

Integrating 3D Models in Construction Management Education: Masonry Interactive Homework

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There is a need to improve construction management students spatial and visualization skills. The growing use of 3-D models, typically referred to as building information modeling (BIM) highlights the importance of this form of communication. As students learning styles change new teaching methods are needed to deliver course content in a manner that reaches the student. The use of 3-D models is one such delivery method. One construction management program previously looked at the student's perceived impact from the use of 3-D models to increase their understanding of core course knowledge. Based on these findings the development and introduction of 3-D homework assignments is being explored in masonry construction. Models were provided by an industry partner and through off the shelf software an interactive homework assignment was developed. This paper discusses the process of that development, the software used, and the outcome opportunities available to the student and teacher. The homework assignment will be implemented in the spring of 2011 and the students will be surveyed to discover the impact, if any, of this teaching method.

Key Words: Visualization, Building Information Modeling, Spatial cognition, Construction education, Problem Based Learning

Introduction

Construction Management (CM) student learning styles appear to be changing. In an effort to reach the "new" CM student on a level they relate to CM educators are focusing on technology as a replacement/ surrogate for experience or experiential courses. In addition, teaching methods for CM educators are dependent on course content, level, and perceived relevance to the student, from the student's perspective. Compound the new learning styles with a decrease in construction experience, different work ethics, and increasing numbers of students raised in urban settings and the challenges facing CM educators becomes more daunting and complex. Administrative constraints also play a role in the construction educator's ability to teach effectively. Budget, space, and time constraints frequently impact the resources available at the classroom level and the type of class offered; lecture or lab. All this impacts the introductory CM student at a very important point in their education, the foundational level. For example, in an introductory materials and methods course the loss of a "hands on" lab is a teaching opportunity loss/cost which must be replicated elsewhere in the curriculum delivery process. This opportunity loss may also be perceived as having a negative impact on the student spatial cognitive skill development.

Many of the concepts that are taught in core level CM courses require the student to conceptualize various relationships based on pictorial or written representations. These core classes typically include materials and methods, estimating/ quantity survey, and scheduling. Student understanding of the interactions between these subjects is an important part of the core knowledge required to be successful in a career position after graduation. The less adept students are at conceptualizing and integrating concepts, building systems, and other key components of a project, the more difficulty they may have in courses that build on core/ foundational content areas. The authors see this as an opportunity to capitalize on technology and develop an interactive homework module that uses the technological savvy of the student in a manner that also helps with spatial cognition skill development. The development of new content delivery systems increases the ability of the student to identify the system(s) that reaches them, provides a focus for the student and increases the chances that the student will better understand the course content.

The question of how to better deliver course content with spatial cognition and visualization components is important to CM educators. If these abilities are not fully developed, the visualization challenges facing CM students, particularly those without prior construction experience, will compound and may have lasting negative impacts. If students cannot visualize building system components, spatial relationships of these components as systems, and the relationship to scheduling, they will remain at a competitive disadvantage to their peers. Kolb (1984) provides a theoretical basis for experiential education and defines it as, "learning is the process whereby knowledge is created through the transformation of experience" (p. 38). One of the many benefits associated with experiential education in entry-level CM coursework is the ability to learn how to conceptually think about building system components and how they interact to form a structure

This paper looks at the process one CM program is going through to integrate 3-D models into an interactive homework exercise. Masonry was chosen based on the results of a study pending publication (Porter, Glick, & Smith, 2010) that found a significant increase in student perception of the impact 3-D models had on their understanding of the topic. The literature indicates the teaching of spatial relations has declined over the last 20 years in engineering curriculum requirements (Sorby & Baartmans, 1996). The topic of spatial relations is important in construction education. The spatial ability of students may be impacted as many CM departments have discontinued their experiential lab component to the materials and methods course. As a result students spend more time in a lecture setting which does not offer the same opportunities for spatial visualization practice as were afforded in a lab setting. In many cases the instructors are struggling to replace the lost learning opportunities within the bounds of a lecture format.

