Internet-based Distributed Collaborative Environment for Engineering Education and Design

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Abstract

This paper proposes a Virtual City framework to investigate Internet-based distributed collaborative environment for engineering education and design. This framework includes a 3D virtual world, an online database, multiple multimedia modules, and a distributed collaborative geometric modeling module. An important part of this 3D virtual world is that all structures are viewable over the Internet. These structures are created and deposited into the virtual world using Internet-based multimedia modules. The multimedia modules are tied together through the 3D virtual world since each multimedia module covers one specific engineering topic in the world, such as traffic engineering, steel structure, surveying, soil, consolidation, and structural analysis. An online database is utilized to manage changeable information such as user account information and design information. The reason to choose an online database instead of normal text files is that it is more efficient to save, update, and delete data.

The distributed collaborative geometric modeling module can be used to design simple structures and deposit them into the 3D virtual world. Employing the geometric modeling module, users in the same group can work on the same geometric object at different locations. Real-time information sharing and real-time manipulation of the same design object are implemented. Real-time text-based chat room is also integrated to support communication between group members. These features are the key requirements of distributed collaborative concept. Interactivity, 3D visualization, encouragement of teamwork are emphasized in the Virtual City. Multiple Internet-based technologies are used in the development of the Virtual City framework. These technologies include Java, Java 3D, VRML, Director Shockwave, Perl, ASP, SQL, JavaScript, SQL database server. These technologies are chosen because they are well defined, inexpensive and used extensively for Internet-based applications.

Introduction

The continuously expanding use of the Internet has provided tremendous possibilities for engineering education, engineering design and analysis. The use of the Internet has opened a door to adopting new ways to teach engineering topics. For example, Internet-based simulations, online collaborative learning, and virtual worlds are three applications among many possibilities. Besides engineering education, the ubiquity of the Internet has made distributed collaborative engineering design and analysis possible. Geographically dispersed engineers can complete design and analysis tasks jointly through the Internet. This paper presents a Virtual City

framework that can be used in engineering education and engineering design. It should be noted that the Virtual City framework is only a prototype application to illustrate an efficient utilization of the Internet and computing power for both industry and engineering education.
Bandwidth and quality of service of the Internet are current major concerns along with connectivity. However, with the introduction of new networking technologies such as wave division multiplexing, bandwidth concern will become less of a problem. New Internet technologies such as IP version 6 are being developed to provide multicasting and quality of service [1]. Not only Internet technologies are improving, but also processor speed is continuing to increase. It is reported that maximum processor speed will be approximately 12GHz by 2005 if Moore's law holds for three more 18-month cycles [2]. Since many technical problems with the existing Internet and computer will vanish, a large number of new applications will be needed to efficiently utilize this available bandwidth and computing power. One such application is real-time concurrent design and analysis over the Internet for engineering education. This parallels the need in industry to conduct real-time concurrent engineering and collaboration between engineers in geographically dispersed locations. One obstacle to Internet-based education and design is a lack of infrastructure, prototypes, and content-rich applications [3].

This paper proposes a Virtual City framework to investigate the possibility of using the Internet to conduct engineering education and engineering design. There are three main research objectives of the Virtual City. First it provides a content-rich prototype for engineering education; second it develops a prototype for distributed collaborative geometric modeling; and third it investigates the possibility of integrating geometric modeling into an educational or training environment over the Internet.

A large number of papers on the distributed collaborative design and Internet-based education have been published. Numerous commercial products are also available on the market, which implement partial features of distributed collaborative concepts. Research on distributed collaborative design falls into two categories. The first one tries to offer theoretical models. Senin, Pahng, and Wallace, et al. proposed a distributed object-based modeling and evaluation (DOME) framework for product design [4]. The basic goals of DOME are intended to link distributed design modules, to aid designers in evaluating the system performance with different design alternatives, to seek optimal solutions, and to make design decisions. Case and Lu proposed a discourse model used in software environments that provides automation support for collaborative engineering design [5]. The discourse model treats interactions between designers as a process of discourse.

