Session 1121

Development of Web-based Interactive 4D Block-Tower Model for Construction Planning and Scheduling Education

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For construction projects implemented in a congested area, the ability to understand spatial relationship between structures is expected to play an important role in construction planning and scheduling. However, students can hardly understand the time-space relationship at the job site using a CPM network or a bar chart. Research shows that visual representation of the construction sequence helps to detect logical errors in the construction schedule. Therefore, a 4D construction model, which depicts the construction sequence in the 3D world is expected to help students learn time-space relationship in the construction schedule more effectively. Also, by disseminating the 4D construction model over the Internet, students will learn the time-space issues in construction planning and scheduling at their own pace.
We developed a Web-based interactive 4D block-tower model in order to teach time-space issues in construction planning and scheduling more effectively. This paper addresses the process of developing a Web-based interactive 4D block-tower model and how it could improve teaching time-space relationship in the construction schedule.

1. Introduction

The construction planning and scheduling process is composed of multiple steps that include interpreting the given information to figure out what to build and visualizing the construction sequence to determine how to build it. In the visualization process of a construction sequence, professionals disassemble the planned structure into identifiable work packages that are logically connected. The critical path in the logical network of the work packages is then identified using Critical Path Method (CPM) and the construction schedule is illustrated using a bar chart.

The conceptual expression of the schedule may be an effective way for explaining the entire construction schedule. A graphic timetable for the Java railroad line drawn in 1937, very well demonstrates the merit of abstractness in describing multi-dimensional information [1]. It expresses six different types of information sets on one sheet using the station title and inclined lines. However, a conceptual expression of the construction schedule often demands a significant amount of education and site experience. The owners or the end users of a proposed structure may experience difficulties in interpreting the schedule documents and understanding why a certain decision is made for the project.

In construction projects, a 3D expression of the proposed structure has been always considered as an effective way of explaining the designer's goal. A 3D expression of the structures in space dates back to the early Renaissance when painters developed a set of rules for constructing realistic spatial settings known as the Perspective [2]. Besides using the perspective, architects started presenting their designs using 3D miniature models [3]. As 3D CAD system was introduced in the Architecture, Engineering, and Construction (AEC) industry, professionals learned that they could use the 3D CAD system not only to represent the configuration of a proposed structure but also to manipulate additional engineering information such as the construction schedule.

The desire of using 3D CAD for visualizing the construction sequence led to the introduction of 4D CAD, which combines the components in the 3D CAD model of the proposed structure and the associated construction schedule. 4D CAD is expected to facilitate construction professionals to understand the impact of changes in the schedule and anticipate time-space conflicts and safety hazard situations [4]. Recently, the construction project of the Walt Disney Concert Hall, one of the most complicated structure ever built in the U.S., utilized 4D CAD successfully to explain the construction sequence to the project participants [5]. By using the 4D model, project participants were able to visualize several 'what-if' scenarios to detect conflicts even before the project began. The 4D model was also useful to the subcontractors in comprehending certain 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 [6].

However, one of technical obstacles that hinder the utilization of 4D CAD for construction education is the process of creating and maintaining a 4D CAD model. The extensive amount of time commitment in manipulating a 4D CAD model often reduces the desirability of utilizing 4D CAD for construction education. If multiple users can modify a 4D CAD model over the Internet, create animation of the construction sequence automatically and display in the Web page, then educators may feel more comfortable in utilizing 4D CAD to explain issues in construction planning.

A versatile vector graphics for representing a 3D model in the Web page is one of the critical technologies required in creating Web-based 4D CAD. The emerging Internet technologies such as Java3D, Extensible Markup Language (XML), Scaleable Vector Graphics (SVG), and ASP.NET inspired us to develop a Web-based 4D CAD model that can be utilized for construction education.

2. Technology for Web-based vector graphics

Bitmap graphics, such as raster images and photos have been successfully utilized for representing graphical information in the Web page. Bitmap graphics are described by millions of pixels in a binary format such as GIF and JPEG. The quality of bitmap graphics is proportional to the size of the image file. Therefore, there is a trade-off between quality and download time. As opposed to bitmap graphics, vector graphics is composed of vertices of polygons stored in the text-based format. Vector graphics is rendered in the Web page by graphic engine only at the time when the graphics is to be viewed. Because of the relatively small size of file, vector graphics can be downloaded faster than bitmap graphics, and yet magified without losing graphical resolution.

