

# Internet-based Simulation and Virtual World for Engineering Education

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## Abstract


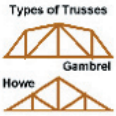

*In this paper the use of an Internet-based structural simulation and a 3D virtual world to view structures for engineering education was investigated. The generic truss and frame structural simulation allows the user to construct a truss or frame structure, apply boundary conditions, and place forces to any joint over the Internet. The computational results are also visually presented. For trusses, both the displacement and member loads are displayed. Different colors are used to demonstrate the load level in each member. For frame structures, moment, shear and axial diagrams are constructed in addition to deflection curves. Finite element method is used to compute all results. Vector-based graphics are used for structure development and results presentation to reduce file size and downloading times. In addition to any general trusses or frames, a special case study of bridge construction was included in the simulation. The user can draw the bridge, analyze it, and animate a typical moving vehicle over the bridge. The user can also deposit the bridge into an Internet-based 3D virtual world, which provides a 'big picture' of the bridge. Assessment was conducted to determine the effectiveness of the simulation. The results showed that the simulation was helpful in visualizing the computational results and reinforcing the understanding of the concepts of the truss and frame structures. To develop the simulation and the virtual world, Shockwave, VRML, ASP, SQL, and Perl were utilized together and programmed so that they communicate smoothly with each other. The simulation and 3D virtual world is open to the public at [www.vcity.ou.edu](http://www.vcity.ou.edu). The structural analysis simulation is just one component at this virtual world design web-portal.*

## Introduction

As student populations increase, universities face the challenge of maintaining high standards and effective education (Lacy, 2000). This is particularly true in the resource-intensive engineering field. Also, in industry, as technological innovations are rapidly taking place, engineers and technicians must always continue to learn and master new technologies. Hence, efficient and inexpensive methods must be found to complement traditional education and training. One solution is to employ the Internet with its advantages of low cost, convenience and collaboration. With the help of the Internet, new approaches, such as Internet-based simulations and virtual worlds, can be adopted to help teach engineering concepts.

In order to make use of the Internet's unique features for education, a project called

Sooner City was initiated at the University of Oklahoma in 1998 (Sun & Gramoll, 1999). A Virtual City framework was proposed to investigate the Internet-based environment for engineering education, design, and analysis (Sun & Gramoll, 2001). The framework adopts a three-tier architecture: an online database, a Web sever, and client browsers. The Virtual City is composed of five components: a 3D virtual world, multiple multimedia modules, an online database, a collaborative geometric modeling module, and a collaborative engineering analysis module. To illustrate the use of the Internet for education, this paper presents the structural analysis module and the 3D virtual world in detail. The structural analysis module and virtual world are examples that can serve as prototypes for Internet-based engineering education. There are also other modules at the web site, in addition to the structural analysis

<b>Sooner</b>	<b>Truss Structures</b>
<b>Structural Analysis</b>	<b>Introduction</b>
<a href="#">Introduction</a> <a href="#">Truss</a> <a href="#">Frame</a> <a href="#">Stability</a> <a href="#">Stiffness Method</a>	<p>Trusses are one of the most common structures used in large scale construction but yet, they are actually one of the simplest to analyze due to a couple basic assumptions.</p> <ul style="list-style-type: none"> <li>All joints are pinned</li> <li>All members are two-force members</li> <li>All loading is applied at the joints</li> </ul> <p>These assumptions are simplifications of most structures, as can be seen in Fig. 1 and Fig. 2 where it is obvious that the joints are rigid. Furthermore, most loading is distributed along the length of the member, as opposed to just at the joints. Luckily, these assumptions are on the conservative side and can be assumed for basic analysis.</p> <p>For all truss member, the load in each member can only be applied at the two ends of each member. If a third load is applied to the member as shown in the figure, then it can not be a truss member. With only two forces on the member, they must be collinear to be in static equilibrium.</p>
<b>Multimedia Module</b>	
<a href="#">Simulation</a>	
<b>Help</b>	<a href="#">Go</a>
<b>Relevant Links</b>	
<a href="#">VirtualCity</a> <a href="#">Engr. Media Lab</a>	<p>Fig. 1 Truss Structure in Nasville Airport</p> <p><b>Main concepts to remember</b></p> <p><b>Figure 1</b></p>

module, that tie other aspects of undergraduate civil engineering courses together into the virtual world.