In an effort to replicate the experiential learning component of the hands-on lab the authors turned to visualization technology. Current technology supports the development of an interactive homework problem in a user friendly format with little cost. The homework content is masonry; specifically the sequencing of a masonry veneer mock-up wall system from the foundation thru finish. An industry partnership provided a 3-D model of an actual project wall system based on a mock-up. Students are asked a series of questions about the sequencing of masonry construction. If the answer is correct the homework model displays the wall in the correct sequence of construction. The introduction of a 3-D model not only builds on the lecture content, it enhances the student's ability to visualize the various building system components and the spatial relationships that exist between them. The intended result is a greater understanding of the course material without an experiential lab component. The authors have created an interactive homework module to introduce to students in the spring 2011 semester. The implementation of this exploratory teaching method as a replacement for experiential lab sections will provide the basis for students to respond to an end of semester survey about the perceived impacts this teaching method had on their understanding of the content. This will help determine the potential impact 3-D interactive homework may have on the development of student spatial and visualization skills and understanding of course content.

The purpose of this paper is to discuss the process, software, and opportunities available using off the shelf E learning software in CM curriculum. The discussion is important to continue the dialog of how to better reach the CM student in a positive manner. The incorporation of technology into this process is also important to keep both the student and faculty up to date on current trends in the industry. The role of measurement is also important to assess the impacts of different material presentation methods.

Spatial Cognition and Visualization

There is no real consensus in the research on the ability to teach Visuo-spatial ability or enhance it through practice (Lord, 1985). Although Lords study is dated it is one of the seminal works in this field and the outcomes are still valid today. Most of the research is focused on engineering and geography students which may not be a good indicator of the impact such teaching may have on CM students. Deno (1995) suggests that part of the failure rate of first-year engineering students at Ohio State (Heinrich, 1989) is associated with the students' lack of spatial abilities. Deno (1995) further suggests that spatial abilities are integral to the understanding of the physical sciences and critiques the use of 3D models for teaching spatial relationships. Leopold, Gorska, and Sorby (2001) looked at the mental rotation test, the mental cutting test, and the differential aptitude test in engineering programs. Leopold, Gorska, and Sorby (2001) used a pre- and post-test with intervention format in their study which indicated that students with poorly developed spatial skills underperformed in a number of areas.

Olkun (2003) also states that spatial relations are necessary for any field requiring scientific thought and argues that math curriculums in geometry (grades 5-8) neglect teaching 3-D views prohibiting opportunities for improvement. Strong and Smith (2002) identify the area of establishing the effects of computer technology on spatial visualization skills and the subsequent measurement of these skills as an up and coming. All these studies point out the need for good spatial visualization skills in thought oriented subjects. Therefore it is important to foster the CM students' spatial abilities in an effort to increase their understanding of the course content at an early stage in their career.

Methodology

This exploratory homework module development is an effort to help determine, define, and guide possible future 3D model use in CM curriculum, specifically in the form of homework assignments. The development of the homework module is based on the responses of students that were previously exposed to 3-D models in a materials & methods course, the course content is limited to the first nine CSI divisions. The students identified a positive perceived impact on their learning of masonry. The case study methodology is appropriate to gain knowledge into the phenomena of using 3D models in construction education. This can lead to the development of "hypotheses, models, or theories. An exploratory study very much resembles a pilot study; the research design and data collection methods usually are not specified in advance" (Scholz & Tietje, 2002, p 11). The following discussion outlines the steps that were taken to develop this module. The results of this research will not be available until after the spring 2011 semester. The data collection for measuring the perceived impacts of this type of homework module will come from a survey instrument administered to students in two materials and methods course sections. One section will receive the new 3-D homework modules and one group will do the homework assignment the traditional way. Difference in perceptions will be measured using inferential statistics. These initial outcomes will be used to determine the effectiveness of this teaching method from the students perspective and if further development of additional homework assignments is warranted. The true test of the effectiveness of 3-D interactive homework modules will only be known after a longitudinal study is done in the future.

The Development of 3D Interactive Homework Modules

3-D Models

The inclusion of 3D models into the CM curriculum was the topic of a previous study that found a significant impact on the student perception of this information delivery method. The material masonry was specifically identified by students as the area where 3-D models had the most impact on their understanding of material and methods course materials. Based on this finding the decision was made to develop a 3D homework module that focused on masonry. One of the faculty concerns was the seamless integration of the homework into the existing course syllabus while allowing the student to interact with the 3-D software. The 3-D homework delivery method would permit the students to test themselves outside of normal class time. Another concern was the time needed to teach the students the 3-D software and the need for the source program on the student's computer. Taking into account these criteria a review found several E-learning software packages that simulate hands-on computer technology training. In addition many do not require the source software and they typically provide self-administered tests and training sessions. E-learning software allows students to work along with a virtual instructor that demonstrates the controls, functions and features available on exhibited software.

