

Developing an Advanced IT-Based Visualization Classroom for Enhanced Engineering Learning

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Abstract — *Interactive learning, critical thinking, creative problem-solving and problem-based learning are all critical elements to enhancing engineering education. Visualization can provide the much needed computer-assisted design and analysis environment to foster problem-based learning, while Virtual Reality (VR) can provide the environment for hands-on manipulation, stimulating interactive learning in the engineering classroom. At the University of California, Irvine a new interactive learning environment, termed VizClass, is being developed. VizClass incorporates a specially designed lecture room and laboratory integrating both 2- and 3-dimensional spatial learning by coupling a series of interactive projection display boards (touch sensitive white boards) and a semi-immersive 3D wall display. The use of VizClass, and the accompanying pedagogical and curricular innovation, will allow for the redesign of existing engineering courses, the development of new courses, and the integration of courses and curriculum across engineering disciplines. Test bed verification of VizClass is targeted towards finite element methods applicable to civil and structural engineering problem solving at the graduate education level. Different pre- and post-processing tools are being developed for an open source finite element software package to assist in smoothly integrating basic visualization concepts into the numerical analysis process.*

This paper will describe the hardware architecture designed for this new environment as well as the initial visualization framework to be integrated with an open source object-oriented general finite element platform. Example numerical analysis results from a representative model building structure are described, illustrating the integration of simple visual paradigms to provide an enhanced understanding of the physical model.

Index Terms — *Educational environments, human-computer interaction visualization, and display technologies.*

INTRODUCTION

Though the field of engineering has changed dramatically in the last 20 years, the study of engineering has changed relatively little. Students continue to passively listen to lectures in chalkboard-based environments that afford them little opportunity for visualization, hands-on manipulation, interaction, or creative design. Indeed, almost all of these skills, which are vital for engineering, are learned through on-the-job practice rather than at universities. A continuation of this trend threatens to weaken the relevancy of engineering and computer science study at the university. Such modes of learning have an especially negative impact on under-represented groups in engineering, such as African-Americans, Hispanic-Americans, and women, all of whom have been shown to especially benefit from interactive forms of instruction (e.g. [1], [2]).

Interactive learning, critical thinking, creative problem-solving and problem-based learning are all critical elements to enhancing engineering education. Visualization can provide the much needed computer-assisted design and analysis environment to foster problem-based learning, while Virtual Reality (VR) can provide the environment for hands-on manipulation, stimulating interactive learning in the engineering classroom. At the University of California, Irvine a new interactive learning environment, termed *VizClass*, is being developed. *VizClass* incorporates both a specially designed lecture room and laboratory integrating both 2- and 3-dimensional spatial learning by coupling a series of interactive projection display boards (touch sensitive white boards) and a semi-immersive 3D wall display. The use of *VizClass*, and the accompanying pedagogical and curricular innovation, will allow for the redesign of existing engineering courses, the development of new courses, and the integration of courses and curriculum across engineering disciplines. Test bed verification of *VizClass* is targeted towards finite element methods applicable to civil and structural engineering problem solving at the graduate education level. Different pre- and post-processing tools are being developed for an open source finite element software package to assist in smoothly integrating primitive visualization concepts into the numerical analysis process.

This paper will describe the hardware architecture designed for this new environment as well as the initial visualization framework that was integrated with an open source object-oriented general finite element platform. Example numerical

analysis results from a representative model building structure are described, illustrating the integration of simple visual paradigms to provide an enhanced understanding of the physical model. First, a brief review of the literature is provided describing environments that have been or are being developed using similar technologies.

PREVIOUS IT-ENVIRONMENTS

In recent years, a number of information technology (IT) environments have been developed at Universities and research laboratories across the United States and internationally. These environments provide infrastructure support for classrooms, office activities, tele-conferencing and meeting spaces. A common thread when comparing these environments is the enhanced visualization and display capabilities provided to support activities held in these spaces. In some cases, multiple tiled 2D display systems are used, while in others 3D (active or passive) stereo support is provided on high-resolution display systems, allowing for full immersion in the space. Important to this, from a user perspective, is the capability of the environment to provide comfortable human-computer-interaction devices to support user activities. Of particular interest to the work described in this paper, are the *eClass*, *iRoom*, and the *Office of the Future* environments.