There are other examples of Internet-based simulations to assist engineering students in learning basic principals. Included is "Mallard" which was developed by Mike Swafford and Donna Brown at the University of Illinois at Urbana-Champaign (Graham & Trick, 1998). Two interactive Web-based applications called Virtual FlyLab and Virtual Earthquake were developed for learning science (Desharnais & Novak, 1998). An innovative use of Internet technologies for education is to employ Virtual Reality Modeling Language (VRML) to teach design over the Internet. Ranga and Gramoll successfully implemented two Internet-based design examples with the help of Practical Extraction and Reporting Language (Perl) (Ranga & Gramoll, 1999). Peterson utilized VRML and Java in teaching machine kinematics (Peterson, 1997). Shockwave is also a widely used Internet technology to design simulations. A number of Shockwave simulations have been

developed to teach specific engineering topics (Sun & Grammol, 1999 & 2000). Multiverse is another example providing a standard interface for various Internet-based simulations (Austin & Liddle, 1998; Thomas & Liddle, 1998) that facilitate the use of Internet-based simulation in education and training by employing Java and Web technologies.

Although educational activities over the Internet are diverse and Internet-based education is maturing, it is interesting to note that in the course of this project, no existing educational program was found to have implemented 3D visualization and generic simulations with flexible graphic input. Therefore, one of the goals of this project is to present an Internet-based prototype virtual world for 3D visualization. Because it is always difficult to provide the user with intuitive graphic input to simulations, the possibility of developing such a simulation was investigated in this project. Also, the concept of displaying 3D objects on the Internet and dynamically changing them for engineering education was demonstrated in

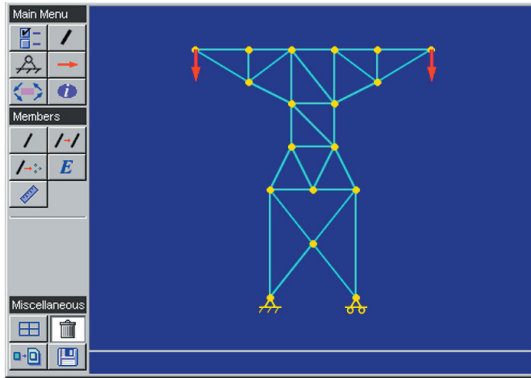


Figure 2

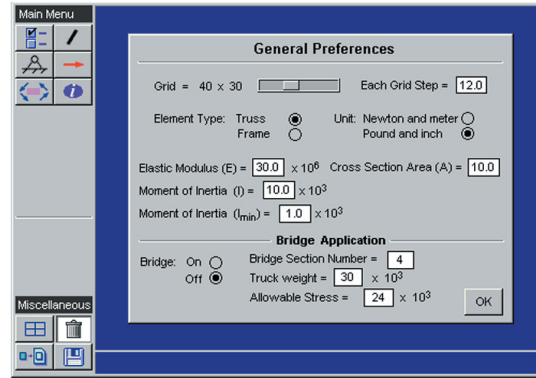


Figure 3a

this project.

### Structural Analysis Module

In the Virtual City framework, there are nine multimedia modules developed for engineering education. In this paper, only the structural analysis module, designed for the Structural Analysis course at the University of Oklahoma, is presented. Its main purpose was to provide a generic solver for plane truss and frame problems. It is important for a structural designer to learn how to compute the forces and displacements of truss structures and how to compute the deflections, moments, shears and axial forces of frame structures. Although complex commercial finite element codes can be used, they are usually not readily available to students and have a steep learning curve. Thus it is particularly useful to provide a convenient solver that can be used to check the computational results of trusses and frames.

The online structural analysis module contains two sections: an information section (Fig. 1), and a simulation section (Fig. 2). The information section covers basic concepts for four topic areas that include trusses, frames, stability, and the stiffness method. This section is to give the student background information about trusses and frames.

