INTERACTIVE 3D VISUALIZATION TO FACILITATE UNDERSTANDING OF ASSEMBLIES AND DETAILS IN CONSTRUCTION EDUCATION

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Abstract

Throughout the years, various teaching methods have been adopted to assist students to better understand building assemblies and construction details. Many current teaching techniques to explain assemblies, components and their sequence of construction rely heavily on traditional instruments such as 2D CAD drawings, photographs and site visits. These techniques have their own drawbacks. However, 3D CAD modeling addresses the third dimension that is not present in 2D CAD drawings, that is allowing better viewing, validating and understanding building components and their construction. This paper addresses the impact of understanding 3D and its advantages over current approaches. The paper describes a pilot study conducted with students from the Virginia Tech Architecture and Building Construction departments. The experiment investigated the advantages of 3D representation as compared to 2D drawings, in understanding construction assemblies and details. The paper also discusses the shortcomings of the traditional methods and compares the suitability of using 3D as a teaching aid. A new approach utilizing Pocket PCs via wireless connectivity, to allow students access to and viewing of 3D models remotely, is briefly presented.

Introduction

Current pedagogies and teaching tools used in construction education are unable to sufficiently include complex details, realistic design and construction problems that could enhance learning. Many current teaching techniques rely on conventional instruments such as 2D CAD drawings (plan, isometric and perspective), photographs and site visits. These traditional teaching approaches have their own drawbacks that could lengthen students' learning curve. The majority of construction details are complex and very hard to understand when presented as 2D CAD drawing. 2D drawings do not address the issue of depth, hence making visualization somewhat difficult for students. Components in a 2D drawing could be expressed as lines, but the depth of such components cannot be represented therefore the difficulty to understand the details increases. Although isometric, axonometric and perspective drawings address the issue of depth only to a degree, they are still limited to only 2 faces and the angles are fixed. Complicated assemblies still cannot be studied and fully understood using these representations. Color photographs and slides are limited to the view captured, which make them unsuitable as an effective approach. Site visits may not be readily accessible to students for various safety and regulation reasons. In addition, you may not be able to see what you need during the site visit because of progressing work schedule.

Interactive 3D modeling tools address the third dimension that is missing in 2D views and drawings, and seems to be the next logical step in enhancing the current teaching techniques. Adding the third dimension to viewing an assembly gives it a unique position in space and clarifies many of the details associated with its components, including connectivity issues. Interactive 3D tools also allow manipulating the 3D view, which adds flexibility of viewing. Using these tools, the 3D model can be rotated around any axis, and panned or zoomed in any direction. Realistic rendering of the components representing the various materials is possible, which gives a "true depth" and "feel" of the model. Texture mapping and dynamic lighting can create a realistic simulation of the structure and enhance the 3D object. With 3D viewing tools, students are able to position and recognize the object with relation to others in the scene, enabling a better and more complete visualization and instigating an interactive learning process. It is even possible to mimic the sequence of construction. Understanding the construction sequence is

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important in developing a student's competencies and enabling them to understand the different alternatives for constructing assemblies.

There have been other studies to improve the quality of education and make the learning process interactive. In one of such studies, Clayton *et al* (2002) considered the following issues:

- The often suggested idea that *"students of architecture do not gain much practical knowledge in construction methods and management during their education."*

- *"Although students typically complete courses in construction methods, many studio projects lack any semblance of cost or project management and may indicate only a rudimentary attention to construction."*

- *"Because faculty members tend to concentrate research and teaching upon aesthetics, theory and history, students may complete their education lacking know-how in building technology and construction. This has also led to frequent criticism that recent graduates lack knowledge of construction."*

Considering these issues, Clayton *et al* (2002) undertook the study and conducted a research with the goal of:

- *"Integrating construction into design education through computer methods that help to isolate construction issues and provide experience through simulation."*

- *"Testing the viability of 3D computer modeling and 4D CAD as a way to enhance learning about construction among design students."*