The *eClass* project (formerly called *Classroom2000*), has been developed by the Future Computing Environments group at the Georgia Institute of Technology ([3, 4, 5]). Since 1995, *eClass* has supported teaching at Georgia Tech in the areas of Computer Science and Engineering, by providing a digital environment for course lectures and discussion sessions. The environment supports playing, recording, and animating (in real-time) lectures. A java-based client-server system, ZenPad, records and stores lecture video clips, slides, and annotations during each lecture. Lectures collected and compiled by ZenPad provide a detailed record of the discussion, including the original presentation, annotations compiled during the presentation, and a full audio record of the session. *eClass* has a unique (2D) display layout for lecturers, primarily including a digital (active) LiveBoard, and two projection surfaces for passively displaying information. Figure 1(a) shows a photograph of the *eClass* environment and highlights the components of this IT-classroom.

The Interactive Workspace Project (or more commonly termed *iRoom*) ([6, 7]) at Stanford University uses a broad array of interactive devices, such as multiple large displays (2D and 3D) and portable (hand held and other) devices to provide an interactive research working space. A software layer developed by Shankar et al. [8], and termed *iROS* (Interactive Room Operating System), is used to provide the underlying middleware architecture integrating the different interaction devices and computational activities together. The *iRoom* project brings together interaction at a broad range of scales and using a variety of interfacing techniques (both wired and wireless devices are integrated into the environment). For example, the user can control multiple displays with a handheld device such as an iPAQ, or remotely activate devices during working sessions (such as scanners, printers, etc.). Figure 1(b) shows a photograph of the *iRoom* environment and highlights the components of this IT-workspace.

The *Office of the Future* environment ([8, 9]) was developed at University of North Carolina at Chapel Hill to provide an immersive space allowing 3D graphical model display and manipulation for the future office environment. The primary focus of the office of the future project is to capture and display 3D data dynamically and on random surfaces within the space it is constructed in. To do this, Raskar et al. [10] have replaced ceiling lights with projection systems and carefully controlled structured light within the room. Using advanced computer vision techniques, the authors create a flexible display environment, whereby changes in geometry, intensity and resolution variations across multiple display areas are dynamically controlled.

These and other systems, are providing state-of-the-art interactive digital workplaces, whether it be for an office, educational, or entirely research environment. Thus far, however, none of these systems have integrated interactive visualization and advanced 3D display components with mathematical solvers. Furthermore, with the exception of the *iRoom* project, previous IT-spaces that provide advanced visual tools, have used *either* a 2D or a 3D (semi-immersive-type) display paradigm, little emphasis has been given to integrating the two (space scales) into a single environment. In engineering education, mathematics and modeling are critical to developing and solving a physical problem, engineers first learn the fundamental mathematics defining a boundary value problem, and subsequently must develop a physical representation of the problem. In most cases, the scale of the problem is broad, thus 3D interpretation and spatial correlation is generally important to understanding the physical constraints imposed. Therefore, in the engineering education environment, it is important that students first interpret the 2D information (equations, algorithms, etc.) and then work with the 3D information (geometric models).

VIZCLASS: AN ENVIRONMENT FOR EXPANDING ENGINEERING THINKING

A new IT-Classroom is being developed at the University of California, Irvine, with the primary objective of providing a completely digital, interactive workspace for research and education in the areas of Computer and Civil Engineering. Test bed application courses include computer graphics, scientific visualization, and numerical methods (finite element methods) in structural engineering. The IT-space serves not only as an educational environment, it also provides a space for

interdisciplinary research centered around simulation and visualization as well as an IT development test bed advancing system level research and education.

A 65 m² classroom in the Engineering Gateway building on the UC Irvine campus (room EG3131) was allocated for the development of VizClass. The original layout of this room is shown in Figure 2(a). In the original room, approximately 20 students passively listened to white board lectures provided at the working front space of the room. Over the past six months, EG3131 was reconstructed, redesigned and remodelled to provide support for a new advanced IT-hardware layout incorporating a range of 2D and 3D displays, driving computational systems, and interactive devices. The layout of VizClass, showing the 2D active display area and the 3D stereo working area is shown in Figure 2(b). The following sections describe the advanced display systems, interactive devices, and driving computational systems designed for VizClass.

