

Web4D: Challenges and Practices for Construction Scheduling

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Abstract

Research has demonstrated that four-dimensional computer aided design (4D CAD), in which a three-dimensional (3D) CAD model is animated through time, is useful in helping professionals understand the construction schedule. However, cumbersome processes to update a 4D CAD model, which involve changing geometry representations, changing schedules and bar charts, linking the geometry to the scheduling information, and generating animations, may discourage professionals from using 4D CAD in actual construction projects.

A software prototype implementing 4D CAD in a Web environment overcomes limitations of current 4D CAD tools. This software permits editing of the construction schedule over the Internet and shows the revised construction sequence visually on a Web browser using 3D computer graphics. This software is composed of a database on a server, Active Server Pages (ASP) scripts, and a Java applet that was developed using Java 3D Application Programming Interface (API) and Java JDBC. The Java applet retrieves the 4D model at the appropriate level of completion over the Internet and allows users to navigate around the model on the Web browser.

Web4D visualization software can help professionals to expedite the schedule updating process by involving designers and constructors in collaborative decision-making.

Keywords

Web4D, 4D CAD, 4D Visualization, Construction Schedule, Internet

1 Introduction

Using Web-based project management professionals can reduce errors in communication, obtain up-to-the-minute intelligence on decisions, and circulate documents cheaper and faster (Doherty 1999). However, current Web-based project management does not provide interactive tools for collaboration on the construction schedule. Scheduling information is typically distributed as files for stand alone software packages, and static graphs and tables. To effectively understand the construction schedule, one must intuitively be able to read two-dimensional (2D) drawings, visualize the structure in one's mind, and then link that visualization with the information provided by tables or bar charts. Experienced constructors can generally interpret and visualize the construction schedules without difficulty by using bar charts and 2D drawings, but owners or novice constructors may have difficulty in visualizing a construction schedule. Owners or novice constructors may need a more explicit method to understand the construction schedule.

Research has explored a new way to represent the construction schedule (Tsay, Hadipriono, and Larew 1996; Vaugn 1996; Williams 1996). A 3D CAD model is integrated with the construction schedule to produce an animation similar to time-lapse photography. The resulting 4D CAD model helps professionals understand the construction schedule intuitively (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 project participants, doctors, and nurses improve the collaborative decision-making process (Collier and Fischer 1996). Other research has confirmed those findings and suggest that 4D CAD can produce superior schedules in comparison to conventional methods (Koo and Fischer 1998; Songer, Diekmann, and Al-Rasheed 1998).

2 Problem: Time-Consuming Production Process

The process for 4D CAD production has often depended on a dedicated expert who uses powerful computers and CAD software to produce a model that can be animated. Often the anima-

tions have been distributed as videotape, which has severe limitations in accessing due to specialized equipment and poor version control. For modifying a schedule, the responsible person must collect the changes in the construction schedule from the multiple project engineers, modify the 4D CAD model, re-create animations of the construction sequence, and then distribute this animation to the users. Project engineers review the 4D animation to make collaborative decisions for the future construction schedule. If they identify any logical errors in the 4D animation, or if the 4D animation does not reflect the actual situation at the job site, then the project engineers change the construction schedule again and send it to the 4D CAD expert to update the 4D CAD model. Typically, the 4D CAD model is updated repeatedly until the project is completed.

Updating the 4D CAD model requires re-linking all activities to their corresponding CAD elements (McKinney et al. 1996). This revision process requires an extensive time commitment that cannot easily be reduced. The time necessary to update the 4D CAD model may be a bottleneck in the construction schedule modification process. The project engineers at the job site may have to wait until the next 4D animation is released to check the current progress as opposed to the construction schedule, and discuss the future construction schedule and its constructibility. A new change in the construction schedule could happen even before the new animation of the construction sequence is released to the users. Therefore, confusion may occur between team members in discussing or implementing the construction schedule because of discrepancies between the 4D animation and the actual situation.