The second category tries to implement the idea of distributed collaborative design in a practical way. Lee, Kim, and Han proposed a prototype to implement web-enabled feature-based modeling in a distributed environment [6]. Cybercut is one of first web-based design systems for fabrication, which was developed at the University of California at Berkeley [7]. Currently, it provides Internet-based services such as design-for-manufacturing CAD, Computer Aided Process Planning (CAPP), and access to an open architecture machine tool for fabrication of mechanical parts. Toshiki Mori and Mark Cutkosky proposed an agent-based prototype implementation in the design of a portable CD player [8]. The agent interface was written in Java, which makes it possible for geographically dispersed design teams to communicate over the Internet. To seamlessly share CAD information across an enterprise, major CAD suppliers have introduced a software system called product development management [9,10,11]. This software system extends CAD data not only to non-design departments of companies such as analysis, tooling development, manufacturing, testing, quality control, sales and marketing, but also to suppliers and partners of these companies. The goal is to shorten product development cycles and streamline product design. The major product development management systems include Windchill from Parametric Technology Corporation, MetaVPDM from SDRC, ENOVIAvpm from IBM and Dassault Systems, ProductVision from Unigraphics Solutions, and OneSpace from CoCreate. Airbus, Sony and Lockheed-Martin are among the early adopters.

In addition to conducting the design of real products over the Internet, engineering education can also use the ubiquitous nature of the Internet. To answer how the Internet will affect the traditional higher education, a study sponsored by the California Education Round Table was performed in the fall of 1996 [12]. Based on this study, it is believed that the Internet and the World Wide Web will play multiple important roles in the higher education. Because of its potential advantages, universities are not only one of the leading forces in developing the Internet infrastructure technologies, but also one of the first to adopt these technologies for educational purposes. There are numerous ways to use the Web for education, such as general course administration [13], information delivery [14], virtual laboratories [15], Internet-based simulation [16], online courses [17], and virtual universities [18].

Based on current research as outlined, it is evident that work has been done in distributed collaborative design but no existing environment has fully implemented it in real-time over the Internet such as being able to collaboratively work on the same 3D model by multiple users at the same time. Educational activities over the Internet are diverse currently, but no existing educational environment can support 3D visualization, collaborative learning, and the encouragement of creativity and teamwork. The Virtual City framework proposed by this paper will address these issues. This paper also presents the working prototype that has been developed and implemented at the University of Oklahoma for teaching Civil Engineering students.

Overview of the Virtual City

The Virtual City provides a content-rich Internet-based engineering educational environment, and it allows the user to perform distributed collaborative geometric modeling. A three-tier architecture is employed in the development of the Virtual City (Fig. 1), which contains an online database server, a Web server with a multi-user server capability, and clients' browsers. Changeable information is managed by an online database management system. The Web server works as middleware to take data from clients and save the data in the database. It also retrieves data from the database and presents it to clients. Static information, which is used for the web site, such as description of engineering topics, is stored directly on the Web server. The multi-user server is independent from the Web server, which takes care of the communication between clients. Since no dedicated computer is available to hold the online database when the Virtual City was implemented, the Web server, the multi-user server and the online database server are on the same machine; but the concept of implementation is still the same as the three-tier architecture.