Advanced Display Systems

The 2D display component consists of three interactive 1.8 meter diagonal (72 inch) SmartBoardsTM connected to three computers with DVI output. The SmartBoardsTM are compactly designed to fit within a thin 60 cm deep space, by backwards projecting images onto an angled mirror and then forward projecting them onto the optical screens. A single NEC 1060 (2500 ANSI Lumens) projector with a short throw lens is used per screen to provide an on-screen resolution of 1024x768 pixels. The front of the room layout of 2D displays provides a large laterally tiled screen for users. The digital SmartBoardsTM have multiple input/output sources - with the primary source being an optical on-screen input (providing active interaction) for annotating and controlling input on the displays. Each SmartBoardTM is also equipped with a digital pen-tray, providing digitally color-coded pens, supporting '*digital ink*', a display surface eraser, and a wireless keyboard with a trackball mouse. These interface devices support input scenarios via direct application of the *digital ink* from touch events, or query or data access interpreted by mouse or keyboard events. Figure 3(a) shows a photograph of the 2D interactive SmartBoardsTM installed in VizClass.

The 3D display component is designed with two projectors vertically stacked and mounted at floor level projecting from the rear, onto a large 3 meter (10 foot) diagonal screen. The projectors are digital light projectors (DLP-based) with a brightness of 3000 ANSI Lumens and resolution of 1280x1024. Each projector is equipped with polarizing filters and together, the two projectors are used to generate the stereoscopic image. A single PC with an nVidiaTM GeForce4 TI-4600 graphics card using quad-buffering is designated to provide the stereo image pairs and a CYVIZTM 3D stereo convertor is subsequently used to assign the left and right eye images to the respective projector. Users can wear simple polarized glasses to engage in a 3D immersive presentation.

In the workspace area (lecture and discussion space), a 3D surround sound and motion tracking system are planned for capturing lectures and discussions in all modalities. Video capture is accomplished by using a single motion tracking camera at the rear of the room and multiple passive (fixed-point) cameras arrayed towards the audience. Sound input and output (via multiple microphones) requires a hardware echo-cancellation system and multiple sound cards to receive and send spatial sound information into the workspace area. Properly synchronized video and audio acquisition is required to allow for archiving course material and later playback.

Device Control

To control all of these devices (2D/3D displays, touch-sensitive LCD display, cameras, sound system), an 8-node PC cluster connected via a Gigabit ethernet switch is provided in the 3D projection room. System software supporting the environment is primarily being developed in C/C++ and Python and integrated with wxWindows and wxPython, respectively for GUI development with operating system specific look and feel. Figure 3(b) shows the PC cluster and working space for development of the software interface layer. The PCs have been actively named based on their function (VizSmart1, VizSmart2, and VizSmart3, each independently controlling the SmartBoardsTM, Viz3D controlling the 3D stereo display, VizAudio controlling the sound system, etc.). A single PC, VizFEA, is dedicated for numerical analysis solution processing.

The synchronization of the multiple input/output devices is controlled through a keyboard-video-mouse (KVM) matrix switch also located in the 3D projection room. The KVM switch supports high resolution video display with no degradation of the signal. Ultimately, additional interactive devices will be integrated to respond to both the 2D and 3D display systems. A prototype of this idea is shown in Figure 4, where datagloves are worn by the user to manipulate a model.

Access and control to multiple devices integrated into VizClass is made possible through an interface software layer running on a LCD touch-sensitive display, mounted at eye-level at the entrance to the environment. Presenters will be able to load their digital data via the VizClass webserver prior to lectures, and subsequently activate this data onto the 2D and/or 3D display systems via the touch-sensitive display. Digital material may include slides, web contents, video clips, sound files, numerical simulations, animations or interactive visualization. This may be further augmented with hand written notes, annotations, the instructors voice and gestures tying information together as well as instructor-student and student-student interaction. The flexibility of this design also lends itself to distance learning scenarios.

