the desirability of 4D CAD in construction scheduling.

3. DEVELOPMENT OF WEB-BASED 4D VISUALIZATION SOFTWARE

3.1. Definition of the Web4D Model

In the process of developing the Web-based 4D visualization software, the first thing considered was how to store and manipulate information to create a series of 3D computer graphics to describe the construction sequence. Since the process to create and display 3D computer graphics over the Internet is not simple, utilizing a commercial CAD package was not considered for the development. Instead, a new way of containing the 3D model along with its construction schedule, which is called Web4D model, was proposed. The Web4D model is composed of 3D geometrical information of the structure and the associated construction schedule. The Web4D model is defined in a single database that has two tables: 1) tblGeometry that stores 3D geometrical information of the components of the structure; and 2) tblObject that stores the construction schedule associated with the components stored in the tblGeometry.

The geometry of the Web4D model is described only by cubic, skewed cubic, and cylinder shapes. These primitive shapes were considered to be enough to depict the structures in the prototype Web-based 4D visualization software. A rule to define these primitive shapes in the Web4D model is illustrated in Figure 1.
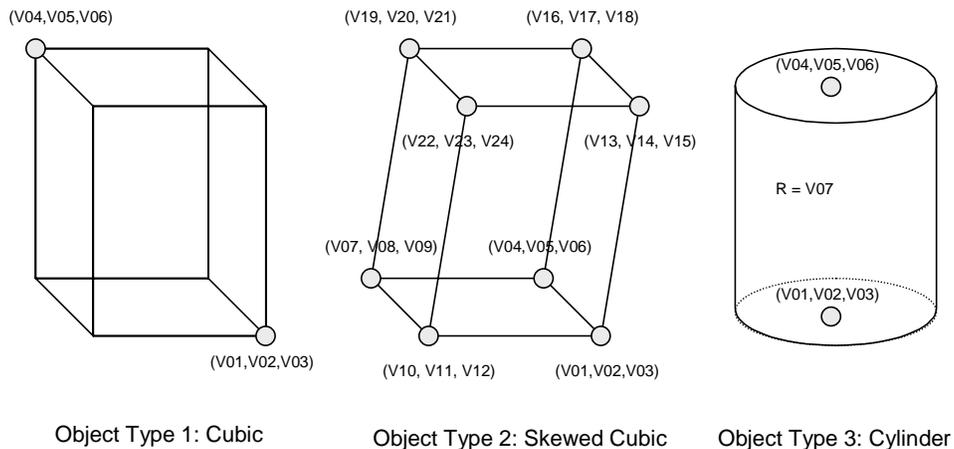

Figure 1: Primitive Shapes and Vertexes used to Define the Web4D Model

3.2. Required Functions

Visualizing the construction sequence on the Web browser requires creating a 3D graphic model of the structure that will be built by a certain time that the users want to review. In addition, it would be better if the structures are color coded to indicate degree of completion. For these goals, the Web-based 4D visualization software should have the following functions:
- Access the database over the Internet to retrieve the geometry information and construction schedule
- Create 3D graphics of the structure using retrieved data and display them on the Web browser
- Navigate around the 3D graphic model for review
- Change the date to show the construction sequence over time
- Assign different colors to the 3D graphic objects to show their expected completion

3.3. Development Tools

In order to develop the functions discussed, Java 3D technology was used. Virtual Reality Modeling Language (VRML) was also investigated, but was not selected because of the complex process to create a VRML model interactively. Java technology of Sun Microsystems enables programmers to develop an applet that can run on any

computers as long as Java Virtual Machine (JVM) runs there. Java 3D Application Programming Interface (API) can help programmers to develop a Java applet that creates and displays 3D graphics over the Internet. In addition, Java JDBC, which is the Java API for executing Structured Query Language (SQL) statements, permits a Java applet to access a database on a server over the Internet.

3.4. Program Algorithm

Java 3D is a hierarchy of Java classes, which serves as an interface to the sophisticated 3D graphics rendering engine. The 3D geometric objects reside in a virtual universe, which is created from a scene graph. The Java 3D scene graph is constructed of a Branch Group node object in parent-child relationships forming a tree structure. The Branch Group (BG) node is composed of Transform Group (TG) node. The Transform Group node is composed of a series of Shape3D nodes.