Virtual Reality Modeling Language (VRML) has been a popular graphic format for representing interactive 3D vector graphics in the Web page. VRML defines most of the commonly used semantics describing 3D geometry, viewpoints, light sources, and material properties. A VRML model is displayed in the Web page through a plug-in VRML viewer such as Cortona or Cosmo Player. Users' capability of manipulating the VRML model is often limited by the functions these VRML viewers provide. Interaction between the VRML model and other information stored the database is sometimes intricate.

Another Web-based vector graphic technology that has gained popularity among Web page developers is Java 3D. The Java 3D Application Program Interface (API) provides a set of Java classes that facilitates the development of a Java Applet to manipulate high-level 3D vector graphics in the Web page. The Java Applet runs on top of Java Virtual Machine (JVM), therefore, 3D vector graphics manipulated by Java 3D API can be represented on any computer systems that employ JVM.

Recently, new graphic formats have been introduced for Web-based vector graphics. The World Wide Web Consortium (W3C) released Vector Markup Language (VML) and Scaleable Vector Graphics (SVG), which are XML-based vector graphic formats, developed in order to facilitate the representation of vector graphics in the Web page.

XML is a simple and flexible text format derived from the ISO 8879 Standard Generalized Markup Language (SGML). It is called extensible because it is not a fixed format like Hyper Text Markup Language (HTML). Originally designed to meet the challenges of large-scale electronic publishing, XML is also playing an important role in the exchange of a wide variety of data on the Web. Teague et al. [7] defined XML as "a set of formatting rules that define structured information in a software-neutral text file." Since XML defines the structured information in a simple text file, it can be recognized by virtually any computer systems. Thus, XML can be used for building software-neutral project legacy data.

In 1999, International Alliance for Interoperability (IAI) proposed aecXML, which is an XML-based language designed for exchanging information in the AEC industry. Harrod [8] noted that "the main idea with aecXML is to not only establish some standard ways of structuring building data but also to do it so as to enable automated processing of that data as much as practicable". Zhua and Issab [9] indicated that a well developed XML schema of the classified construction information is one of the critical key issues for successful data exchange.

Vector Markup Language (VML) is an application of XML, which defines a format for the encoding of vector information together with additional tags to describe how that information may be displayed and edited. VML is written using the syntax of XML and can be incorporated with the HTML code. A Web page coded by VML can be displayed on the Microsoft Internet Explorer without any plug-ins software installed.

Scalable Vector Graphics (SVG) is another application of XML, designed for describing two-dimensional graphics in the Web page. It allows for three types of graphic objects: vector graphic shapes, images, and text. SVG graphics are scalable, so the same SVG graphic object can be placed at different sizes on the Web page without sacrificing graphic resolution. For last few years, various attempts have been made to best utilize the new way of representing vector graphics. Baravalle et al. [10] demonstrated the use of SVG for producing a pictogram representation of numerical data obtained from scientific computer programs. Gonzalez and Dalal [11] presented a web service that allows end-users to specify a database query and visualize the extracted data as charts or graphs using SVG.

Although VML and SVG effectively deliver vector graphics and additional information to the end users over the Internet, they are designed for displaying 2D vector graphics in the Web page. Gareth Richards [12] at gersolution.com introduced a 3D VML library to display 3D vector graphics using VML. The 3D VML library is essentially a collection of JavaScript codes that creates a perspective view of the 3D model using 2D VML. Therefore, the speed of displaying the 3D SVG model depends on the computing power of the client computer. Lutz Tautenhahn [13] later introduced an SVG-VML-3D, which is essentially similar to the 3D VML library, for illustrating 3D vector graphics in the Web page using SVG or VML. Kang et al. [14] modified the 3D VML library for architectural modeling.