Visualizing Numerical (Finite Element) Models in VizClass

Finite element analysis (FEA) is one form of modeling commonly used in civil, mechanical and aerospace engineering (among other fields). In FEA, the problem domain is spatially discretized into known primitive elements (1D, 2D, or 3D elements) and nodes with given boundary and loading constraints. In classic FEA environments, engineers usually spend 70% of their time working on 3D shape modeling and mesh generation (pre-processing), 20% on analysis and review of results (post-processing), and only 10% on running the FEA solver. Thus, enhancing the visual representation of the numerical model, especially during the pre-processing (model development) stage will increase productivity, while providing increased time for analysis interpretation. Most current commercial FEA software, such as ANSYS, ADINA, MSC-Nastran, have good 2D graphical user interfaces for the pre- and post-processing steps, however, such commercial packages have yet to achieve stereoscopic visualization and full interaction during the visual previewing stages.

Virtual Reality (VR) technology is premised upon creating a real-time synthetic environment, believable to users as being as near to the physical world as possible. Human-computer interaction within VR is a critical component to realizing this true immersion and grasping near-physical world reality. Wrapping VR technology around FEA can assist in immersing the analyst in the model, driving a clearer picture of the design, during both the pre- and post-processing phases. Such an approach is particularly appealing, since the cost of computational systems and stereoscopic devices have seen a reduction over recent years. A brief review of the literature indicates there has been various application-specific VR-FEA integrations.

Literature Review - Virtual Reality Techniques Applied to Finite Element Analysis

Research has been conducted to integrate VR technologies with FE (commercial and proprietary) packages. In general, previous approaches have been focused on first providing a wrapping layer for the FE analysis package with VR (engaged with either pre- or post-processed data) and subsequently, attempting to enhance the level of immersion within VR by providing new interaction devices for event triggering and model manipulation (such as data gloves, pens, head-mounted-displays, etc.). Additional devices can help enhance the feeling of immersion within the scene if the user can grab, lock, and manipulate objects or the scene. In an application by Yeh and Vance [11], for example, the integration of post-processed data from FE analyses within a virtual environment, provided a visual space in which the model deformation and stress contours could be projected in stereo view for users. Using a flexible (sensitivity studied) data set, the user could interactively change design parameters using data gloves, without re-running the analysis. In an application by Ryken and Vance [12], virtual reality techniques were applied to study the stress analysis of a tractor lift arm. NURBS-based free form deformation, sensitivity analysis, and collision detection, were combined with VR and FEA to create an interactive environment for designers to view and modify the shape of the part, evaluate the resulting stresses, and check for interference of the new part shape and surrounding parts in real-time. Their application provided a particularly novel hardware solution for attempting to fully immerse the user into the model scene, by using a surround screen environment, C2, similar to a CAVE environment.

Others have developed wrappers for either pre- or post-processing stages of FEA. Liverani et al. [13], for example, developed a semi-immersive real-time 3D-enabled VR software layer for FEA called VRFEA. Interfacing tools that were encoded into VRFEA were fairly flexible, including stylus and glove devices providing an interface with the model, allowing users to operate on the elements and nodes, create and adjust the mesh, specify boundary conditions and control which results are visualized. The software framework was directly integrated into the popular OpenInventorTM toolkit by SGI. In a similar (API-wrapper approach), Lu et al. [14] studied two different API software packages for interfacing VR and FEA - the popular dVISE 3D program and SUN's Java3D package. In their study, it was concluded that dVISE, although powerful when interfacing with VR hardware, is relatively slow when loading objects, mostly due to its file reading approach, which required transforming data from multiple formats. Java3D was selected to maximize performance and speed of the VR-FEA interaction.

VRML-Based Approaches

The expansion and popularity of the Internet has led to implementation of 3D graphics contents based on the Virtual Reality Modeling Language (VRML). VRML is appealing since it is operating system independent, only requires a VRML plug-in and may be run stand-alone in a network browser. FE analysis modules have been integrated with VRML in an effort to provide a VR-interface via the Internet. For example, Del Pino et al. [15] directly integrate a ray tracing package with the FE model of a 3D acoustic problem. In their approach, a VRML-based wrapping of the FE modeling layer is used to provide model interaction. Similarly, Ranga and Gramall [16] present an application of FEA actively running over the Internet using a VRML-based software layer.