Their approach was to integrate construction into design education and they used computers to help isolating construction issues and provide experience through simulation. The simulation incorporated 3D graphics for visual modeling, rendering and animation. Their proposal was to institute a design-build studio in schools of architecture. The educational objective of this has been to cultivate teamwork and impart the knowledge of construction. They adopted the Virtual Design - Build technique. Small buildings were developed that included even the minute details such as every brick, anchor bolt, wall tie, stud and joist with particular consideration to weatherproofing, structure and finish materials. The objective is to help students learn about materials and assemblies and the need to consider the integration of the structure, the mechanical and electrical systems. All of these were integrated using Autodesk's 3D Studio Viz software. The use of this software allowed students to move the camera into different positions and also to focus on particular elements that were being constructed. They were even able to illustrate the movement of the constructed elements and modules e.g. how a stud wall is assembled in a horizontal position and then tilted up into place. Another example for the use of the software is the construction of a roof. Here, once the sheathing had been applied, the interior construction was hidden. With 3D Studio Viz, the color or transparency of the objects were varied to communicate the progress of construction of a particular element. Clayton *et al* (2002) concluded that:

- *"Our experiments demonstrate the viability of 3D modeling and construction simulation as a method of incorporating construction issues into studio courses."*

- *"The discipline of creating 3D models that are precisely sized to match actual dimensions helps students obtain an awareness of construction materials. The creation of assembly and construction in a more powerful way than does conventional 2D drafting."*

- *"Teaching with 3D CAD can increase construction content in architectural education. Our use of virtual construction appears to be a viable way to respond to industry demands for increased knowledge of construction among architecture school graduates."*

Elsewhere, Haque (2002) looked into the usage of 3D model information to enhance learning. He argued: "*Traditional lecture format teaching methods sometimes fall short of conveying complex analysis and design principles that need to be mastered in reinforced concrete design course. One of the methods of reducing this* *shortfall is to use simple animated virtual models, which demonstrate basic structural design concepts that can be used to enhance the students understanding. The interactive computer aided learning allows students to proceed at their own pace, motivated by a curiosity about "what happens" interactivity and "the need to know" the design/analysis principles*."

Haque demonstrated that some of the visualization techniques used are Image visualization / Animation, Digital Image Manipulation, Interactive Design Animation (Java) and Walk-through Virtual Navigation. The author's view is if 3D objects can be presented on the web and can be interactively changed / navigated, it will be beneficial for the students' conceptual understanding on the domain topics. According to Haque, nothing can be more convincing to a student than being able to walk-through a virtual model of a transparent concrete beam with all the reinforcement details. With a walk-through, things can be discovered, added or corrected before the actual construction begins. A walk-through is an excellent way to show students the reinforcement details. In conclusion, Haque stated that various visualization techniques can be valuable aids not only in teaching design principles of reinforced concrete structures in the class room, but also effective self directed tools for open learning via the web. It is evident that these new technologies can be used to enhance the quality of education as compared to the current teaching methods employed everywhere.

This paper addresses the impact of understanding 3D and its advantages over current approaches that depend mostly on 2D representation. The paper describes a pilot study conducted with students from the Virginia Tech Architecture and Building Construction departments as subjects. The pilot study investigated the advantages of 3D representation as compared to 2D drawings, in understanding construction assemblies and details. The paper discusses the shortcomings of the traditional methods and compares the suitability of using 3D as a teaching aid. The paper also presents a proposed method of utilizing Pocket PCs via wireless connectivity, where students can access and view 3D models stored at a remotely located web server. We believe this will further assist teaching and students' learning experience.

Methodology

The experiment presented in this paper was to study the impact of utilizing 3D visualization on current learning process, particularly to understanding construction assemblies, components, details, and sequence. In addition, the study aimed to determine how much value 3D visualization can add to students' understanding of construction assemblies and detail.