3. Web4D block-tower model

Kang and Lho[15] developed a Web-based 4D construction model of simple wooden toy block tower to demonstrate the merits of 4D CAD. Their Web-based 4D construction model provided the functions for navigating around the block-tower and reviewing its construction sequence, and was efficiently utilized for implementing their investigation. However, the 4D construction model was not able to allow the users to modify the construction sequence because it simulated 4D CAD by utilizing a series of bitmap images. Their investigation was limited to the merits of 4D CAD in terms of detecting logical errors in the construction sequence. We therefore decided to develop an interactive Web-based 4D CAD model that can be modified by the users over the Internet. We expected that the interactive Web-based 4D CAD model may be utilized not only for measuring the merits of 4D CAD, but also in construction education.

A toy-block-tower was selected for our interactive Web-based 4D construction model because of two reasons: First, the construction sequence of toy-block-tower has issues that are also very common in real construction projects. Activities involved in laying blocks have fundamental similarities to actual construction processes. For instance, no beams can be installed unless columns are constructed to support them, and similarly no toy blocks can be laid in the space without stable supports. Therefore, the toy-block-tower model may be an efficient instrument for testing one's ability of understanding spatial relations, such as time-space conflicts, in the construction process. Secondly, the configuration of the toy-block-tower is relatively simple. It is composed of rectangular parallelepipeds, which can be represented by rectangle faces. The data structure for storing the geometry of the toy-block-tower is expected to be simple. Therefore, the process of manipulating 3D objects in the Web page is expected to be less complicated.

We decided to describe the configuration of the parallelepiped block using two points in the diagonal line as shown in Figure 1. The database structure we adapted to store the toy-block-tower is shown in Table 1.

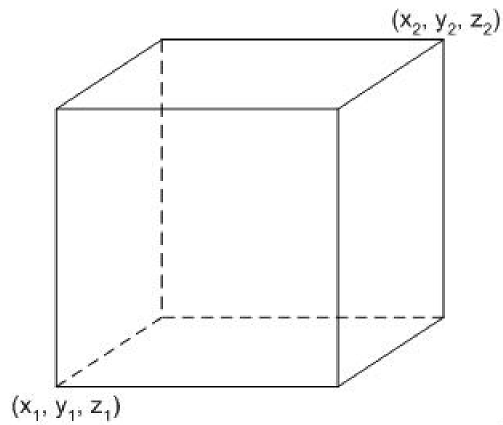

Figure 1: Primitive parallelepiped

Table 1: Database structure of the toy-block-tower

Field Name	Description
blkID	Block number
blkX1	X coordinate of the first point
blkY1	Y coordinate of the first point
blkZ1	Z coordinate of the first point
blkX2	X coordinate of the second point
blkY2	Y coordinate of the second point
blkZ2	Z coordinate of the second point
blkStart	Starting day of laying the block
blkEnd	Ending day of laying the block

4. Web-based 3D visualization engine

The 3D VML library mentioned in the previous chapter is a collection of JavaScript codes, and therefore, 3D vector graphics are also represented by JavaScript code in the Web page. Since JavaScript is designed to be running at the client computer, it lacks the ability of communicating with the server, for example, to extract the configuration of the structure or schedule information from the database. In terms of handling the construction information, the modified 3D VML library is relatively static, which may not satisfy the need of communicating dynamically with the database in the server computer. Instead of utilizing the modified 3D VML library, we therefore decided to develop our own Web-based 3D vector graphic engine in order to manipulate the vector graphics along with external database more effectively. We used Scaleable Vector Graphics (SVG) and ASP.NET to develop a Web-based 3D engine. Our 3D engine was targeted to manipulate only parallelepiped blocks. It was designed to take two diagonal points of the block and generate six individual faces that compose the block as shown in Figure 2.

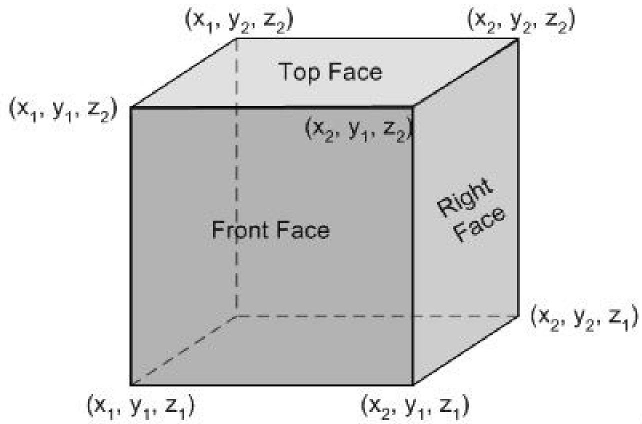

Figure 2: Configuration of six faces in the parallelepiped block

The coordinates of vertexes of each face then transformed based on the rotation angle and the level of zoom. For the rotation transformation we used the following matrix equation.