Although not using the FEA-framework, in a related geometric modeling application (specific to building structures), Cross et al. [17] developed VRML application tools for visualizing the earthquake retrofitting of structures. The educational

module developed by Cross et al. provides a powerful, stand-alone visual learning tool. Similarly, Haque [18] developed VRML-based structural design modules allowing students to immerse in the 3D Internet-based module.

Integrating VR with FEA for Engineering Education - OpenSees

The approach taken in this project includes first developing an application wrapper framework for an open-source finite element platform. The platform selected is the Open System for Earthquake Engineering Simulation (OpenSees)[19] being developed by researchers within the Pacific Earthquake Engineering Research Center (PEER). OpenSees was designed as an open source framework for simulating the seismic response in structural and geotechnical systems. The platform (operating system) independent framework was developed entirely in C++ and provides an intuitive Tcl/Tk scripting front-end. With this front-end, complex structural systems can be defined, covering aspects such as specimen geometry and material properties, boundary conditions, and loading, among others. However, the primary focus for this system is on delivering precise numerical results, while data analysis and interpretation are left to other (external) post-processing tools.

The general library OpenSeesViZ is being developed to wrap OpenSees based on the general software flow shown in Figure 5. Upon initialization of OpenSees (to perform analysis), OpenSeesViZ is initiated, and this instance creates a thread, which maintains a separate data structure for visualization specific tasks. OpenSeesViZ then displays snapshots of images of the analysis in an OpenGL window as the analysis is performed (i.e. at each user defined time step). Simple visual paradigms are used to represent common elements used in structural analysis (trusses, beams, solid elements, etc.). Nodes are represented using geometric proxies (spheres), and some specialty sections have been implemented, as will be described in the subsequent sections, to graphically represent physical members (modeled numerically by the user).

Example Structure

An example structure, modeled in OpenSees and visualized during analysis using OpenSeesViZ, is shown in Figure 6. Figure 6(a) shows the finite element representation of the 2-story, 3-bay structure. The structure is composed of varying sectioned girders (beams) and columns and constructed of reinforced concrete. Floor level dead and live loads representative of practical (field) conditions are applied. The structural model itself is a modified form of an example structure provided with the OpenSees analysis package. Both gravity (vertical load) analysis, lateral load analysis, and dynamic (base input) analysis are performed on the structure and the visual deformations of the structure observed. Figure 6(b) shows an example snapshot of OpenSeesViZ during the lateral analysis. The horizontally placed reinforcing bars (which would otherwise be hidden) are articulated by using translucent colors for the outer (concrete) patches. In such a fashion, the user can understand the extent of the sectional detailing as it occurs along the finite element (representation) of the girders.

SUMMARY

At the University of California, Irvine a new interactive learning environment, termed *VizClass*, is being developed. VizClass incorporates both a specially designed lecture room and laboratory integrating both 2- and 3-dimensional spatial learning by coupling a series of interactive projection display boards (touch sensitive white boards) and a semi-immersive 3D wall display. Test bed verification of VizClass is targeted towards finite element methods applicable to civil and structural engineering problem solving at the graduate education level. Different pre- and post-processing tools are being developed for an open source finite element software package to assist in smoothly integrating basic visualization concepts into the numerical analysis process. The initial hardware architecture designed for this new environment as well as the initial visualization framework to be integrated with an open source object-oriented general finite element platform are described in this paper.

Future Plans: Integration of VizClass into Course Curriculum

VizClass is planned for integration into two specific engineering education areas: (i) Civil Engineering and (ii) Computer Engineering. Integration is planned by using VizClass through several means, including, specifically holding lectures and discussion sessions in VizClass. Through the integration of both engineering disciplines, a new breed of students who learn using interactive visualization environments can be targeted. Specifically, for the structural engineering student, the new approach holds promise for enhancing their ability to understand modeling and analysis via geometric interpretation. In addition, to enable remote education and collaboration support, the VizClass environment will also provide AccessGrid 2.0 connectivity.