Considering the process to modify the 4D CAD model, the method may have limited effectiveness in actual projects where frequent revisions of the construction schedule are unavoidable. The multiple steps required to modify the 4D CAD model and distribute it to the project participants may impede collaborative decision-making about construction schedules. The difficulty of the current processes to utilize the 4D CAD model may reduce the likelihood of 4D CAD being widely adopted in the construction industry.

3 Proposition: Web-based 4D CAD

A Web-based project management system can expedite the process of collecting and distributing the revised schedule, the revised 4D CAD model or revised animation of the construction sequence. An interactive 4D CAD scheduling system that is distributed over the Web could further reduce the difficulties of the process.

McKinney et al. (1996) suggested that the process can be improved by working across a network to build a 4D CAD model with input from several professionals and support evaluation from multiple perspectives. 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 a Web browser, then professionals could expedite the revision process of the 4D model and access up-to-the-minute 4D visualizations. Project participants could communicate synchronously or asynchronously through cyberspace to discuss current progress versus the scheduled progress, and could revise a schedule proactively for future construction.

This research has developed Web-enabled software that displays a real-time animated 4D model and enables users to update the construction schedule dynamically over the Internet. The intention of this application is to expedite collaborative decision-making about construction schedules by enabling multiple stakeholders to contribute to identification of errors and inadequacies in the schedule.

4 Architecture of the Web4D Software

The Web4D software developed in this research is composed of components for:

- storing a facility's geometry and schedule,
- serving the geometry and schedule to Web browsers,
- displaying the schedule as a bar chart,
- displaying and manipulating the geometry and schedule as a 4D model, and
- updating the schedule.

Each time the user wants to browse the visual construction sequence, the Web4D software is downloaded to the user's computer from the Web server and then executes on the user's computer. The Web4D application accesses a database on the server to extract geometric information de-

scribing the building components that have been scheduled to be completed or underway at the reference time. The software displays the 4D CAD model and provides for navigation and viewing changes to the model. It also displays a bar chart of the schedule and permits manipulation of schedule items.

The implementation has made use primarily of Java™. Java is a programming language devised by Sun Microsystems® that is designed for use on the Internet. Java technology provides the ability to produce applications that can be distributed across the Internet and work with shared network services. A Java applet is a compiled binary code, and runs on any computer that supports the Java Virtual Machine (JVM). The JVM takes Java binary code and converts it into binary code that can be executed on that specific computer. The Java 3DTM Application Programming Interface (API) allows the creation and display of 3D graphics on a Web browser. Java 2 Software Development Kit (SDK) version 1.2.2 and Java 3D API version 1.1.3 of Sun Microsystems were used for the development of the Web4D Java applet.

The Web4D Java applet runs on any Intel-compatible personal computer as long as a Web browser and Java Virtual Machine (JVM) are available. Sun Microsystems Java 3D API plug-in programs should be installed in the personal computer prior to running the Web4D Java applet in the Microsoft® Internet Explorer. The plug-in programs installed for testing are Java 2 Runtime Environment version 1.2.2_006 and Java 3D Windows Runtime for the JRE. These programs can be downloaded from the Sun Microsystems' homepage (www.java.sun.com).

Other components of the software have been constructed using other tools. A Microsoft® Access database stores the geometry and schedule information. NetDirect JdataConnect version 2 provides an integration interface by which the Java code can send Structured Query Language (SQL) instruction to the database. Microsoft Internet Information Server (IIS) serves Web pages to the browser. Microsoft Active Server Pages (ASP) incorporating Visual Basic® Scripts (VBScripts) provides the generation of HTML Web pages dy-

namically from user interaction and database query results.

The Web4D software developed in this research does not provide functions to create or modify geometrical information in the Web4D database interactively through the Web browser. One must manually obtain numeric information such as coordinates of the vertices and open the database at the Web server to add or update that information one by one. No function has been developed to manipulate geometrical information over the Internet. Manual calculation of the x, y, and z coordinates of the vertexes that compose each 3D polygon is tedious. It is recommended to use a 3D CAD model to obtain the coordinates of the vertexes.