The second section is the actual simulation that includes a help page. The simulation was programmed using Macromedia's Director that can be saved as an Internet-

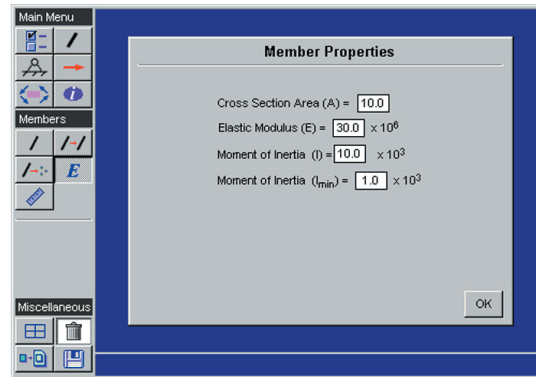


Figure 3b

based Shockwave file. The actual scripting or programming language in Director that was used is called Lingo. The simulation is basically a finite element method (FEM) solver for trusses and frames. Although it is easy to obtain the code of the computational procedures of FEM, programming FEM in Lingo was challenging since it is actually a scripting language that is not suited for matrix operations.

In addition to the actual FEM solver, the other main challenge to programming the simulation was the graphical input and output. It was important to design the interface so that any engineering student could easily understand how to operate the program without the need of a reference manual or keeping track of node and element numbers. The purpose of the simulation was to help the student understand trusses and frames, and not FEM. Also, to minimize file size, all input and resulting graphics were based on vectors and not pixel-based graphics. Vector-based

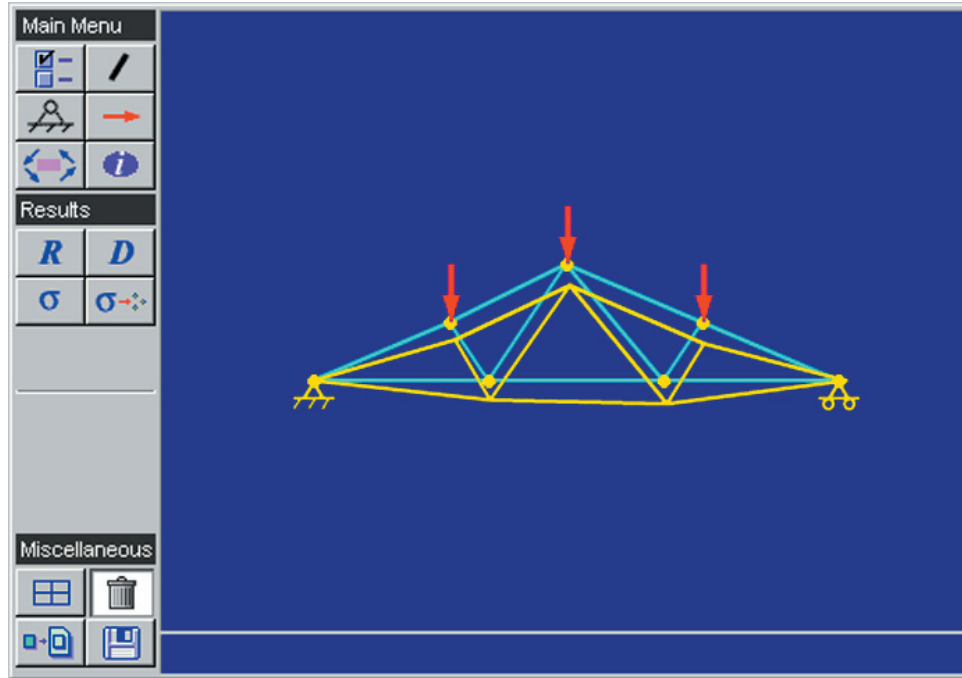


Figure 4

graphics can be completely controlled by Lingo, therefore it is particularly efficient to create, move, and delete the graphics dynamically. Using vector-based graphics minimizes the simulation's file size to about the size of a large graphic file.

Basically, two types of structures can be solved using the simulation of this module — truss structures and frame structures. For truss structures, the user can draw any kind of valid truss structure, apply boundary conditions such as pinned joints and roller joints, and specify the forces to any node of the truss. Because each truss member is considered internally as an element, the user can draw only one member at a time. Only point forces can be applied to the node. The maximum number of total members is 85. The maximum number of joints is 13 for each type of joint. The maximum number of forces is 20 for each type of force. The simulation therefore cannot be used to solve large truss problems.