Four types of assemblies where chosen for the experiment. 2D drawings for each assembly (plan, and elevations) were developed using AutoCAD. Drawings for each assembly were mounted on 3/8 in. boards. An example 2D drawings for one of the assemblies is depicted in Figure 1. The 2D drawings were imported in 3D Studio Viz to generate the corresponding 3D models. Figure 2 depicts an example the 3D model developed. All 3D models were saved as 3DS file format and exported into the Deep Exploration™ (Right Hemisphere, 2003), a 3D visualization software that allows viewing and real-time manipulation. The viewing of the 3D models was conducted using a desktop PC running Windows XP. Two types of displays were used; (1) a SVGA desktop monitor and (2) the Elumen's VisionStation (Elumens, 2003). Figure 3 illustrates the overall setup of the experiment.

Each student was asked to analyze two different assemblies; one presented in 2D, the other in a 3D format. Students were also asked to perform specific tasks and identify specific details in each assembly. Varying the assemblies viewed in 2D and 3D for each user allowed for unbiased results to be achieved.

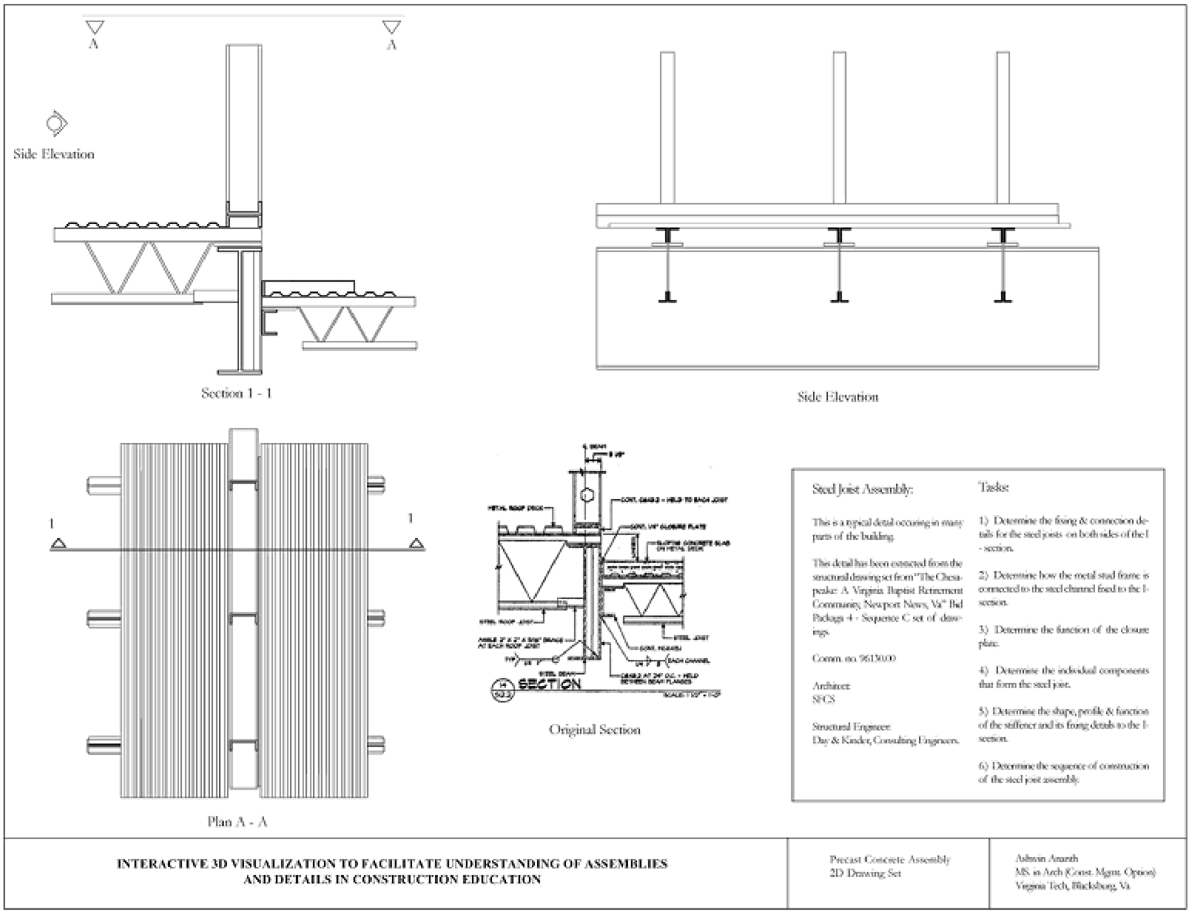

Figure 1: Example 2D Drawing (Steel Joist Assembly Detail)