5 Implementation of Web4D Database

The Web4D model is a collection of 3D geometrical information of the fundamental components of the structure and the construction schedule associated with these components. The Web4D model is defined in a single database that consists of two tables: 1) *tblGeometry* table that stores 3D geometrical information of the components of the structure; and 2) *tblObject* table that stores the construction schedule associated with the components stored in the *tblGeometry*. These two tables in the database are linked with each other through an ID value.

The software only permits geometric components of three primitive types. Since most civil structures can be described using cubic and cylinder shapes, these two primitive shapes were used to define the Web4D model. A skewed cubic was also considered for better representation of the structure. Developing functions to depict these complicated shapes such as round holes on the wall was not considered.

Minimum information to define the primitive shape varies by the type of shape. Two diagonal

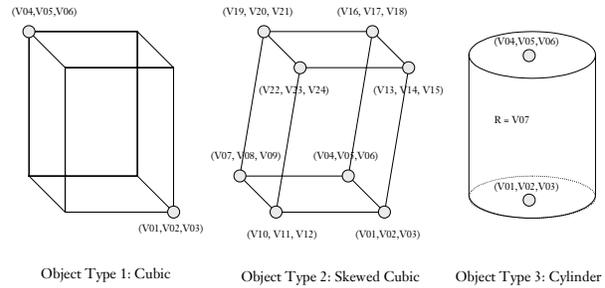


Figure 1. Primitive shapes and vertexes used to define the Web4D model

vertexes may be enough for a regular cube; however, all six vertexes are required to express a skewed cube. For a cylinder, the vertexes of the center of the circles and radius of the cylinder should be defined. Figure 1 shows the basic shapes used to define the Web4D model and necessary vertexes to define these primitive shapes.

For simplicity in implementation, the database for geometry is a simple flat table. As shown in Figure 1, 24 fields, from V01 to V24, have been allocated in *tblGeometry* for storage of x, y and z coordinates of vertexes of geometric objects. Table 1 shows columns to define this information in the *tblGeometry* table.

The field objID is used to connect the entity of this table with the entity of the table for the construction schedule. The *tblObject* table contains the components of the structure and their construction schedule. Table 2 shows fields of the table and Figure 2 shows the relationship between these two tables.

6 Development of Bar Chart Functions

Two ASP files were written to support to provide further functionality: 1) displaying the construction schedule using the bar chart; and 2) updating the construction schedule.

Figure 3 shows the page displaying the construction schedule using the bar chart. The VB Scripts

Table 1: Columns of the *tblGeometry* table.

Column Name	Description
geoID	Identification number of the graphic object
objID	Identification number of the structure that this graphic object belongs to
geoType	Type of the graphic object
geoV01~geoV24	Numerical information to define the graphic object

Table 2: Columns of the tblObject table.

Column Name	Description
objID	Identification Number of the structure or activity. It is used to make a connection with geometry information
objName	Name of the structure or activity
objStart	Date that the construction of the structure begins
objDuration	Duration that the construction of the structure continues

in the ASP file access the *tblObject* table of the database to retrieve the work package name and associated schedule information. The VB Scripts then create HTML codes to display the work package name and the bar chart for the schedule. The bar chart is represented by placing several square images consecutively, based on starting date of the work package and its duration. The scale of the bar chart is fixed but the time range of the bar chart is changeable. As shown in the Figure 3, if the “[-30]” or “[+30]” link provided on top of the bar chart is clicked, the time range moves backward or forward by 30 days. This function is convenient when the entire construction schedule cannot be displayed on the computer screen.

When a bar of the chart is clicked with the mouse, another ASP Web page appears, shown in Figure 4. This ASP Web page allows the user to change the work package title, start date, and duration. If the user clicks the “Update Record” button in this page, the VB Scripts written in this page access the database to update the work package information and display the revised schedule.