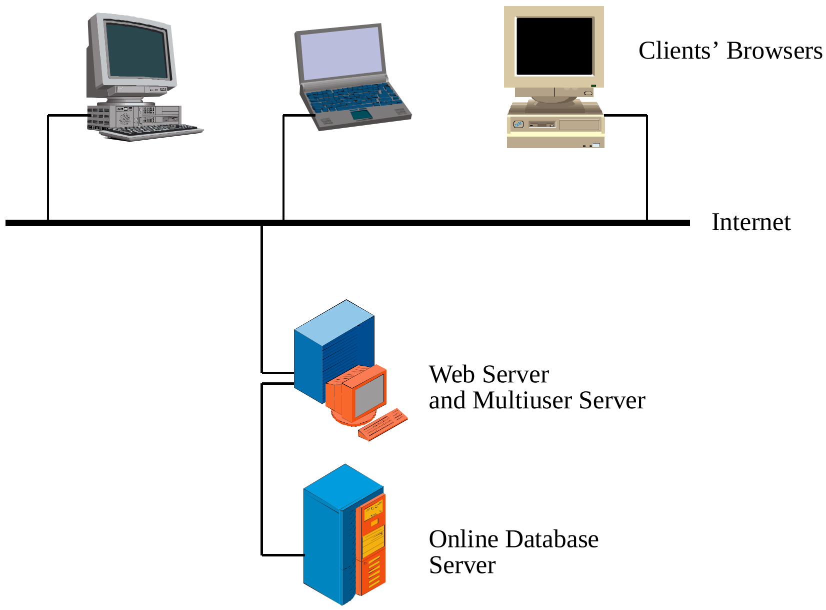

Fig. 1 A Three-tier Architecture of the Virtual City

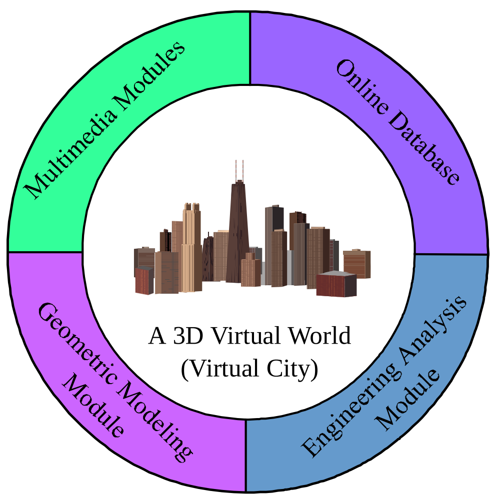

Fig. 2 Overview of the Virtual City

The actual Virtual City is composed of five parts – a 3D virtual world, Internet-based multimedia modules, an online database, a distributed collaborative geometric modeling module, and a distributed collaborative engineering analysis module (Fig. 2). A key part of the 3D virtual world is that it contains various structures. These are created and deposited by corresponding multimedia modules, which is the second portion of the Virtual City. Different multimedia modules are tied together by the 3D virtual world. Each multimedia module covers one specific engineering topic. A SQL database is utilized to manage changeable information such as user account information, and design information. The distributed collaborative geometric modeling module is used to design simple structures and deposit them into the 3D virtual world. The distributed collaborative engineering analysis module is the natural extension from geometric modeling, which can read in data from the geometric modeling module, conduct typical 3D finite element analysis, and display the stress results in color, all over the Internet.

Three-dimensional Virtual World

The Virtual City implements an Internet-based 3D virtual world with a true 3D perspective. Students are allowed to build segments of the 3D virtual world upon completion of appropriate undergraduate courses in civil engineering. The end result is a complete virtual world that contains designs from all of their coursework, for example, highway system, bridge, dam, building, and steel structures. The virtual world is viewable on the Internet and can be navigated by anyone over the web. The 3D virtual world is the key to the Virtual City and ties all of the other components together (Fig. 3).