There are two ways to specify detail input information: the preference window and the member property window. Figure 3a illus-

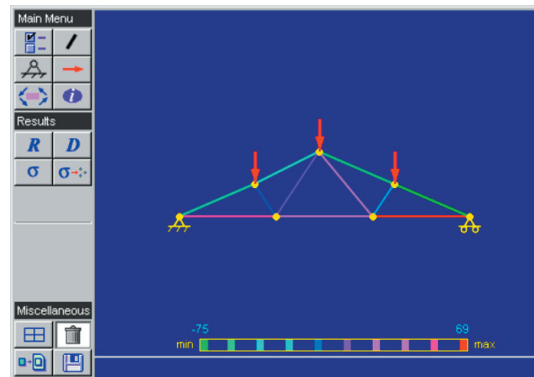


Figure 5

trates the preference window of the simulation. In the preference window, the user can specify appropriate grid step ratio of the grid system to map real-world dimensions. The lengths of the members are determined implicitly based on the grid system. Default values for material and member geometric properties are also set in the preference window. The user can also give material and geometric properties to individual members (Fig. 3b) by double clicking individual members.

The results for truss structures are presented in four ways: summary of results, report of individual members, displacement visualiza-

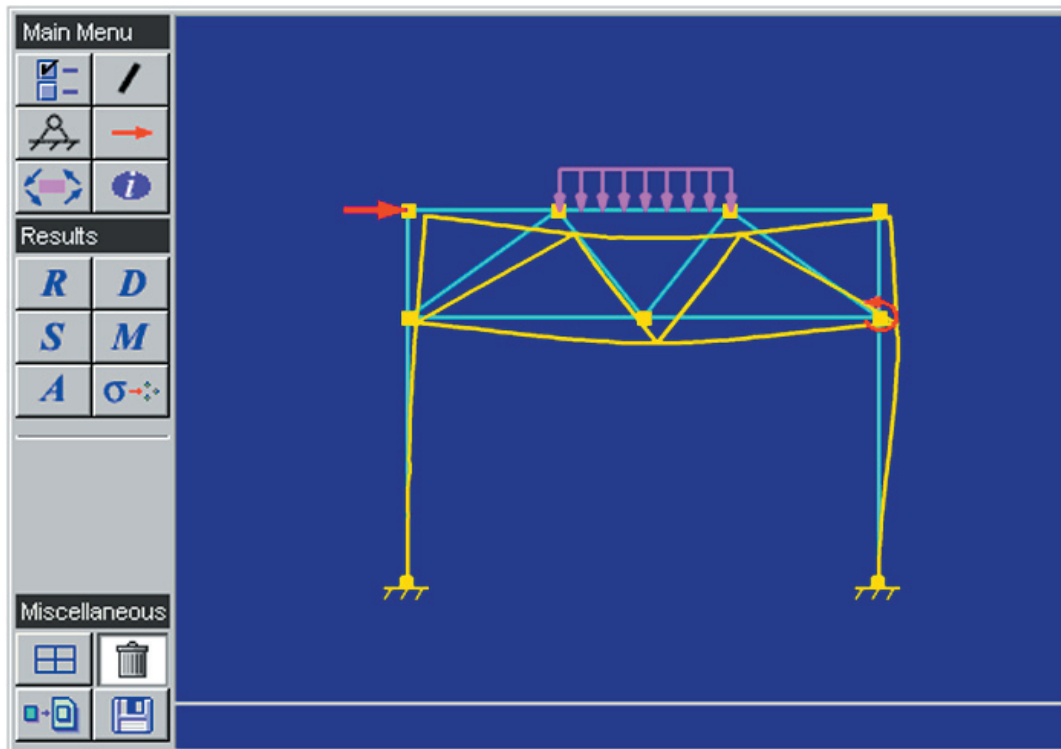


Figure 6

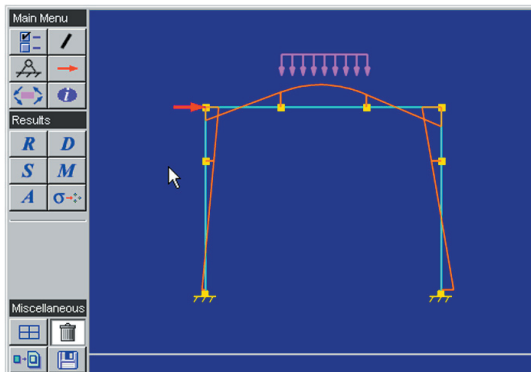


Figure 7

tion (Fig. 4), and load visualization (Fig. 5). In the summary of results, the values of the maximum displacement and maximum stress are reported. If an individual member is double-clicked, its displacements and stress can be accessed. Also, the stability of each member is checked and reported based on the basic Euler equation. To demonstrate the relative difference of the displacement, a new truss structure with node movement based on the displacements is drawn. The color is utilized to show the loads in each member.

In addition to truss structures, the user can draw any type of frame structure. The number of members, joints, and forces are limited, similar to the truss structures. Point forces, moment, and distributed loads in  $x$  direction and  $y$  direction can be applied to the frame. By double-clicking the forces, the user can change their magnitudes. Similarly, the simulation reports a summary of the computational results, such as maximum displacement of nodes, maximum moment of nodes, and maximum axial force of members. Each member's deflection (Fig. 6), moment diagram (Fig. 7), shear diagram, axial force diagram can be visually presented.