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \cos\phi\sin\theta & \cos\phi\sin\theta & -\sin\phi \\ \sin\phi\sin\theta & \sin\phi\cos\theta & \cos\phi \end{bmatrix} \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

Transformed faces are then coded in the Web page using SVG as shown in Figure 3, and then embedded in the HTML document.

```
<?xml version="1.0" standalone="no"?>
<!DOCTYPE svg PUBLIC "-//W3C//DTD SVG 1.0//EN"
"http://www.w3.org/TR/2001/REC-SVG-20010904/DTD/svg10.dtd">
<svg width="800" height="600" viewBox="-200 0 400 600">
<rect x="-449" y="1" width="898" height="598"
      style="fill:none; stroke:black"/>
<a xlink:href='Kang4D_Edit.asp?BID=4'>
<path d='M 117.810889132455 376.721689802595
         L 57.1891108675447 370.644003584253
         L 57.1891108675447 164.179058165243
         L 117.810889132455 170.256744383586 z'
         style='fill:#CCCCCC; stroke:red'/>
</a>

.. .. ..

</svg>
```

Figure 3: Sample SVG code generated

5. User interface

Visualizing the construction sequence in the Web page requires creating a 3D graphic model of the structure to be constructed only in a certain amount of time. In addition, it would be better if the structures are colored differently to indicate degree of completion. To obtain these goals, we designed the following functions for the interactive Web-based 4D block-tower model:

- 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 in the Web page
- Navigate around the 3D graphic model
- Navigate the 3D model over time frame
- Update the construction schedule

Figure 4 shows the user interface of the Web-based 4D block-tower model. There are buttons for navigating around the 3D model and observing the construction sequence. A “+1 Day” button can be used to move forward by one day and the model will show any blocks that either have been constructed or being constructed. The blocks being constructed are represented transparently.