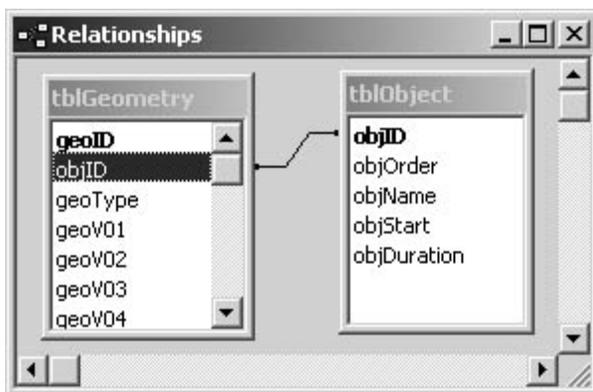


Figure 2. Relationship of the tables

7 Development of Web4D Java Applet

7.1 Program Algorithm

To display structures that are completed at specified times in the schedule, the Web4D Java applet accesses the central database over the Internet, and retrieves geometry and construction information of all objects that will be constructed by specific times. Then, it creates 3D computer graphics and displays them on the Web browser. 3D computer models are color coded by the completion ratio. For example, if a user wants to see structures that will be started or completed 7 days later, the Web4D Java applet will create 3D computer graphics to show all the structures that will happen in 7 days as follows:

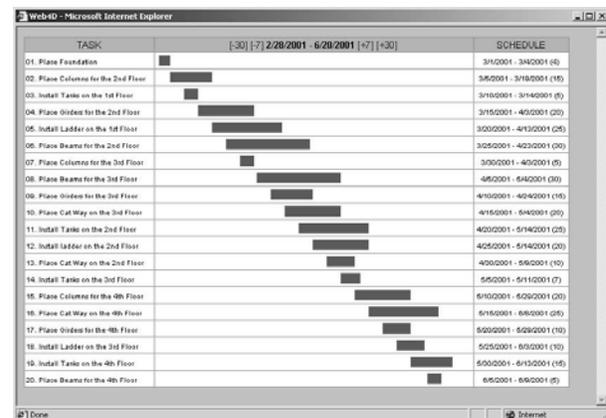


Figure 3. ASP Web page displaying the construction schedule.

Figure 4. ASP Web page to revise the schedule

- Add 7 to the current date, and consider it as a new current date
- Using SQL queries, 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 50%, Green for 75%, and Blue for 99%. If an object is completed by the current date, gray will be assigned.
- Create 3D graphic objects based on the color and object type.

Figure 5 shows the flow chart of the Web4D Java applet.

7.2 User Interface

The Web4D Java applet provides the following opportunities for user manipulation:

- Buttons to navigate around and approach the 3D graphic model;
- Buttons to go forward or backward in the schedule by 1 day, 7 days, or 30 days.

The Web4D Java applet only provides a bird's-eye-view of the structure for navigation. Walk-through functions were not implemented. To simplify user interaction and development of the

code, the target point for the observation is fixed in the center of the building group.

Figure 6 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 observe the construction schedule. A date in the middle of the schedule navigation button shows the current date that users are reviewing. Table 3 explains the detailed functions of each button.

8 Testing the Web4D Software

8.1 Test Case

A MicroStation 3D CAD model of a 35 MW power generation plant, shown in Figure 7, was used to obtain the necessary coordinates of the vertexes. The building components were categorized as cubic, skewed cubic, and cylinder shapes. Coordinates of the vertexes to define these primitive shapes were detected in the 3D CAD model by snapping the mouse on the specific vertexes of the model. The vertices were then typed into the MS Access table. Component names, start dates and durations were typed into the table for schedule data, shown in Figure 8. The resulting display in the Web4D application is shown in Figure 9. All functions work as intended. Displays resulting from modifying the schedule are shown in Figure 10.