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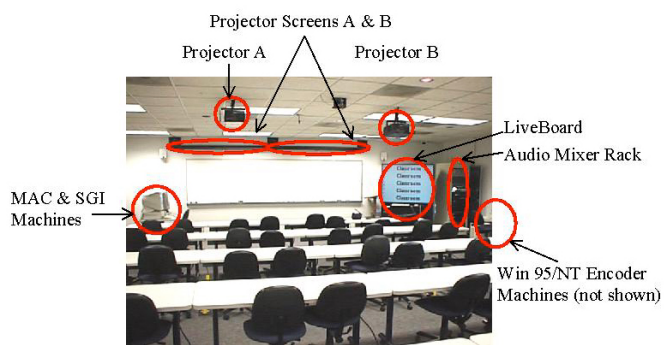
support is greatly appreciated. In addition, the assistance of Mr. Bob Kazanjy, the student researchers of the Structural Engineering Test Hall and the Visualization and Interactive Systems (VIS) group at UC Irvine are greatly appreciated.

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FIGURES AND TABLES

FIGURE 1.
EXAMPLE IT-ENVIRONMENTS, PHOTOGRAPHS COURTESY OF [5] AND [6], RESPECTIVELY.

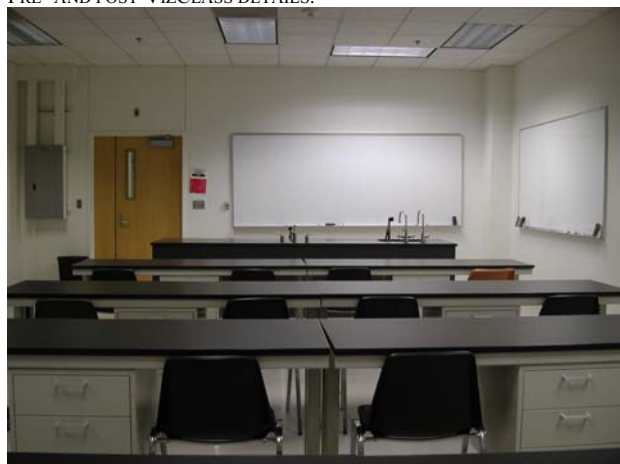


(A) *eCLASS* (AT GEORGIA TECH UNIVERSITY)

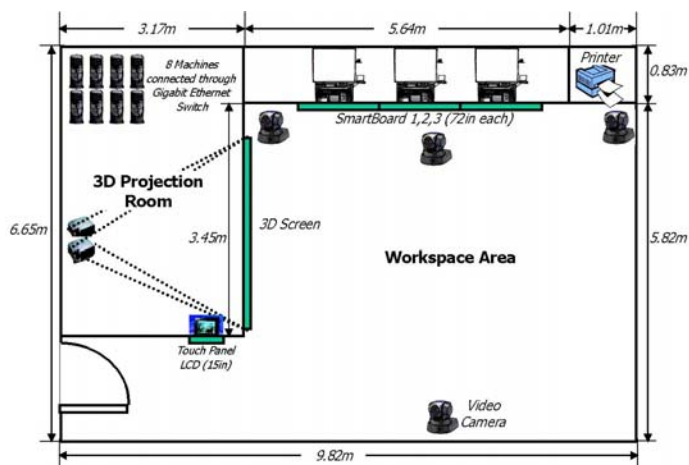


(B) *iROOM* (AT STANFORD UNIVERSITY)

FIGURE 2.
PRE- AND POST-VIZCLASS DETAILS.



(A) ROOM EG3131 - PRIOR TO VIZCLASS DEVELOPMENT



(B) SCHEMATIC ILLUSTRATION OF VIZCLASS LAYOUT.

FIGURE 3.
EQUIPMENT INSTALLED IN VIZCLASS.



(A) ARRAY OF THREE-2D SMARTBOARDS™



(B) PC CLUSTERS IN VIZCLASS

FIGURE 4.
EXAMPLE OF INTERACTING WITH THE 2D ACTIVE WHITEBOARDS USING DATAGLOVES.