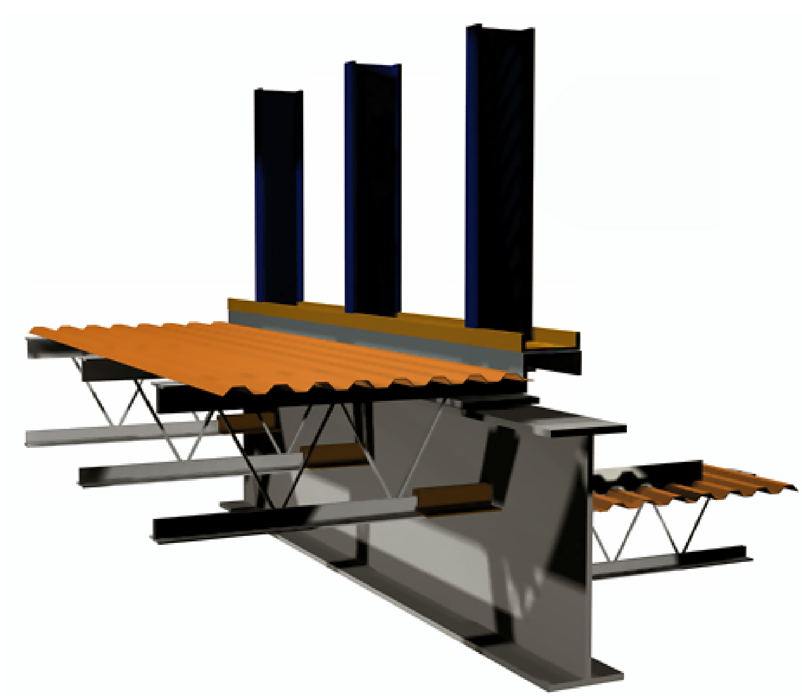

Figure 2: Example 3D Model Developed

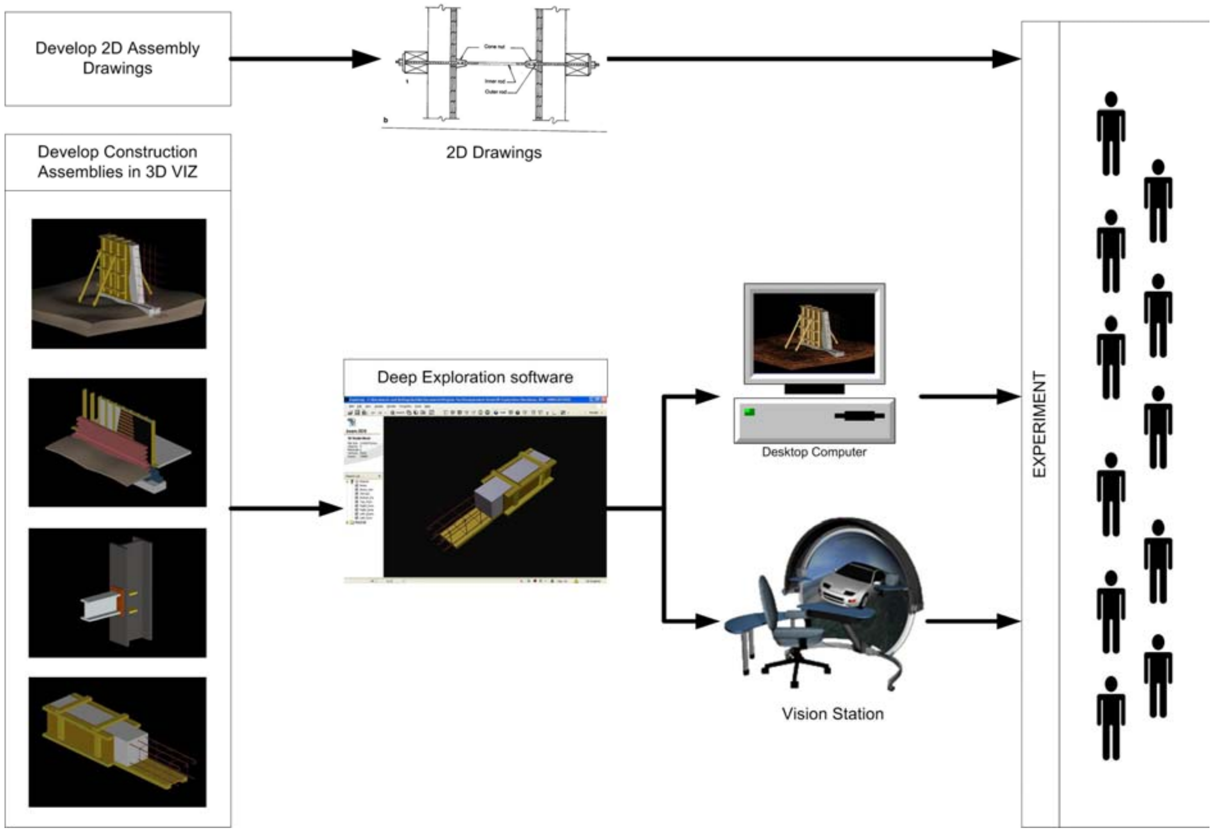

Figure 3: The experiment overall setup

Questionnaires

The main points considered in preparing the questionnaires were:

- The ease with which components can be identified in both 2D and 3D models.
- The ease with which components' shapes, profiles & general dimensions can be determined in both the 2D drawing sets and the 3D models.
- The ease with which connection details such as steel-to-steel, steel-to-concrete & masonry details can be determined in both 2D and 3D.
- The ease with which solutions for the tasks could be determined as listed in each of the construction assemblies in both 2D and 3D.

The ease with which the sequence of construction can be determined in both 2D and 3D.Prior to the actual experiment, a pilot survey was conducted with a few students to get feedback regarding the questionnaire, the presentation and quality of the 2D drawing sets and the 3D models. Their comments and suggestions were incorporated to improve the final survey questions. For the final experiment, a sample population of 25 students was selected from the Architecture and Building Construction programs.

The population samples varied; there were undergraduate, masters and PhD students with background in architecture, arts & design, civil, and construction. Also more than 50% of the population was comprised by international students from Asia and Europe. Such variations in the population sample were important for the success of the study. The advantage of having such a variation was that each student had a diverse background and the construction practices used in his/her respective country is different from what is available here in the USA. Their unfamiliarity to these processes was a good way to determine the effectiveness of using 3D models in building construction education. Table 1 shows the population sample breakdown.