Web-based 4D visualization software, which is named the Web4D Java applet, is supposed to access the central database over the Internet, and retrieve geometry and construction information of all objects that will be constructed by the specific date. Then, it creates 3D computer graphics to display the structure on the Web browser. For these goals, a series of Java 3D objects of the structure should be created in the Web4D Java applet. Java 3D objects that represent one stage of completion are defined in the TG node using a number of Shape3D nodes. If a different stage of completion needs to be displayed, the Shape3D nodes should be added to the TG node or removed from the TG node. If the expected completion percentage is changed, a different color should be assigned to the Shape 3D nodes. This is not simple process. Therefore, an algorithm to reconstruct a whole TG node is proposed instead for this development. Whenever a new stage of completion needs to be displayed the whole TG node is removed from the BG node and a new TG node is constructed and attached to the BG node. This algorithm may not be effective in terms of handling Shape 3D nodes, but it should be good enough to develop a prototype of the Web4D Java applet.

According to this algorithm, if a user wants to see components of the structure that will be started or completed, for example, in 7 days from today, the Web4D Java applet implements as follows:
- Bring the current date from the computer. Add 7 to the current date, and consider it as a new current date.
- Remove the current TG node from the BG node.
- Access central database over the Internet, and bring the geometry and construction schedule information of all structures that are supposed to start to be built earlier than the current date
- Calculate an expected completion rate of each object by comparison between the start date of the object and the current date.
- Determine the color for each object based on the completion rate. Yellow will be assigned if the object has been built for less than 25% of its total duration. Red will be assigned for between 25% and 50%, Green for between 50% and 75%, and Blue for between 75% and 99%. If an object is completed by the current date, gray will be assigned. The colors for the completion rate did not follow any typical color scale.
- Create the Shape3D nodes for each object using the geometry and the assigned color.
- Construct a new TG node using Shape3D nodes created.
- Attach the TG node to the BG node.
- Display the Scene Graph on the Web browser.

3.5. User Interface

The Web4D Java applet was designed to provide the following user interfaces:
- Graphic display to show the structure in a 3D environment
- Navigator to observe the structure
- Navigator to observe the schedule

Figure 2 shows the interface of the Web4D Java applet. Buttons at the left corner of the picture are navigation buttons to observe the structure; those at the right corner are buttons to change the date to observe the structure. A date in the middle of the schedule navigation button shows the current date to observe.

3.6. Modification of the Construction Schedule

The Web4D Java applet itself does not provide a function to modify the construction schedule. Two Web pages were developed instead using Active Server Pages (ASP). The ASP is a technology from Microsoft that provides the

capability for the Web server to process application logic and then deliver standard Hyper Text Markup Language (HTML) to the client browser (Johnson, 1997). Therefore, it was possible to develop dynamic Web pages that enable
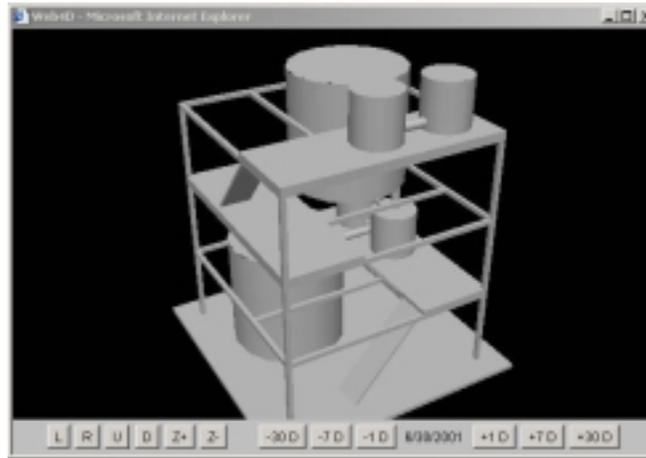

Figure 2: Interface of the Web4D Java Applet

users to update the construction schedule over the Internet. These Web pages display the bar chart of the construction schedule and enable users to modify the schedule of the work package. When a certain 2D graphic bar is clicked with the mouse, another Web page appears. This Web page allows the user to change the title, start date, and duration of the work package that is associated with the selected bar. Using these two Web pages, multiple project participants can update the construction schedule over the Internet at the same time.

4. SOFTWARE TESTING

4.1. Creating the Web4D Model

The Web4D Java applet itself does not provide functions to create or modify the geometry of the Web4D model interactively. Therefore, coordinates of the vertex should be collected and defined in the database manually to create the Web4D model. Since manual collection of the coordinates will take significant amount of time, a MicroStation 3D CAD model was utilized to collect the coordinates of the vertexes faster. The collected coordinates were then typed into the database. Figure 3 shows a 3D CAD model used to collect the coordinates. Figure 4 shows the tblGeometry table and tblObject table of the database where the 4D model is stored.
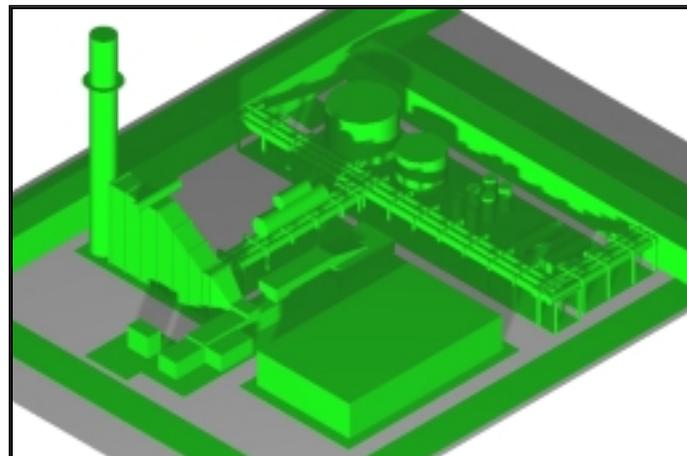