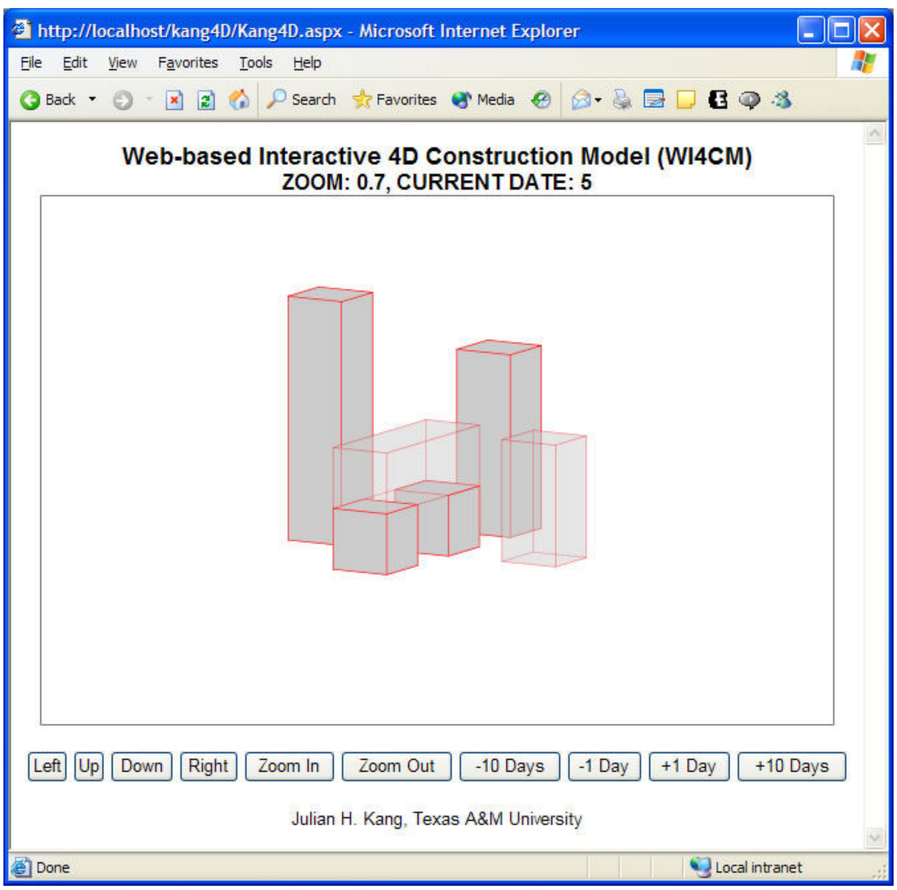

Figure 4: User interface of the Web-based interactive 4D model

6. Test model

We created a simple toy-block tower to test the interactive 4D model. Since we have not developed any tools to create the model interactively or transmit the model from a commercial CAD application, the 4D model was manually created in the database as shown in Figure 5.

tblBlock : Table

blkID	blkX1	blkY1	blkZ1	blkX2	blkY2	blkZ2	blkStart	blkEnd	twrID
1	-50	-50	0	50	50	100	2	6	1
3	-250	-50	0	-150	50	100	6	9	1
4	150	-50	0	250	50	300	3	4	1
6	-250	-50	100	50	50	200	1	10	1
7	-50	-250	0	50	-150	200	1	5	1
8	-50	-250	200	50	50	300	1	5	1
9	-50	-50	300	250	50	400	1	5	1
10	-50	150	0	50	250	400	1	5	1
11	-50	-50	400	50	250	500	1	5	1
mber)	0	0	0	0	0	0	0	0	0

Record: 1 of 9

Figure 5: Sample toy-block-tower model constructed in the database

Figure 6 shows the sequence of constructing the toy-block-tower represented by the Web-based interactive 4D model.

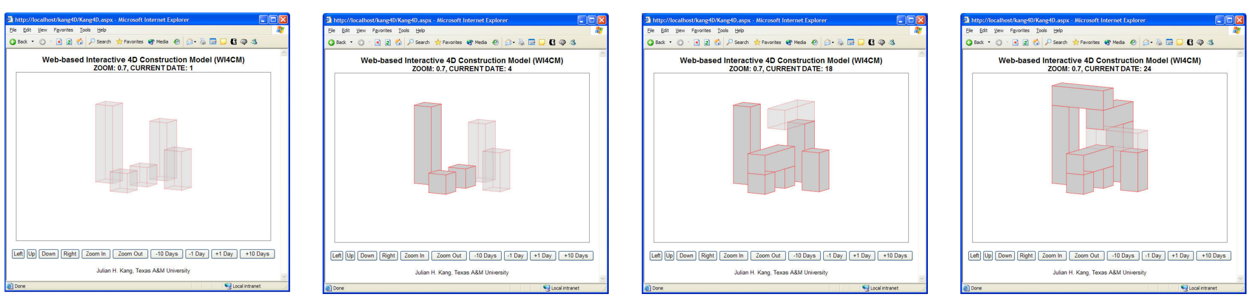

Figure 6: Construction sequence of the block-tower represented in the 4D model

Once the user selects any block in the model, the interactive 4D model brings another Web page as shown in Figure 7 to allow the user to update the construction schedule. In our model, however, the start date is the only construction information that users can change.

Figure 7: Web page for updating the construction information

7. Conclusion

The paper presents the fundamental logic used to develop the Web-based interactive 4D block-tower model. The algorithm of the Web-based 3D graphic engine developed for the 4D block-tower model is also briefly addressed. The Web-based interactive 4D block-tower model introduced in this paper is expected to be utilized in the following area.

- Interactive learning for better understanding the time-space relationship in the construction scheduling
- Investigating the impact of 4D visualization on the cognitive process of understand the spatial relations in the space
- Investigating the merits of 4D CAD in the process of construction planning and scheduling
- Investigating the merits of Web-based 4D visualization in the collaborative decision process for construction planning

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