		Sub-Total		Sub-Total	Total
Gender	Male	10	Female	15	25
Nationality	Americans	12	International	13	25
Study level	Other	2	Graduate	23	25
Major	Building Construction	6	Other	19	25

Table 1: Subjects' demographic information

Experiment

The length of the experiment was approximately 20 minutes for each subject. The experiment was divided into 2 sessions with 10 minutes allocated for each session. Firstly, a subject was given a set of 2D drawings and asked to determine the solutions for the given tasks. At the end of the first session, the subject was asked to complete a questionnaire. Next a 3D model assembly that differs from that of the 2D assembly drawing from the first session was displayed on the desktop computer. For better visualization, the 3D model was displayed on the VisionStation. Instructions were given prior to the experiment to familiarize each subject with the experiment setup. All the controls and functions were briefly explained to help subjects to navigate around the model and perform the given set of tasks.

Results and Discussion

Each question was weighted on the lines of the Likert Scale with "Very Helpful" carrying 5 points and "Very Unhelpful" with 1 point. The intervals between was 1 point for each intermediate answer. Hence, for each question in the entire total of 25 questionnaires, multiplying the corresponding weight and dividing the total by the number of participants resulted in the weighted average. Hence the mean was established.

In the students' ability to identify the assemblies, Chart 1 shows a comparison between the 2D drawing sets and 3D models. The result indicates that it was easier for the subjects to identify the assemblies using the 3D models than the 2D drawing sets.