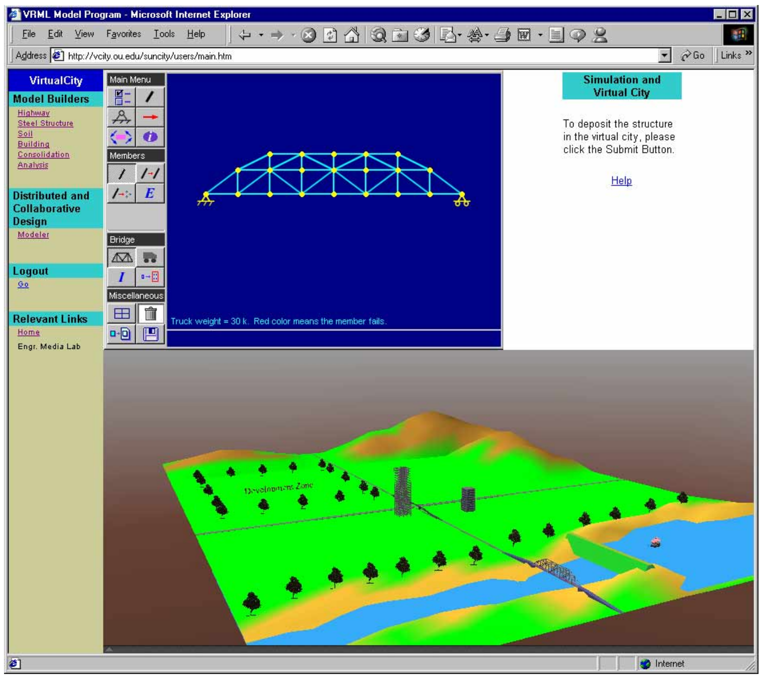

Fig. 3 Three-dimensional Virtual World

Database Management

The Virtual City uses an online database management system to manage all of the changeable data. This is because it is more efficient to save, update, and delete data in the database than in text files. The changeable data include data of user accounts, data of team accounts, and data of generated structures in the 3D virtual world. To use the Virtual City, each user must provide necessary information to create a user account. After creating an account in the database, the user can log into the Virtual City, explore the multimedia modules, create structures, and deposit them into his/her own 3D virtual world. Only the authorized user can log into his/her own individual account that contains his/her private 3D virtual world. In order to use the distributed collaborative geometric modeling module and engineering analysis module, a shared team account must be created in the database. The team members then can log in the team account and use the geometric modeling module, the engineering analysis module, and multimedia modules. In the team account, only one shared copy of the 3D virtual world is kept but the number of structures in the shared 3D virtual world can be constantly changing since structures can be designed, constructed and deleted.

The Virtual City for Engineering Education

Since one of main purposes of the Virtual City is for engineering education, it focuses on interactivity, 3D visualization, collaborative learning, inspiring creativity, and encouraging teamwork. Interactivity is achieved by developing multiple multimedia modules, which cover numerous engineering topics. In general, each multimedia module has two subsections. One is an information subsection that explains a specific engineering topic and the other is a simulation that is designed to allow the user to explore. Usually, the user is expected to study the information subsection and related materials carefully before they start using the simulation since the simulation assumes that the user has a basic knowledge of the particular topic. Flexible interactivity is always the central design concept of the simulations. For example, the user can modify multiple parameters at one time and they can draw a truss structure, a frame structure, or a cross section as input information. The results are then presented by use of animations, graphics, color contours, and tables. Another key design concept of the simulations is the intuitive interface since ease of use is a required element for any product.

Three-dimensional visualization is hard to realize over the Internet because of heterogeneous computer systems. However, it is vital to let the user see and work with 3D models in engineering education. Due to the introduction of Virtual Reality Modeling Language (VRML) and Java 3D, it has become possible to present 3D models through the Internet. In the Virtual City, an Internet-based 3D virtual world is utilized to offer a central location to manage various 3D structures created by different multimedia modules. Since structures such as buildings, steel structures, bridges, highways, and dams come from different multimedia modules, the 3D virtual world also ties all of them together in one environment.

Collaborative learning and teamwork are difficult to integrate into the design of an Internet-based engineering educational environment because server-side and client-side applications need to work together. However, since one of main research objectives of the Virtual City is to implement a truly distributed collaborative environment, teamwork and collaborative learning are key functions of the Virtual City.

Inspiring creativity is always essential in engineering education. Generic modules are designed to achieve this. For example, the structural analysis module provides a generic truss and frame simulation that can perform analysis of any simple or complex truss and frame structure. The user can draw any kind of topologically different structures and apply any kind of valid boundary conditions. The results can be obtained through finite element analysis. Minimizing the restriction on the user’s input is one way to encourage creativity. The distributed collaborative geometric modeling module is another example that allows the user to create flexible design objects and deposit them into a 3D virtual world.

The Virtual City for Engineering Design

The Virtual City is not only for engineering education but it can also be used for engineering design. The distributed collaborative geometric modeling module implements sharing information, communication, and manipulation of design objects, which are key elements for a distributed collaborative environment.

In general, the geometric modeling module is a simple CAD program that provides a generic general-purpose 2D drawing tool, and 3D operations such as extrusion and revolution, and a rendering tool. However, it is different from traditional tools since its internal design supports multi-user capabilities. Users in the same group can work on the same geometric object in different locations. Real-time information sharing and real-time manipulation of the same design object can be implemented. As it is hard to implement the feature of natural communication such as video over the current Internet due to the bandwidth limitation, only real-time text-based chat room is used in the Virtual City for communication.