While the use of 3-D computer models has been effective in providing greater understanding of construction materials and methods to CM students, greater student interactivity is a continuing department goal. To this end Adobe's *Captivate 5* was chosen for this project based on the established criteria as well as the availability of on-campus expertise with the program. *Captivate* provided the instrument that combined the presentation of existing 3-D computer models with the additional learning objectives focused on in the 3-D interactive homework assignment. One such goal is to enhance the understanding of masonry construction within the entry level courses. Using a *Sketch-up* model created by Mortenson Construction, the assembly of a brick veneer wall mock-up was chosen to teach masonry construction sequencing. This model is also used to provide specific sequencing instruction to sub-contractors in a real application setting. The overlap of CM and industry education provides a crossover learning outcome for both parties which further enhance the contributions that 3-D models can make to construction education.

The *Sketch-up* model in its original format was somewhat limited. Initially the model was divided into individual frames and exported from *Sketch-Up* and imported into Google *Layout.* This software platform is able to capture screen shots that can be enlarged, rotated and flipped within their frames. *Layout* allowed for the evolving models to be manipulated into the most ideal views for the particular sequence or desired detail. These individual frames were then imported into *Adobe Captivate* along with the entire sequenced video.

An initial design proposal focused on CM students using *Captivate* to arrange *SketchUp* slides showing the correct order of assembly for a complete masonry wall mock-up. After consultation with our on-campus expert, it was determined that while the proposal was possible, a simpler design may provide a greater educational benefit. This simpler design also alleviated the need to teach the students the modeling software prior to the homework exercise. Another benefit was the ability to use one of Captivate's pre-designed work templates. A self-grading test format was chosen for this project to provide immediate feedback to the student and the ability to quickly analyze test scores. Modification to the work template also allowed students to change the construction sequence in an effort to correctly identify the sequence needed to build the wall assembly. When the correct construction sequence is chosen, the program displays the correct construction sequence by activity; i.e. foundation first, stud wall, sheathing, moisture control, masonry veneer, etc. This reinforces the student's choice in a visual manner while the student is viewing the 3-D visual sequencing of the assembly.

The 3-D representation of the masonry mock-up wall consisted of one model divided into several sub-assemblies showing the actual job site evolution of the wall building process. Additionally, individual views were combined into a virtual video of the entire assembly process of the mock-up wall. This sub-assembly format allowed the model to be edited as well as labeling the individual construction sub-assemblies. In addition the ability to rotate the individual slides provided for particular details of the mock-up wall to be displayed. An example of the importance of these features would be horizontal joint reinforcing used to strengthen the mortar joints. Without the ability of the modeling software to rotate the 3-D image, this detail would be lost as it is in a typical architectural elevation view.

Captivate's test template works on a slide format similar to a PowerPoint presentation. Curriculum designers have the option of inserting both audio and visual instructions for the students as well as action activated videos and pop-ups. The audio function was added as a voice-over to the written instructions on the first slide. The written instructions informed the participants that they were viewing a list of components and out of sequence construction steps. Students were then asked to correctly sequence the assembly of a masonry veneer wall system. The initial instructions were supplemented with a 3-D rendering of the completed wall mock-up. This was done to help students visualize the outcome referenced in the written instructions that were given in the first few slides; a skill set that is also needed in the field. Students are allowed several opportunities to select the proper sequence.

Due to a restriction in *Captivate* the number of homework questions allowed on a single slide is 8. This forced the division of the homework into two sections, each consisting of eight separate assembly stages. In each section the students are allowed three chances to arrange the wall construction sequencing in the proper order. In stage one the third failure at sequencing automatically advances the student to section two. Any time the student correctly identifies the construction sequence the completed mock-up wall video is shown. In either outcome the student does get the benefit of the 3D model wall video showing the correct sequence. It is hoped that student engagement in homework assignments will be increased through model use. Upon completion of the homework the student's score is displayed.