Figure 3: 3D CAD Model Used to Collect the Coordinates

Figure 4: Web4D Model Defined in the Database

4.2. Browsing the Web4D Model

Web4D Java applet runs on any Intel-compatible personal computer when the Java Virtual Machine (JVM) is available in the Web browser. However, Sun Microsystems Java 3D API plug-in programs should be installed in the personal computer if the user wants to run the Web4D Java applet in the Microsoft Internet Explorer. The JVM provided in the Microsoft Internet Explorer does not support the Java 3D at this time. The plug-in programs need to be installed are Java 2 Runtime Environment and Java 3D Windows Runtime for the JRE. These programs can be downloaded from the Sun Microsystems' homepage (http://www.java.sun.com). Figure 5 shows the Web4D Java applet that displays the Web4D model.

Figure 5: Web4D Model Displayed in the Web4D Java Applet

4.3. Revising the Web4D Model

Figure 6 shows the Web page that displays the construction schedule associated with the 4D model. Users can change the construction schedule by clicking the bar with the mouse. When the bar of a certain work package is clicked, a new Web page will appear and allow users to change the work package title, start date, and duration. Figure 7 shows the Web page that shows the schedule of the "HRSG-OFFLOAD, ERECT, WELDOUT". When the user updates the schedule and clicks the "update record" button, the Web page accesses the database and updates the associate record. Figure 8 shows how the Web4D model is changed after the early start date of the "HRSG-

558

OFFLOAD, ERECT, WELDOUT" work package is changed from "3/8/2001" to "4/7/2001". The HRSG does not appear in the Web4D model on 3/8/2001 any more.
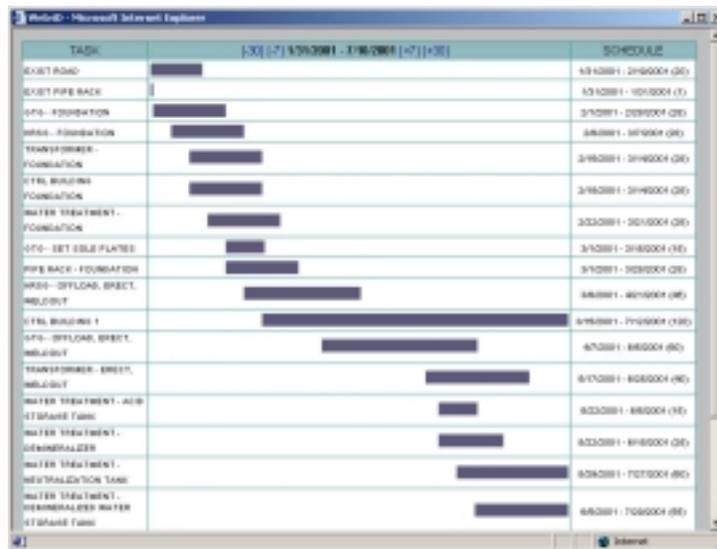