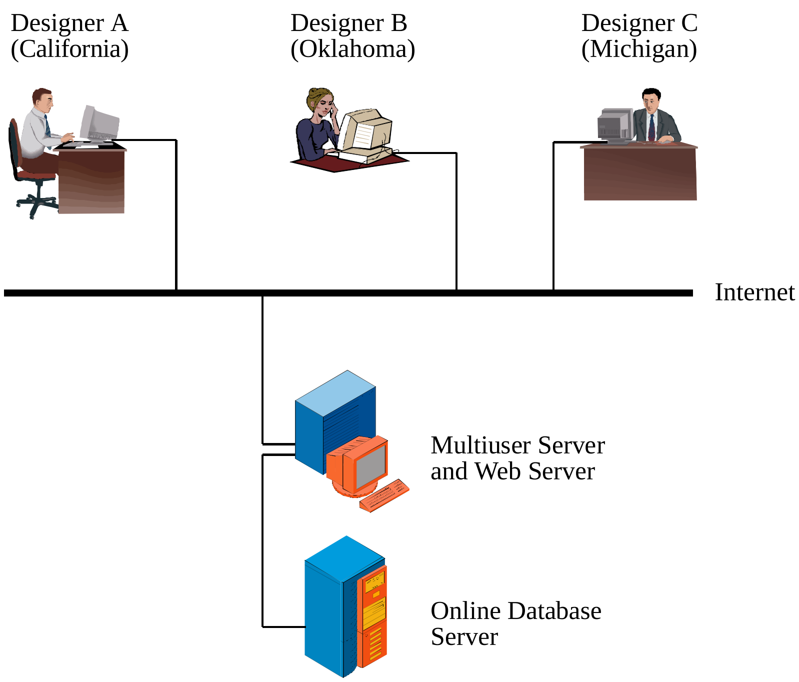

Fig. 4 Distributed Collaborative Design

The distributed collaborative geometric modeling module works as follows. Let's assume there are three designers in a design group. Designer A is in California; designer B is in Oklahoma; designer C is in Michigan (Fig. 4). First designer A and B log in the design environment. Designer A draws a line and designer B sees it immediately; designer B draws another line and thinks the location of first line is not good enough and moves the first line; then designer A sees changes designer B has made. Designer C then logs into the design environment, and joins the work of other two. Designer C immediately sees the work-in-progress from the other two designers. The main idea is that only one copy of the file is kept and the designers share the same design object. If designer A disagrees with designer C, he can communicate with designer C through a chat room. After the cross section is finished, it can be extruded to obtain a 3D object. Then designer C feels that it is difficult to produce this part and wants to discuss it with his peer designers. He rotates the object and his peer designers immediately see the part rotation on their own screen. Then they can discuss the production problem while viewing the object from the same point of view.

Multimedia Modules

Multimedia modules are the key elements of Virtual City and each one contains two sections – an information section and a simulation section. The information section covers the key engineering concepts related to the module; the simulation section is a Shockwave simulation that allows the user to learn these topics by exploring the simulation. Most of the modules are also tied to the 3D virtual world by allowing the user to design a specific structure and deposit it in the 3D virtual world. Currently, the finished multimedia modules are a traffic-engineering module, steel structure module, surveying module, foundation module, soil module, consolidation module, and structural analysis module. As an example, only the structural analysis module will be discussed in this paper.