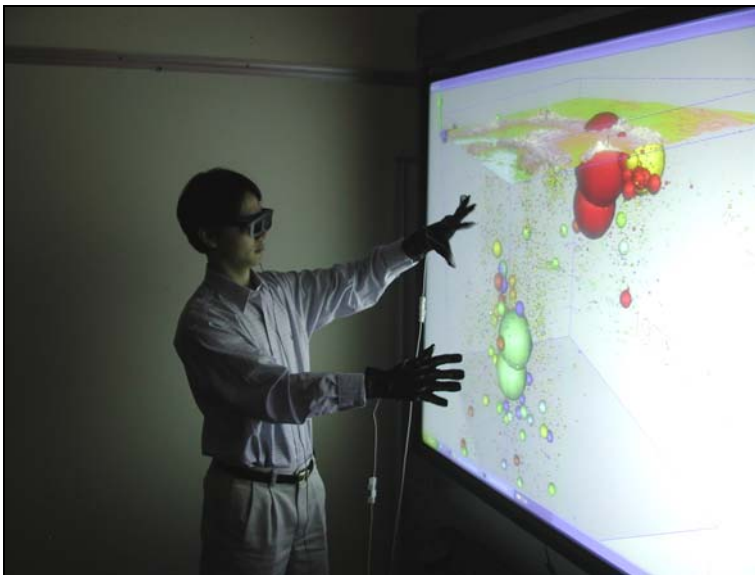


FIGURE 5.
SOFTWARE FLOW - VISUAL INTERPRETER FOR OPENSEES.

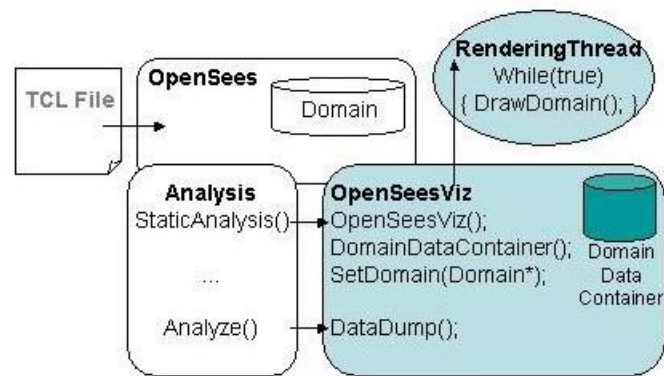
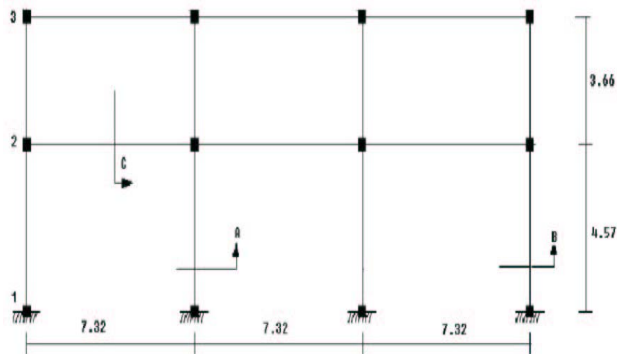
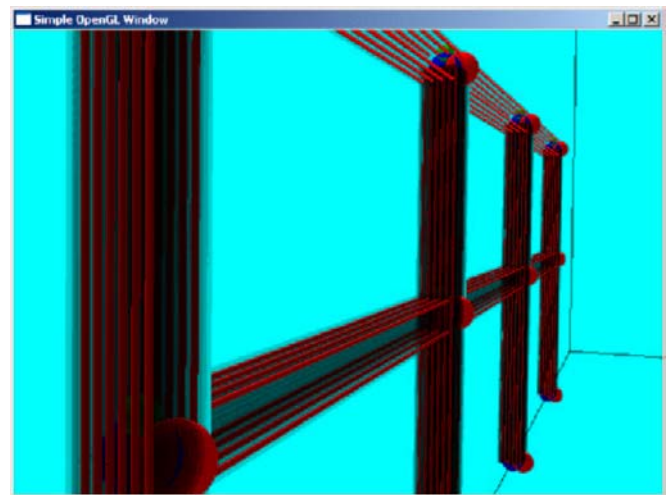


FIGURE 6.
EXAMPLE STRUCTURE SHOWN IN 2D AND IN 3D (WITHIN OPENSEESVIZ).



(A) FEA REPRESENTATION OF 3-BAY STRUCTURE



(B) CLOSE-UP VIEW SHOWING REINFORCING STEEL SECTIONS (IN RED)