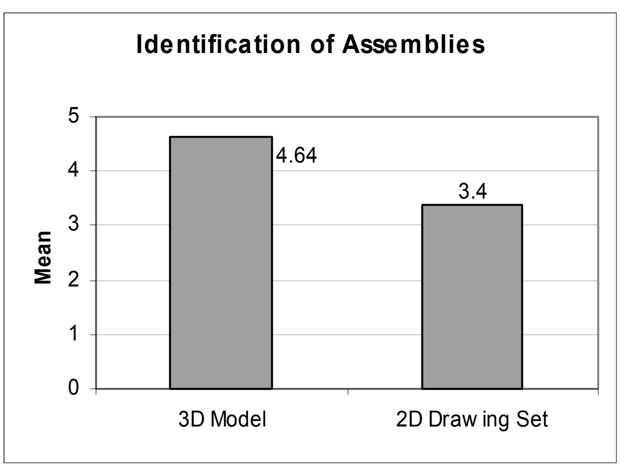

Chart 1: Identification of Assemblies

Chart 2 depicts a similar comparison for identification of the assemblies' shapes and profiles. Students were able to identify the assemblies' shape and profile easily using the 3D models than the 2D drawing sets. In the 3D models, the existence of the 3rd dimension helped students to understand better. Although all the supporting drawings were provided in terms of plans, sections and elevations, students may have missed out or were not able to correlate and position one drawing with the other.

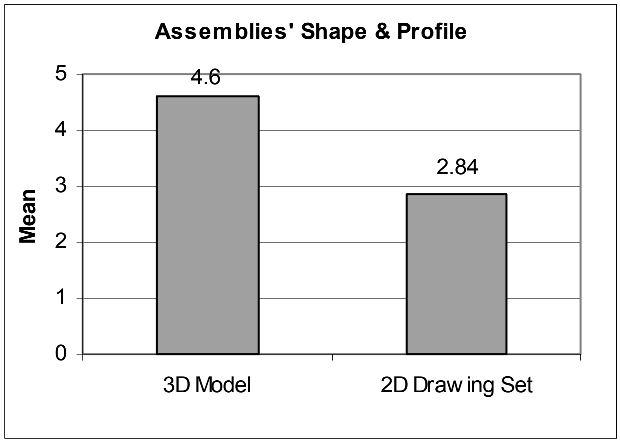

Chart 2: Identification of components' shapes and profiles

In the understanding of the connection details between the components of the assemblies, Chart 3 shows the results. The determination of connection details e.g. steel-to-steel; steel-to-concrete etc., students have a clearer understanding when using the 3D models. This is because the 3D models were able to provide all the required details in one single representation.

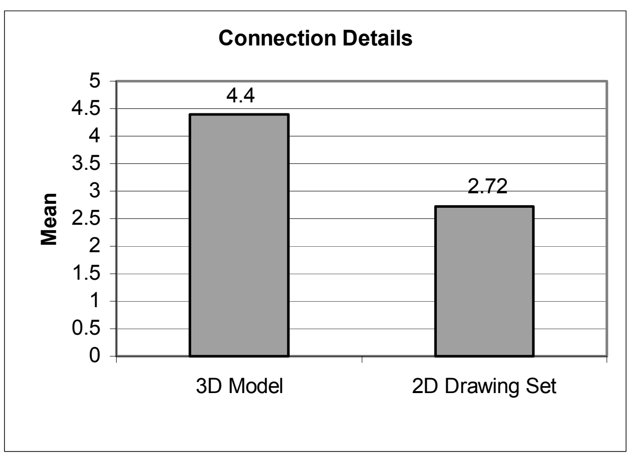

Chart 3: Understanding of connection details

Chart 4 represents the results of understanding the construction sequence for different assemblies. A simple animation feature in the 3D viewing application helped students to trace the sequence of construction by clicking 'on' and 'off' on the graphical components of the 3D model in the order of their construction. This task was much harder to achieve for assemblies viewed in 2D format. Most students agreed that the 3D models were superior to 2D drawings in understanding the construction sequence of the components.