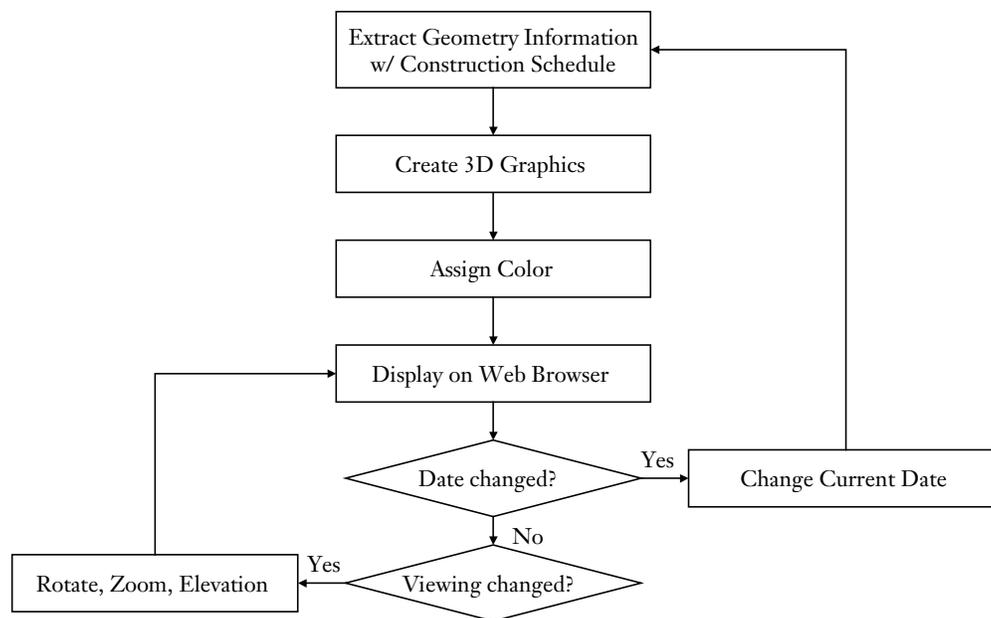
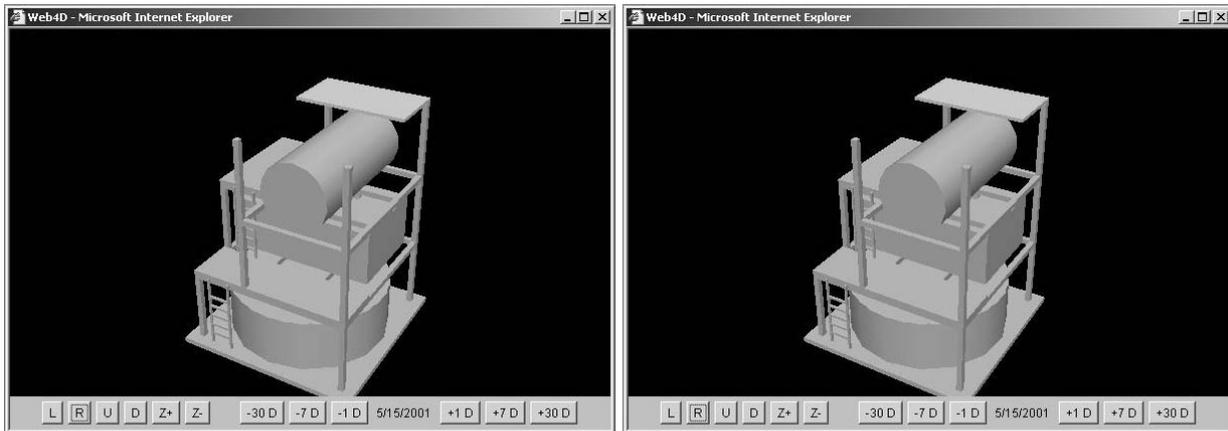
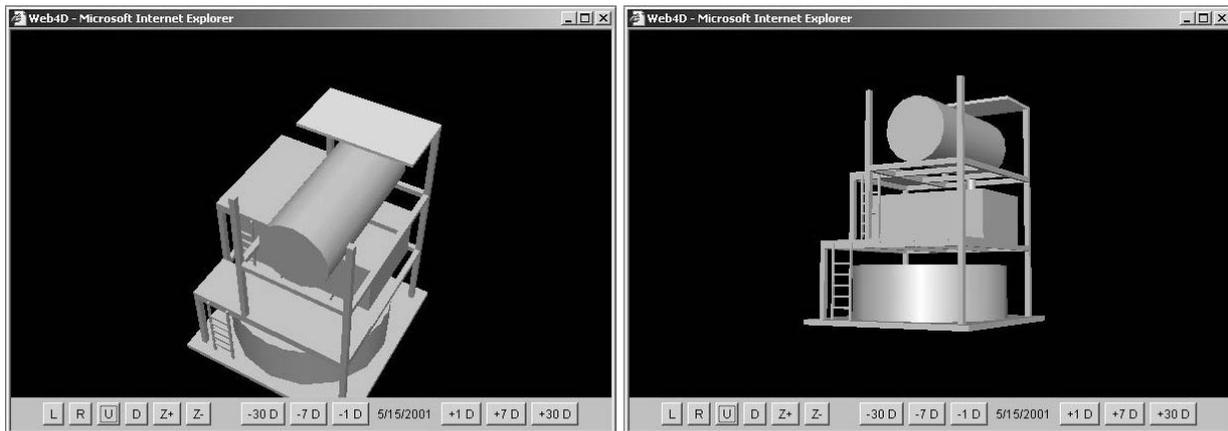