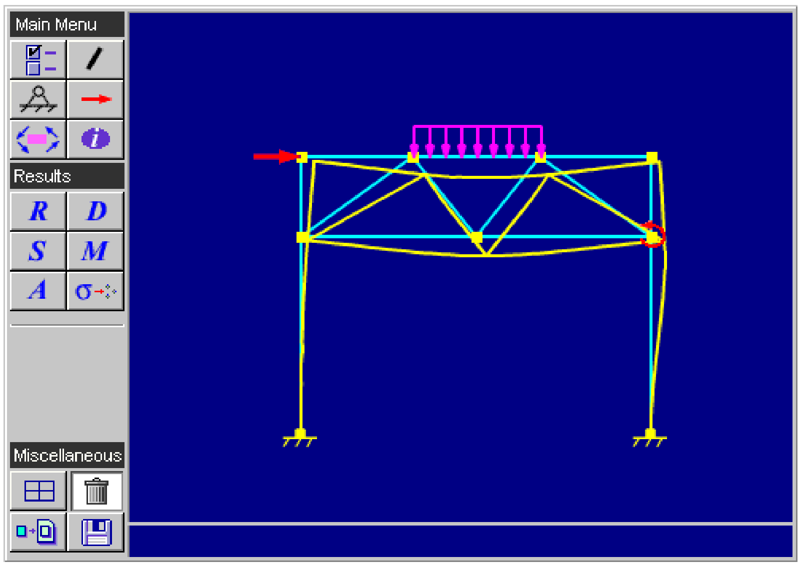

Fig. 5 Deflection of Each Member for a Frame Structure

The structural analysis module was designed for the Structural Analysis course. Its main purpose was to provide a generic solver for plane truss and frame problems that are the main two topics in any structural analysis course. It is important for a structural designer to know 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 code could be used to check the results, the problem is that such programs are hard to learn and not always available. Thus it will be particularly useful to provide a convenient Internet-based solver that can be used to check the computation results of trusses and frames (Fig. 5) at anytime. Furthermore, the user can learn the concepts of structural analysis by designing and solving structures using the solver.

Finite element method (FEM) is the heart of the structural analysis simulation. FEM can apply to any topologically different trusses and frames with no need to change any computation procedure, which is significantly efficient for programming. Although it is relatively easy to program the computation procedures of FEM, it is always a challenging task to conveniently specify the input information and to correctly present the results.

The analysis tool also includes special tools for the design of bridge structures that include moving loads. If a moving load is applied, the influence line for any member due to that load can be graphic in the program. An animation of the moving load is also shown to visually show the displacements of each node. Similar to other modules, the bridge can be deposited in the 3D virtual world (Fig. 6). Another feature of this simulation is that the user can save a structure with boundary conditions and forces on the server and then later retrieve the structure for further analysis. The computational results are not saved because they can be easily obtained by running the simulation again.

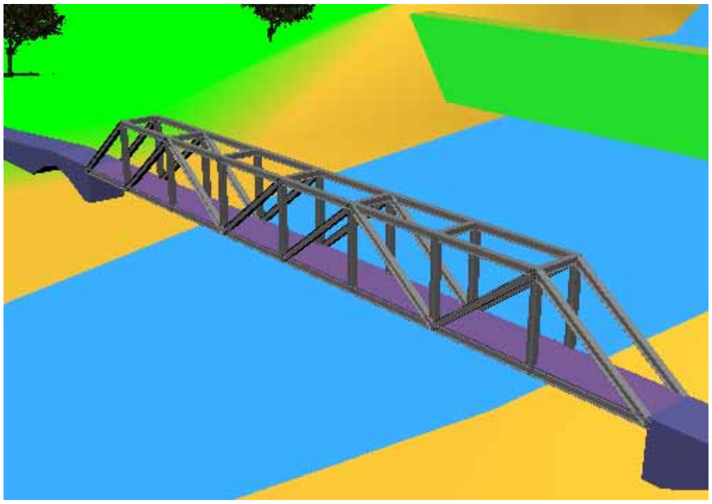

Fig. 6 A Bridge Deposited in the 3D Virtual World

Distributed Collaborative Geometric Modeling

The distributed collaborative geometric modeling module is comprised of two parts. One is a client-side application, which is the geometric modeling application and the other is a server-side application, which is a multi-user server. The client-side application performs the geometric modeling, and the server-side application takes care of communication and coordination. Computer networking and graphics are the foundation of this module.

Server-side Application

The server-side application includes two programs – a Director Shockwave multi-user server and a Java multi-user server. Both have the same capability to receive and deliver packets to client-side applications (Fig. 7). The Shockwave multi-user server works with the Shockwave simulation of the client-side geometric modeling. The Java multi-user server, which was developed for the geometric modeling, distributes the packet of one client's applet to the applets of other clients. The design concept of both is similar; both keep a table for each design group. When the user starts the client-side geometric modeling application, both the Shockwave simulation and Java applet send a registration packet with the name of design group, client's IP address and port numbers to their corresponding multi-user servers. The multi-user servers record these data in the related table. Since the IP address and port number are unique at any given time, the Shockwave multi-user server uses them to communicate with the Shockwave simulation and the Java multi-user server uses them to talk with the Java applet. Members are not allowed to communicate between different design groups since the design object is shared only in the same design group.