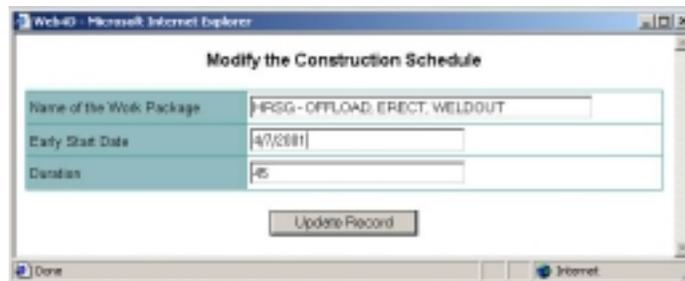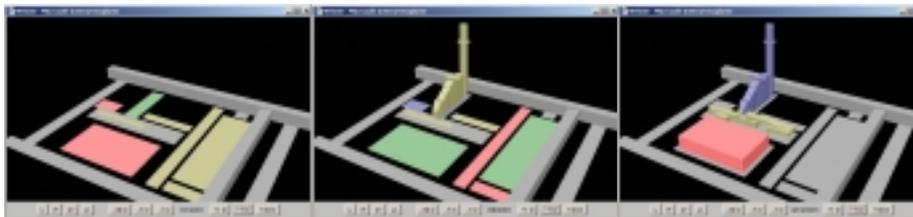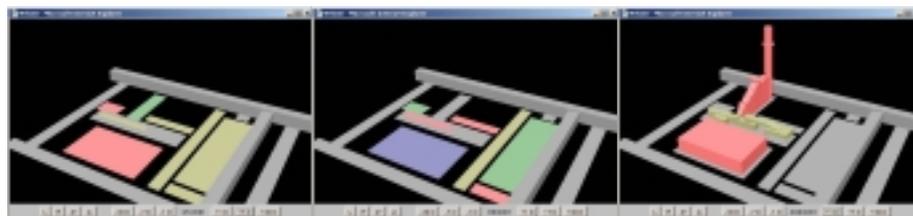**Figure 6: ASP Web Page for Displaying the Construction Schedule**

Figure 7: ASP Web page for Revising the Schedule

Before "HRSG-OFFLOAD, ERECT, WELDOUT" work package was changed

After "HRSG-OFFLOAD, ERECT, WELDOUT" work package was changed

Figure 8: Web4D Model Before and After Modification

5. CONCLUSION

The software testing demonstrated that the Web4D Java applet provides immediacy for updating the 4D model. This immediacy will allow the professionals to update the construction schedule over the Internet and review the modified schedule immediately on the Web browser. As a conclusion, the Web4D Java applet helps the professionals experience the full benefits of 4D CAD, and as a result, it will improve the collaborative decision-making process in construction scheduling.

However, the Web4D Java applet has several limitations. One of them is that no functions were developed to build or update the 3D shapes of the Web4D model interactively. Currently, 3D shapes are created manually in the local computer. If the interactive modeling tool is available, the entire process to manage the 4D model can be accomplished through the Internet, so that the model can be created or modified by multiple persons from multiple places. For example, civil engineers can create the Web4D model for structures while mechanical engineers modify the Web4D model for pipes at the same time.

The way to manipulate the visualization in the Web4D model also needs to be improved. As structures are built, sometimes one component blocks another component. If a concrete slab for the second floor is placed, some components underneath that slab are hardly visible. In order to observe those components the concrete slab needs to be removed temporarily from the model. When thousands of components are mixed together in the 4D model, engineers may want to observe only those items of interested to them. If the Web4D Java applet has a capability to distinguish the objects of the 4D model and display them by material, by function, or by location, it would help the user observe complicated structures.

6. REFERENCES

Collier, E. and Fischer, M. (1995). "Four-Dimensional Modeling in Design and Construction." *Technical Report, No. 101*, Center for Integrated Facility Engineering, Stanford University, Stanford.

Collier, E. and Fischer, M. (1996). "Visual-Based Scheduling: 4D Modeling on the San Mateo County Health Center." *Computing in Civil Engineering: Proceedings of the Third Congress Held in Conjunction with A/E/C Systems '96*, Ed. Jorge Vanegas and Paul Chinowsky, American Society of Civil Engineers, New York, 800-805.

Fischer, M.A. and Aalami, F. (1995)."Scheduling with Computer-Interpretable Construction Method Models." *Working Paper*, Number 41, Center for Integrated Facility Engineering, Stanford University, Stanford.

Goldstein, H. (1995). "Is Virtual Reality for Real?" *Civil Engineering*, Vol. 65(6), American Society of Civil Engineers, New York, 45-48.

Johnson, S. (1997). *Using Active Server Pages*, Ind.: Que, Indianapolis.

Koo, B. and Fischer, M. (1998). "Feasibility Study of 4D CAD in Commercial Construction." *Technical Report*, No. 118, Center for Integrated Facility Engineering, Stanford University, Stanford.

McKinney, K., Kim, J., Fischer, M., and Howard, C. (1996). "Interactive 4D-CAD." *Computing in Civil Engineering: Proceedings of the Third Congress Held in Conjunction with A/E/C Systems '96*, Ed. Jorge Vanegas and Paul Chinowsky, American Society of Civil Engineers, New York, 383-389.

Tufte, E.R. (1990). *Envisioning Information*. Graphics Press, Cheshire.

Williams, M. (1996). "Graphical Simulation for Project Planning: 4D-PlannerTM." *Computing in Civil Engineering: Proceedings of the Third Congress Held in Conjunction with A/E/C Systems '96*, Ed. Jorge Vanegas and Paul Chinowsky, American Society of Civil Engineers, New York, 404-409.