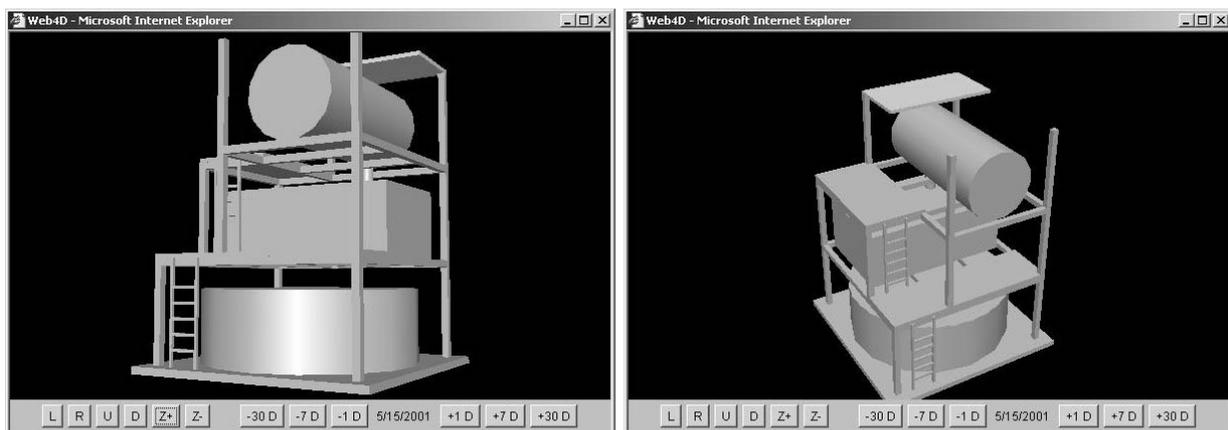
Figure 5. Program algorithm of the Web4D Java applet.



Rotating around the model



Changing the elevation to observe the model



Getting closer to the model

Moving forward in the schedule

Figure 6. Actions in the Web 4D software showing rotation, change of viewpoint elevation, moving closer, and advancing the schedule.

Table 3: Buttons of the Web4D Java applet.