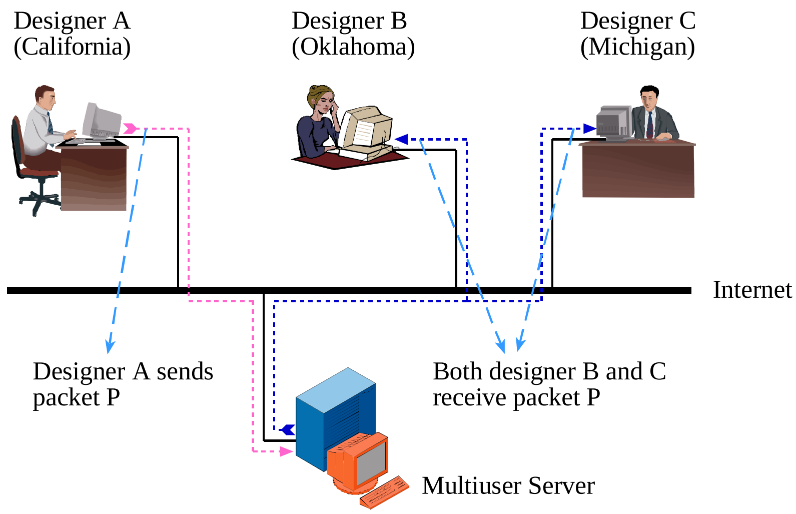

Fig. 7 The Function of Multi-user Server

The Java multi-user server was developed using Java and the Java Shared Data Toolkit. Socket implementation is chosen because it is widely accepted in the networking world. Both TCP and UDP socket were used in developing the Java Multi-user server.

<u>Client-side Application</u>

The Client-side application also includes two programs – a Director Shockwave simulation and a Java applet. The Shockwave simulation generates the 3D wireframe since it is efficient in creating points and lines, but it doesn't provide support for rendering 3D models. The Java applet shades the models with its native Java3D rendering engine. In general, the user first creates a 3D wireframe model, gives it a name, and saves it on the server. Then the user initializes the Java applet and types in the same name given to the wireframe model. The Java applet loads the model data from the server, renders it, and displays it. Both work simultaneously to display the same model. If the user makes any change to the 3D wireframe model, it will automatically propagate the change to the model in the Java applet since both of them share the same model name. As discussed previously, the Shockwave simulation talks to the Shockwave multi-user server and the Java applet communicates with the Java multi-user server. Both are real-time collaborative applications.

The data structure used to design the geometric modeling is a B-Rep data structure. The reason to chosen the B-Rep data structure is that it can be easily implemented. The B-Rep data structure stores the basic elements composing the boundary of a solid – the vertices, the edges, and the faces. Currently, the client-side geometric modeling application supports two methods of generating 3D models – extrusion and revolution. Figure 8 shows a part that was designed by the geometric modeling module.