The structural simulation is a generic application, and can be used to help develop various specific applications. One particular application, a bridge with a moving load, was a specific case that was programmed into the simulation due to its unique output needs. After the user chooses the bridge option, the number of the sections in the preference window can be specified. Then the user needs to add the actual truss members between the

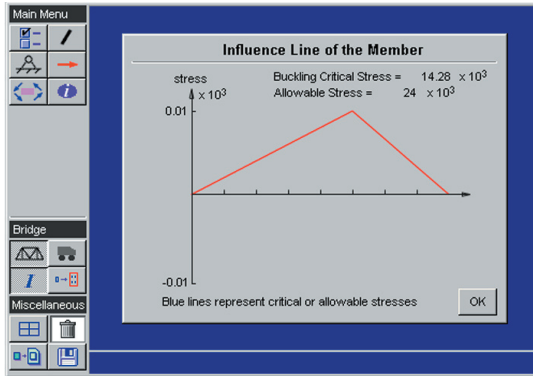


Figure 8

two end points of the bridge. A moving load, which simulates a vehicle, is applied to the bridge and the program calculates and records the member loads as the vehicle moves across the bridge. From this information, an influence line is drawn for any selected member (Fig. 8). In addition, an animation is developed to show the displacements of each node when the vehicle is moving.

A 3D virtual world, which is an Internet-based city built by the use of various multimedia modules, is used to provide a 'big picture' of the bridge (Fig. 9). The user can draw a 2D bridge in the simulation and then generate a 3D bridge by depositing it in the virtual world. More discussions about the virtual world can be found in the next section.

There are a number of attractive features for the web-based simulation. First, the simulation is completely Internet-based which allow easy access to any user. Second, the user can define the truss and frame structures by simply drawing individual members, which is an intuitive and convenient approach. Third, the computational results are visually demonstrated. For truss structures, the solved truss structures are drawn to display the displacement at each node. For frame structures, deflected frame structures are generated to represent the deflection of each member, which is usually difficult to draw by hand. Moment and shear diagrams for each member are also drawn for the frame structure, which are simple in concept but tedious to draw. Fourth, a complex

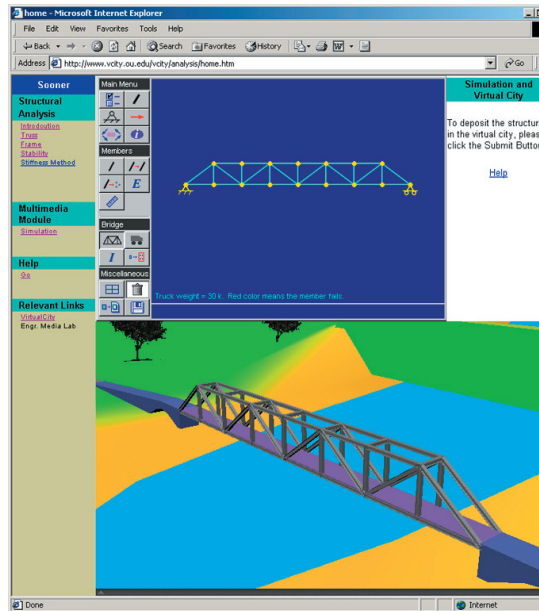


Figure 9

bridge can be designed using this simulation and then deposited into the virtual world. Fifth, the structure, as well as the forces and boundary conditions, can be saved on the server and retrieved later. Last, the simulation can help students design simple truss and frame structures with analytical results.