Button	Description
L	A button to turn left around the structure by 15 degrees
R	A button to turn right around the structure by 15 degrees
U	A button to move up to observe the structure from higher elevation
D	A button to move down to observe the structure from lower elevation
Z+	A button to move close to the structure
Z-	A button to move further from the structure
-30	A button to move backward in the construction schedule by 30 days
-7	A button to move backward in the construction schedule by 7 days
-1	A button to move backward in the construction schedule by 1 day
+1	A button to move forward in the construction schedule by 1 day
+7	A button to move forward in the construction schedule by 7 days
+30	A button to move forward in the construction schedule by 30 days

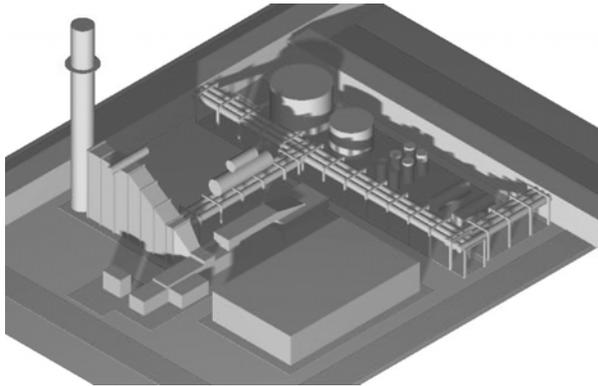


Figure 7. MicroStation 3D CAD model for the co-generation power plant.

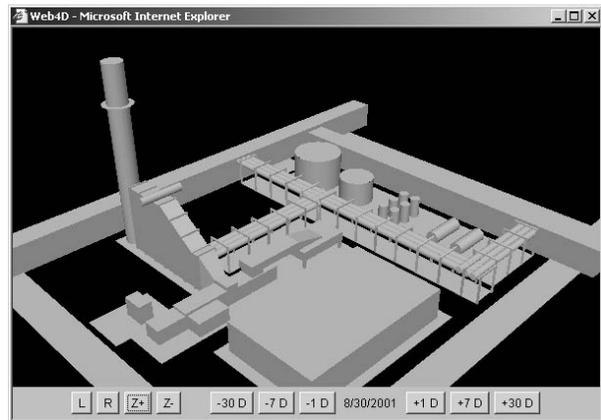


Figure 9. Web4D model of the 35 MW co-generation power plant.

 A screenshot of a Microsoft Access database window showing two tables: tblObject and tblGeometry.

objID	objOrder	objName	objStart	objDuration
1	1	CTRL BUILDING	3/15/2001	120
2	2	GTG - FOUNDATION	2/1/2001	28
3	3	GTG - SET SOLE PLATES	3/1/2001	15
4	4	GTG - OFFLOAD, ERECT, WELDOUT	4/7/2001	60
5	5	HRSG - FOUNDATION	2/6/2001	28
6	6	HRSG - OFFLOAD, ERECT, WELDOUT	3/6/2001	45
7	7	PIPE RACK - FOUNDATION	3/1/2001	28
8	8	PIPE RACK - ERECT, MODIFICATION	6/30/2001	45
9	9	PIPE RACK - INSTALL PIPES	8/14/2001	60
10	10	TRANSFORMER - FOUNDATION	2/15/2001	28

geoID	objID	geoType	geoV01	geoV02	geoV03
1	4	1	-2.715758	-0.016368	0
2	4	1	-1.866654	-0.016368	0
3	4	1	-1.628916	-0.016368	0
4	4	1	-0.75124	-0.016368	0
5	4	1	-1.036292	0.008986	0
6	4	1	-0.201636	-0.016368	0.383028
7	4	1	0.818726	-0.148356	0.17225
8	4	1	-0.1329	-0.134764	0
9	4	1	-0.12095	0.380342	0
10	4	1	0.799172	-0.1274764	0
11	4	1	0.799172	0.380342	0

Figure 8. Information defined in the tblObject and tblGeometry table of the database.