There are still several things that need to be considered prior to implementing this type of homework delivery system to ensure there are adequate measurement systems in place to better understand the impacts of this delivery system. The numbers of times the student will be able complete the homework and which grade will be used is an important consideration. Will the first grade be used or will there be an average grade based on the number of attempts? This choice may be dictated by the online delivery system available to the instructor at a particular institution. Building upon student engagement with the model, multiple attempts may yield a greater understanding of the topic. Once these considerations are fully synthesized the homework problem will be placed on the universities inner-campus virtual learning environment. Students will be able to access the homework outside of the classroom and complete it in the prescribed timeframe. *Captivate's* added assessment tools make it possible to automatically display an accumulated score for the student, as well as record and analyze overall class grades from the instructor's vantage. *Captivate's* design should allow CM instructors to add a modeling component to their existing syllabus with limited modifications.

While the use of *Captivate's* design templates helped develop the homework assignment quickly, the software is far from intuitive. Captivate 5 is not a supplement to previous software additions, but rather a complete redesign of the software. Even with experienced support the software changes to *Captivate* proved challenging. The on-line tutorials available for this software assume a level of prior knowledge of previous versions, and are not designed for beginners. The inclusion of the audio portion of the introduction proved challenging and required several adjustments before the entire script could be inserted into the assignment. Some type of formal training would be advisable for those unfamiliar with this software before proceeding with extensive projects.

Once the online homework assignments are implemented the opportunities for study will need to be exploited to measure which choices of presentation yield greater benefits to students. An example would include the choice of one homework attempt or an average of multiple homework attempts. The number of attempts a student tries may also be worth measuring as it may tell us that the learning of the sequence is more important than the actual grade. If this is the case then a student survey could help identify the positive impacts of this type of homework presentation that could lead to further presentation methods being developed.

Models vs. Traditional Documents

Three dimensional models have virtual depth, height, and width, x, y, and z axes. These models can be scaled to meet user preference or requirements. When compared to the typical isometric drawing that represents x, y, and z dimensions on a 2-D plane, the 3-D model can be rotated providing continuous views from any angle. This spatial model can assist in user visualization regardless of the model’s attributes. As long as the model can show and manipulate spatial relationships it enhances user understanding.

Models of all types are used in the construction industry. While full size mock-up walls can be found on many job sites the introduction of 3-D modeling can aid in their design. Typically these mock-ups are used to show detailed connections, relationships of materials, finishes or color schemes, and reinforce the design intent to workers. The primary function of a mock-up is as a reliable means of communication of design information. Although 2-D plans are typically used in the field to communicate, gaps may remain from undisclosed or missing details. While virtual 3-D models lack the physicality of an onsite mock-up, they significantly improve the level of communication over 2-D models.

Building Information Modeling (BIM) use is increasingly becoming the preferred way to communicate information to multiple stakeholders in a visual format accessible to many. BIM is a term first coined by architect Jerry Laiserin to describe 3-D (three dimensional), object-oriented, AEC (architecture, engineering, construction)-specific CAD (computer-aided design) (Davis 2003). BIM is both efficient and visual. Database efficiency allows BIM information to be stored centrally, updated quickly, and accessed by multiple stakeholders; a process that reduces waste. The visual aspect of BIM allows a 3-D model to represent a building based on the information in the database. This visualization allows users, either students or workers in the field, a 3-D image of the project and its components. It is hoped that this visualization will enhance the students’ or workers’ ability to conceptualize and understand the construction concepts they trying to learn. As future construction managers, students will need the skills to effectively manage information and communicate with others.

The object in Figure 1 is the actual plan elevation detail from which the model in Figure 2 is based. The differences in 2-D drawings (Figure 1) and 3-D models (Figure 2) are substantial. The image in Figure 1 cannot be rotated to see a plan or section view as Figure 2 can be. This rotation may provide the student the visual stimulus needed to help develop and hone their spatial visualization skills early in their CM education. The use of 3-D models in industry for clarification is important to ensure that all members of the project team understand the different products and details required in the building. The image in Figure 2 (3-D) can be rotated, enlarged, and made solid, all significant advantages in understanding the relationships of building components and possibly erection sequences.