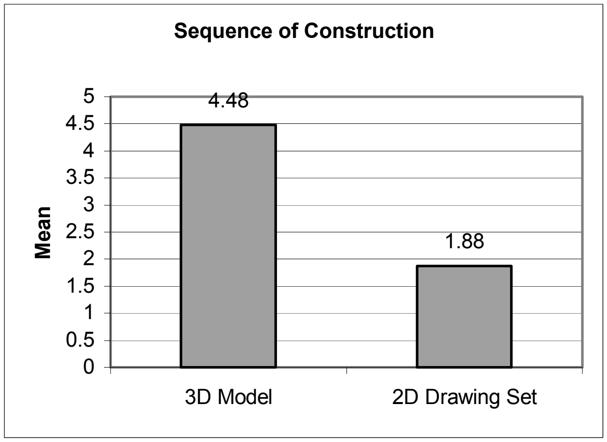

Chart 4: Understanding of construction sequence

Proposed Framework for 3D Visualization in the Classroom

The use of 3D visualization in the classroom could be made more flexible by allowing students to wirelessly log into a remotely located web server to extract information about assemblies and their components needed to complete specific class exercises conducted. The ability to acquire and visualize construction assemblies and components as they are needed can increase the students' level of and improve their learning curve as compared to current teaching techniques.

Previous research effort at Virginia Tech by Shiratuddin *et al* (2002) has investigated the suitability of the Pocket PC platform to visualize 3D models of construction assemblies and components. The study explored several applications running on the Pocket PC that will allow viewing 3D model files saved in the Virtual Reality Modeling Language (VRML) format. The proposed framework to view 3D models in the classroom builds on this research work and proposes to utilize wireless technology to allow the viewing of construction assemblies, components and other related information to various platforms, namely the Pocket PC and including the desktop and notebook computers.

Figure 4 shows the proposed framework. The framework presents two options and in both the 3D models of the construction assemblies is created using any standard 3D modeling software available in the market that is able to export the models to a VRML file format. In Option 1, the VRML 3D models are stored in a desktop PC server. A wireless access point is connected into the same network as the desktop PC server. The wireless access point will allow wireless connection that enables download of a model to the Pocket Pc using a FTP client software. Once the model is fully downloaded, the user will launch the Pocket Cortona software to view the models.

At the time of writing Pocket Cortona from Parallel Graphics (Parallel Graphics, 2004) is the only 3D VRML file viewer software available for the Pocket PC. In Option 2, the models reside on a desktop PC web server. A website is created with links to the respective 3D models whereby students will be able to access it wirelessly. Once connected to the web site, students will be able to download and view the models on the Pocket PC using Pocket Cortona. Many academic institutions have started to offer wireless connection. With such offering, a wireless LAN could easily be setup using a wireless access point that will allow students to connect their laptop or Pocket PC to any websites.