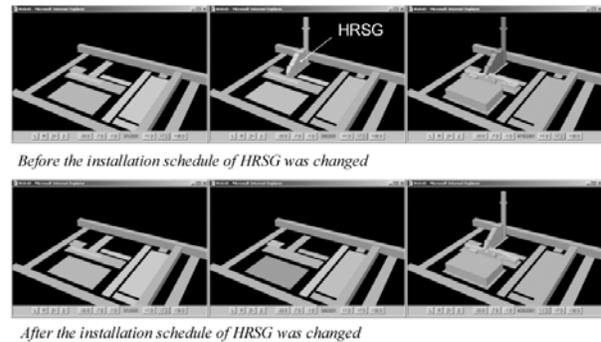


Figure 10. Example of changes in schedule illustrated by different image sequences.

8.2 User Testing

A dozen graduate students have assisted in testing the software. Operation has proven straightforward, with a very short learning curve.

A test is underway in which between 30 and 40 teams of two students are using the software across the Web for debugging construction schedules. The pairs of students collaborate to find errors in the construction schedules for several different facilities. The researchers will measure speed of completion and accuracy of results. A survey will collect the participants' subjective impressions.

9 Conclusions

The research has produced a working prototype of a 4D CAD application that runs on the Web using a central data repository for CAD and schedule information. Preliminary testing suggests that Web4D will provide to project teams the improved accessibility and increased effectiveness predicted by theory.

Web4D visualization software may help construction professionals understand the construction schedule intuitively and make collaborative decisions in construction planning. They could change the construction schedule and check the revised schedule visually over the Internet using Web4D visualization software.

Owners could obtain and understand the newest construction schedule by themselves if they can use Internet. They do not need to wait for the next animation of the construction sequence to make a collaborative decision for the future construction. Since they can see the construction schedule whenever they want, they could provide their knowledge and experiences more actively in the process to develop the construction schedule.

Architects could communicate with the constructors more effectively. When conflicts are detected in the design, or when the constructors request for design information, they can communicate with the constructor effectively using the Web4D model. Both of them can see the same 4D model for their discussions. They do not worry about taking different version of the 4D CAD model into their conversation. They can make decisions a lot faster with stronger confidence.

Constructors could reduce the time to revise the 4D visualization. The project participants can modify the Web4D model to reflect the change of the construction schedule and observe the schedule using revised Web4D model. They do not need to rely on a professional to manipulate 4D animation of the construction sequence. Therefore, they can expedite the process to revise the Web4D model. They can use the Web4D model to discuss about cost saving, productivity, and safety issues with owners and architects.

10 Future Study

Further research is being conducted to quantify the increase in effectiveness of a Web4D application in comparison to conventional construction scheduling tools. Detailed tests could determine specifically which categories of project participants are most likely to benefit from a 4D CAD approach and in which situations. Trials with the software in the classroom could be conducted to determine whether 4D CAD can improve learning about construction issues, particularly among architects or developers who currently have little exposure to construction scheduling.

The collaborative process with the Web 4D software could be compared with a face-to-face process. Videotapes could document the activity and communication of face-to-face interaction and serve as the comparative data to the interaction across the Web.

Refinements to the software should be undertaken. As Web4D models are displayed, sometimes one component blocks another component. Engineers could rotate the Web4D model or move into the model to see the hindered objects, but it would be better to have a capability to filter the structure in more complex ways to isolate areas of interest. For example, mechanical engineers will pull out only tanks and pipes to see the process to install them.

The creation of the geometric representation is very clumsy. A translator could be written to automatically import an AutoCAD or MicroStation model into the geometry tables. Alternatively, a more robust 3D representation could be used, such as Virtual Reality Modeling Language (VRML). Although performance is adequate with

modestly sized models, Web4D could benefit from optimization of algorithms to speed displays. Integration with a Web-based, collaborative geometry editor would greatly increase utility.

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