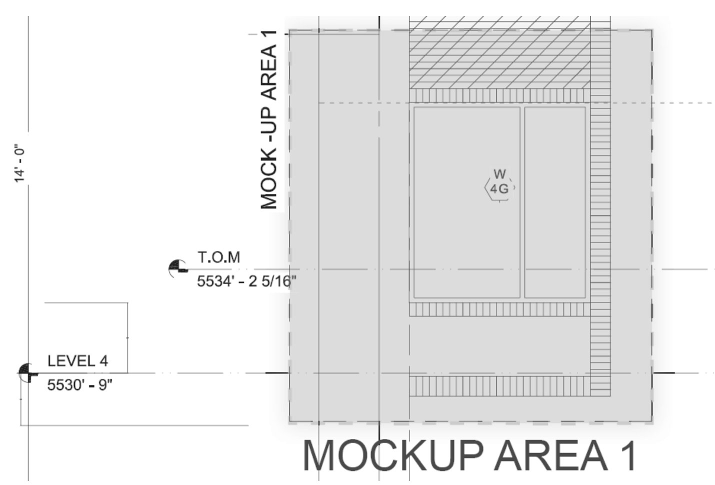

Figure 1: Typical parapet top cap detail (Mortenson Construction)

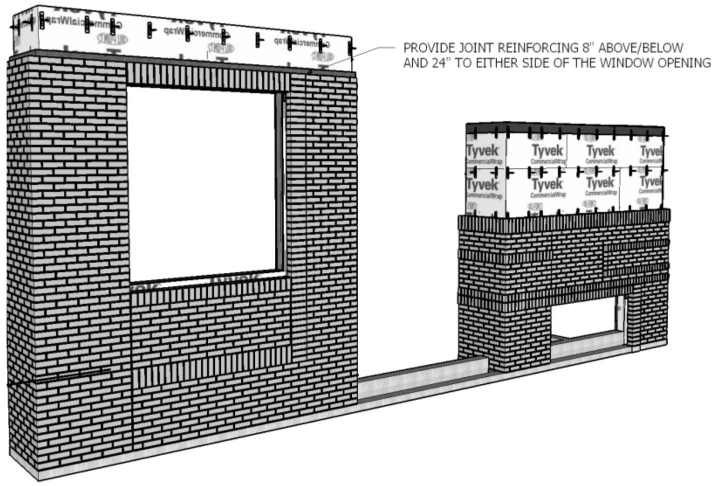

Figure 2: Three-D model of parapet top cap (Mortenson Construction)

Conclusion

The desired outcome of this research is an increased knowledge from the student's perspective evidenced by an improvement in homework grades as the result of adoption of 3-D models. It is further hoped that this improvement will translate into higher test scores and better student foundational knowledge development that will carry forward into advanced level construction courses. The goal of the faculty is to promote the use of mastery learning among the students in the CM program.

According to Davis & Sorrel:

> "…the mastery learning method divides subject matter into units that have predetermined objectives or unit expectations. Students, alone or in groups, work through each unit in an organized fashion. Students must demonstrate mastery on unit exams, typically 80%, before moving on to new material. Students who do not achieve mastery receive remediation through tutoring, peer monitoring, small group discussions, or additional homework. Additional time for learning is prescribed for those requiring remediation. Students continue the cycle of studying and testing until mastery is met" (1995, para. 2).

If students are challenged and become engaged in their education at an early stage the outcome assessments of the students measured by employability should increase. From a CM educator perspective the ability to identify and build on successful course content presentation methods is critical to providing the industry with the best product possible. The ability to team with industry partners allows the lessons learned in both settings to be applied in the other setting as needed. This not only helps improve outcomes of education and industry but encourages a closer collaboration and a better understanding of the role of construction education in our industry.

This study is based on the outcomes of a previous study that introduced 3-D models into a materials and methods classroom. The measurement of the student's perception of the impact of the 3-D models and the focusing of the specific material, masonry, helped to focus the research in this area. In addition, the ability to focus scarce resources on an area where significant impacts are anticipated provides an incentive to strive for increased student understanding of content rich core courses during an economic downturn.

Future research will be driven by the results of this research once completed. Topics may include longitudinal studies of a group of students throughout their entire program to better understand the long term implications, if any, of the use of 3-D models in construction education. The involvement of industry partners may also provide research opportunities focusing on improvements in the trades resulting in increased productivity and material savings.

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