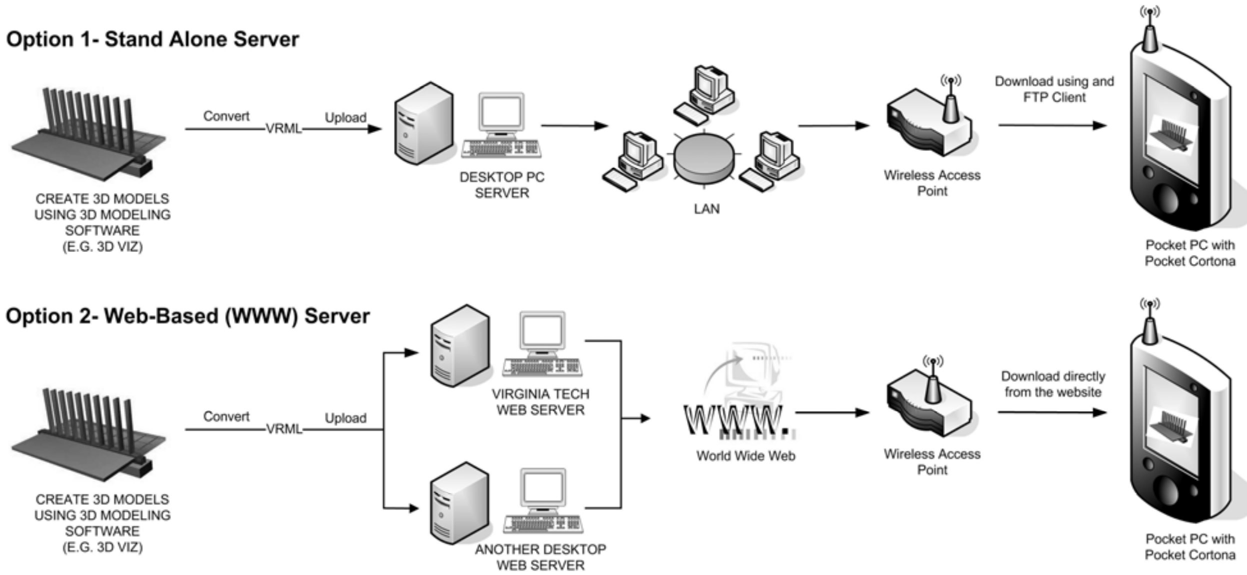

Figure 4: Proposed framework for wireless 3D visualization in the classroom using the Pocket PC

<u>Conclusions</u>

As summarized in Table 2, the survey results show that 3D modeling can be of great advantage for imparting building construction teaching and learning. A minor setback (that will diminish as more construction assemblies and components are modeled in 3D) is the initial time required to develop these assemblies in 3D and tailor them to the course curriculum. Once an established database of 3D models is developed, less effort will be needed to adapt and utilize them for various purposes.

Survey Questions	**3D Models**	**2D Drawings**
Identification of Components	4.64	3.4
Components' shape & profile	4.60	2.84
Connection details	4.40	2.72
Sequence of construction	4.48	1.88

Table 2: Summary of the results
Note: 5 = "Very Helpful" and 1 = "Very Unhelpful"

Some of the important considerations in this study were not to develop high technology, complex and expensive computer intensive solutions, but rather to select and use any widely available off-the-shelf software (with little or no modifications required) that is capable of running on any standard PCs. The central idea is this method can be adopted without any difficulties by the academic institutions and use it as a tool to create a value added education for the students.

Although it is accepted that 3D can provide better visualization than 2D, the specific advantages are needed to be identified. The methodology to use these tools needs to be developed and evaluated to see the level of effectiveness and usefulness rather than just proclaiming that 3D is better than 2D. Obviously, one of the most important aspects of the study is the students' review & feedback. As they will be the end-users of 3D technology, it is important to review their suggestions and feedback for development and improvement for future study. Many students gave a positive attitude and displayed interest to use the 3D technologies in learning. A few of them mentioned that it could be an interactive education tool in classroom sessions. Some of the positive comments gathered were:

- "*Much easier in 3D, 3D grabs attention thus one learns faster, enjoyed the step by step assembly process, wish some of the building construction classes used this tool*."
- "*This is awesome!! You can see every detail and get an understanding about exactly what is going on. This is so much easier to see how things fit together. The 2D was good for identifying materials but not the assembly. The 3D is awesome for both! This is awesome to use and very easy. I can see how everything fits together.*"
- "*The opportunity of turning on / off the layers and also using the opacity control tool helps a lot to understand the model and to see details and shapes in different views*."
- "*The 3D viewer software is a great idea. Certainly think it will help aid communication between architect, builder and client."*

Also a few students pointed out some limitations and expressed that if these features were incorporated, it maybe even more useful. Some of the comments were:

- *"A tool that would generate a real time construction sequence chart along with the 3D model could prove more powerful."*
- *"Dimensioning would be easier in a 2D drawing."*

Recommendations

With positive results obtained from the study, it can be concluded and recommended that the 3D technologies can be adopted and used to enhance building construction education without significant investment in manpower or even computer systems, and yet able to achieve a more interactive learning environment. This tool may not only be useful for institutional teaching and learning but also to various agencies involved in any construction project.

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