### Virtual World

After a truss simulation is complete, it can be placed into a 3D virtual world or city and viewed on the Internet. This is demonstrated in Figure 9. The 3D virtual world provides an excellent way to tie various components from each simulation together. The truss/frame simulation program is only one of nine such simulations in the system and each simulation will help design a different component of the virtual city. The virtual world concept links together the online database, the multimedia modules, and collaborative engineering design modules, together into one system. The concept of using an online virtual world to visualize the simulation results is currently unique in engineering education and is one of the main reasons this project was started. By organizing multiple simulations together into

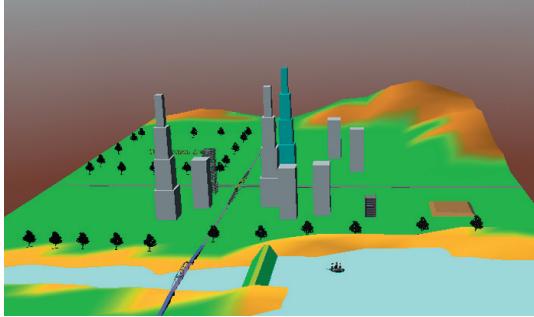


Figure 10

a single world allows the user to better understand the overall design concepts of each component as it fits into the "big picture" (Fig. 10). Also, since it is Internet-based, it can be accessed by any student from any location with real-time collaboration.

The 3D virtual world was designed using VRML with the help of Perl, Active Service Page (ASP), Structured Query Language (SQL), and an online database (Fig. 11). These Internet technologies work together to generate 3D visual structures on the web page in real time. The steps to generate 3D structures are as follows. First, a Shockwave simulation is used to help design and prepare

the data for a particular design. For example, designing a bridge requires data that includes section numbers, node positions, and the layout of the bridge. Second, the data is transmitted from the simulation to the server. The server then starts a Perl program to take the data and generates a VRML format file of the structure. Since the simulation forces the virtual world to be updated simultaneously, the structure can be seen immediately. Third, the user can modify the structure by re-submitting new data. For instance, if the user dislikes the layout of the generated bridge they can modify the previous bridge by adding, deleting, or moving trusses and resubmitting it to the server.

In addition to using Perl to create individual structures, the entire virtual world is dynamically generated and managed by an ASP script with the help of SQL statements that access the online database. The virtual world is a customized world belonging to individual users. It is inefficient and inconvenient to save multiple copies of the virtual worlds. One solution is to save only the customized parts of the virtual worlds and utilize a cre-