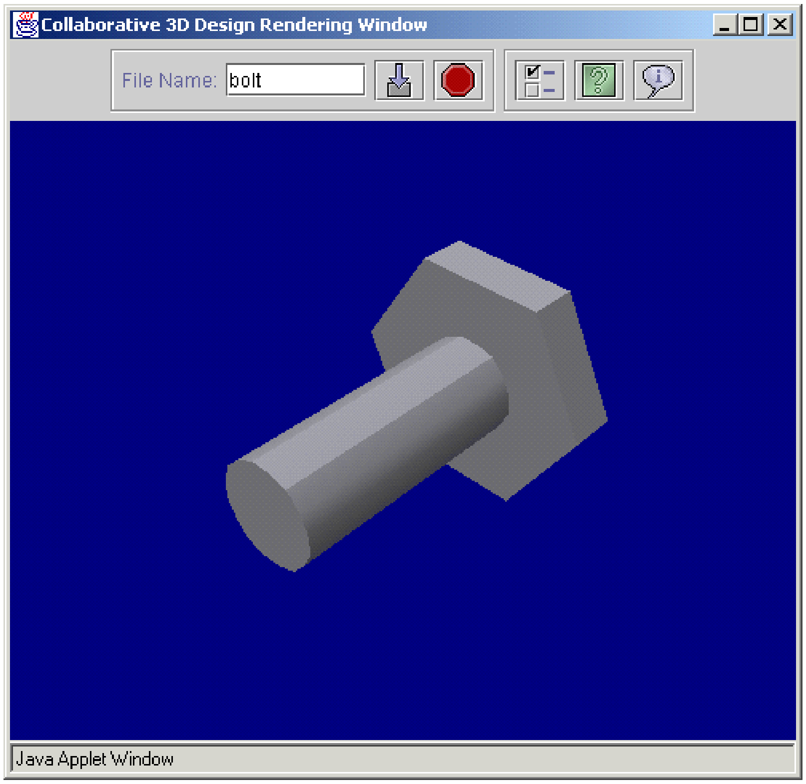

Fig. 8 Bolt Designed by Geometric Modeling

Assessment

In order to assess the effectiveness of the multimedia modules, a survey was done about previously discussed structural analysis module. First, the professor demonstrated the module in the classroom to show how the module could be used to solve frame problems. Second, two homework problems were assigned and if the students used the structural analysis module to check the homework solutions they could earn five points bonus. The following table shows the survey questions and results (Table 1).

The total number of students that responded is twelve. Although the responses are subjective, they do provide useful information about the module. One of the objectives of the module was to help students better visualize the computational results. The responses to question two suggest that the module was particularly successful in this regard. Another objective of this module was to help student understand the concepts of truss and frame structures. The responses to question one shows that it was successful. Other objectives of module include encouraging students to design new structures other than assigned homework. The responses to question four indicate that the module was mildly successful in this objective. This module can be used to deposit a bridge in the virtual city. However, it is interesting to notice from responses to question five that half of respondents had no opinion, which probably means that they didn't try to design a bridge and deposit it into the virtual city or they didn't care about this feature.

Table 1 Survey Questions and Results

Questions	Useless	Not so good	No opinion	Good	Excellent	Average
1*	0**	1	1	7	3	4.00***
2	0	0	0	7	5	4.41
3	1	2	1	5	3	3.58
4	0	0	5	5	2	3.75
5	0	0	6	5	1	3.58

*Question Number:

1. How good is this module at helping you understand the concepts of frame or truss structures?
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?
3. How good is the module at helping you check homework solutions?
4. How good is the module at encouraging you to design new truss or frame structures?
5. How good is the Virtual City at helping you visualize 3D models?

** Number of students who responded "Useless". The total number of students that responded is 12.

*** Average score based on the following: 1 = Useless; 2 = Not so good; 3 = No opinion; 4 = Good; 5 = Excellent.

In addition to answering survey questions, these twelve students also gave useful comments about the structural analysis module. Good comments are, for example, "If I would have learned to use this (module) earlier in this semester I think it would have helped me tremendously", "The graphics and bending demonstrations and shear and moment diagram are great". Major complaints include that user interface was not too friendly and that it was easy to forget to keep all units consistent.

Conclusion

Owning to the increasing Internet bandwidth and computing power, the idea of the Virtual City can be extended to design virtual products for the purpose of engineering education in the future. To obtain a mechanical engineering degree, the user usually needs to take numerous courses, such as statics, dynamics, mechanics of material, and machine design. If carefully organized, these courses could be integrated to design multiple meaningful parts using the knowledge learned in respective particular courses and these parts can be assembled together to form a virtual product. This model can be the basis of a virtual university for engineering education.

In addition to a virtual university, the idea of the Virtual City also has potential applications in industry especially in engineering. It is possible to shorten development cycles if the CAD/CAE/CAM products realize the idea of the Virtual City. This is because the idea of the Virtual City is to allow geographically dispersed individuals to collaborate over the Internet.

In summary, this paper proposes a distributed collaborative framework - Virtual City to conduct engineering education and design over the Internet. The Virtual City framework is used to provide an infrastructure for content-rich engineering education environment, to test the concept of distributed collaborative geometric modeling, and to explore their capabilities, potential applications and limitations. Further work will be done on distributed collaborative engineering analysis over the Internet.

Acknowledgement
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