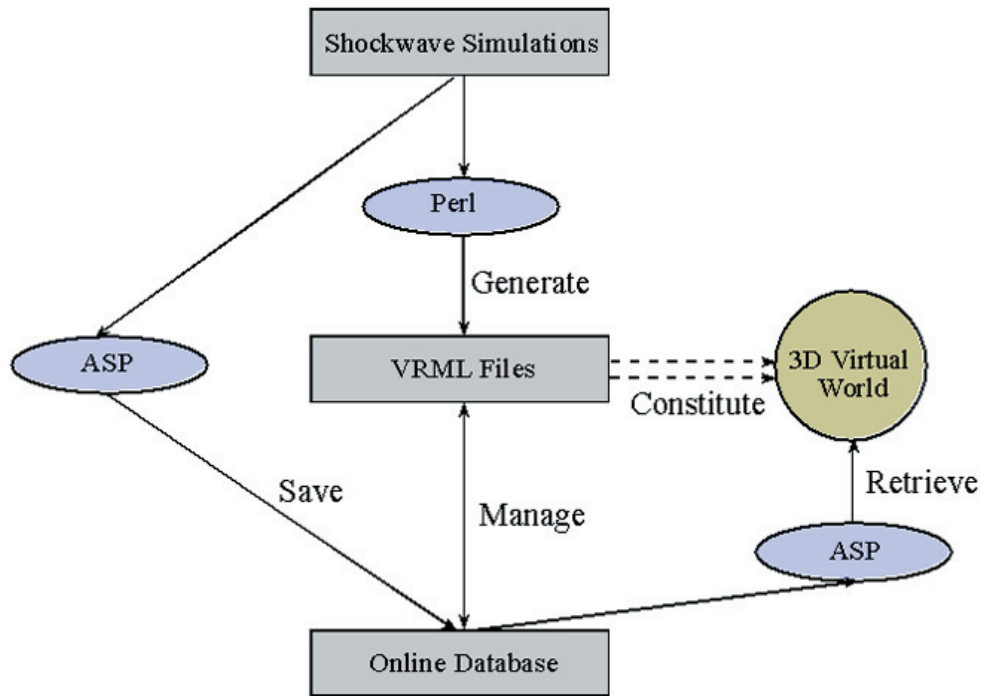


Figure 11

Questions and Results about Structural Analysis Module					
Questions	Useless	Not so good	Good	Excellent	No Opinion
1. How good is this module at helping you understand the concepts of frame or truss structures?	0	1	7	3	1
2. How good is this module at helping you better visualize the computational results of frames or trusses such as the moment diagram and deflection?	0	0	7	5	0
3. How good is the module at helping you check homework solutions?	1	2	5	3	1
4. How good is the module at encouraging you to design new truss or frame structures?	0	0	5	2	5
5. How good is the Virtual City at helping you visualize 3D models?	0	0	5	1	6

*The total number of students that responded was 12.*

**Table 1**

ative strategy to manage them. This strategy employs an ASP script to accept the user's account data as input. Based on the input data, the ASP script then searches the database to retrieve virtual structures associated with that particular user and dynamically generates the virtual world. Also, it is easy to set different default viewpoints for different simulations. The strategy is efficient because it does not save redundant data and can be used to manage a large number of users.

**Assessment**

Since the structural analysis module was developed for engineering education, it is important to evaluate its effectiveness. An assessment was therefore conducted at the University of Oklahoma in the fall of 2000. The professor first demonstrated in class how the module could be used to solve frame problems, and two homework problems were then assigned. The students were offered five bonus points for using the structural analysis module to check their homework solutions.

The survey questions and their corresponding results are shown in the Table 1. Twelve students in all responded to the survey. Table 2 summarizes the means and standard deviation performed on the student responses to the questions about the module.

From the responses to questions one and two, it was concluded that the module was successful in helping students better visual-

ize the computational results and understand the concepts of truss and frame structures. Based on the responses to question three, it was concluded that the students believed that the module was useful in checking homework solutions. The responses to questions four and five indicated that the module encouraged students to design new structures outside of the assigned homework and helped visualize 3D models. However, it is interesting to note that half of the respondents had no opinion in response to question five. This probably means that they did not try to design a bridge and deposit it into the 3D virtual world.

In addition to answering survey questions, these twelve students also provided useful comments about the structural analysis module. Examples of positive comments are, "If I would have learned to use this (module) earlier in this semester I think it would have

Mean and Standard Deviation about the Responses on the Structural Analysis Module		
Questions	Mean	Standard Deviation
1	2.0*	0.85
2	1.58	0.51
3	2.41	1.31
4	2.23	0.75
5	2.41	0.66

*\* The mean based on the following scale:  
1 = excellent, 2 = good, 3 = no opinion,  
4 = not so good, 5 = useless.*

**Table 2**



helped me tremendously" and "The graphics and bending demonstrations and shear and moment diagram are great." Major complaints were that user interface was not user-friendly and that it was easy to forget to maintain consistency among all units.

### Conclusion

In summary, the use of an Internet-based structural simulation and a 3D virtual world for engineering education was investigated in this paper. The user can employ the structural simulation to define the truss and frame problems intuitively and obtain visual results. The 3D virtual world provides the user a 'big picture' of the design components created by the use of different simulations. The assessment showed that the structural simulation helped the user to visualize the results and better understood the concepts of the truss and frame structures.

### Acknowledgement

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