System Component Visualization: The Role of 3D Models in Construction Management Education

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A need exists within construction management education to teach students spatial and visualization skills. Three Dimensional models, typically constructed using Building Information Modeling software, present an opportunity to facilitate such learning. As hands-on lab courses are eliminated from construction management programs for budget, time, and space reasons, students lose the benefit of an experiential educational process. For students with little or no experience in the construction field this creates a significant void in educational preparation. A student without ability to visualize components and systems in construction processes are at a distinct disadvantage to their peers with construction experience and/or spatial cognition skills. This paper describes one construction management department's exploratory effort to evaluate the contribution that 3D models can make to student's educational experience in entry-level core classes. The goal is to document and compare perceptions of students exposed to 3D models throughout the semester to those exposed to 3D models at the end of the semester to gauge the potential impact these models have on their understanding of course materials. We will use the exploratory findings to direct future graduate research if warranted by the students' perceptions.

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

Introduction

Teaching methods for construction management (CM) educators are highly dependent on course level, course content, and student construction knowledge. As more students enter the field of CM without firsthand experience or exposure to construction, construction trades, or building delivery, the challenges facing CM educators become more daunting and complex. Challenges are exacerbated by budget, space, and time constraints, and hands-on classes or lab sections are frequently the first to fall victim to such pressures. Unfortunately, they are also typically where CM students first learn construction concepts through experiential education. In introductory materials and methods coursework, loss of exposure to spatial relationships between building components experientially through hands-on lab exercises, represents a significant deficiency. The loss of the spatial cognition and visualization skills poses a challenge to both teacher and student.

Many of the concepts that are taught in materials and methods, estimating, and scheduling courses require the student to visualize relationships in order to understand how systems work and integrate with one another. The absence of experiential learning in the lab settings poses not only a problem but creates an opportunity for educators. Increasingly, they are called to experiment on ways to increase the students' learning level and understanding without access to physical examples. In an effort to reach as many students as possible, teachers may present course material using multiple formats including Power Points, lecture, reading assignments, outside speakers, handouts, videos, slide shows, mock-up models, field trips, in-class assignments, out-of-class group assignments, lab sections, and, where applicable or available, bringing samples to class. Such an assortment of teaching methods may, in fact, increase the variety of instruction methods since different students have different learning styles and, therefore, may benefit from different instructional methods.

With or without access to experiential labs, the question of how to better deliver course content with spatial cognition and visualization components should be a constant priority for construction management programs. 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.

Kold (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). Of the many benefits associated with experiential education in entry-level CM coursework, the ability to learn how to conceptually think about building system components and how they interact to form a structure may be the most important skills for success. While a lack of construction experience can persist throughout all levels of CM coursework, it is most likely to occur in the entry-level courses where CM students may be exposed for the first time to concepts like rebar overlap, compression and tension, modulus of elasticity, and a variety of other terminology. If the student is not able to grasp these concepts at the core level, the learning curve they will face in subsequent courses will steepen and in some cases be insurmountable.

This paper looks at the process one CM program is going through in order to address the deficiency in spatial visualization skills in the student population. The literature shows that the teaching of spatial relations has declined over the last 20 years due to changes in engineering curriculum requirements (Sorby & Baartmans, 1996). This phenomenon, if accurate, may have implications for construction educators as well as their students' ability to comprehend topics dealing with spatial relationships. Such challenges have been compounded in the CM department due to discontinuation of the experiential lab component to the materials and methods course. While the course content may have survived, the experiential learning component was lost and course instructors have continued to struggle with how to replace the lost learning opportunities within the bounds of a lecture format.

In an effort to replace the experiential learning component of the hands-on lab with something providing a similar experience, the authors turned to visualization technology to address this concern. Students are asked if the introduction of 3D models into the lecture materials enhance their, the students', ability to visualize the various building system components and the spatial relationships that exist between them thereby increasing the students understanding of the course material. To answer this question, the authors are in the process of conducting an exploratory case study during the fall 2009 semester. The goal of the exploratory case study is to ascertain the effectiveness of using 3D models as a replacement for experiential educational lab experiences and as a teaching method to develop the student spatial and visualization skills. If the initial study shows promise, additional research will be conducted over the next two years by a graduate student in an effort to better understand the impacts of 3D models and their role in construction education.

Background of Spatial Cognition and Visualization

Recognizing the value of spatial skill and ability is not specific to construction management. Studies from the 1930s looked at the spatial abilities based on gender, the effects of socioeconomic class, ethnicity, and race. These studies were used as predictors of performance for the military, college, and industry. The jobs requiring the highest levels of spatial ability included engineering, science, drafting, and design. They identified spatial abilities in males as being higher than those of females following childhood (McGee, 1979). The gender issue as it was perceived in the 1930s may not reflect or have any bearing on the current student in construction management.

Research surrounding issues of spatial ability is not in agreement on whether visuo-spatial ability can be taught or enhanced through practice (Lord, 2006). Research to date regarding the use of 3D models in the classroom primarily targets engineering and geography 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 and the fact that this causes frustration in coursework which leads to dropping out of the program. Deno (1995) further suggests that spatial abilities are necessary for the understanding of the physical sciences and discusses the use of 3D models in an effort to teach spatial relationships to students. Leopold, Gorska, and Sorby (2001) looked at the role of spatial relations in an engineering curriculum. The instruments they used include the mental rotation test, the mental cutting test, and the differential aptitude test. Spatial relations are used to determine the spatial capabilities of introductory engineering students. They also noted that gender plays a significant role in spatial ability. The test methodology included the use of a pre- and post-test with intervention and was given in three universities. Leopold, Gorska, and Sorby (2001) results indicated that students with poorly developed spatial skills had a hard time performing a variety of spatial tasks.

Another study noted that 85% of people learn by sight and that visualization skills are needed to enhance this method of learning in physical sciences like engineering (Sorby & Baartmans, 1996). This study also observed that academic requirements for graphics understanding have continued to decrease while changes in technology have actually increased the demand for improved spatial cognition. The authors concluded that personal background and life experiences were highly correlated with a students' spatial abilities (Sorby & Baartmans, 1996). The decline in experiential education opportunities in the education process necessitates the need to replace these experiences with a suitable tool to help in the development of spatial and visualization skills. Mcgee (1979) defines spatial visualization as "the ability to mentally manipulate, rotate, twist, or invert pictorially presented stimuli" (p. 893).

Spatial aptitude was tested by Braukman and Pedras (1993) using quasi-experimental and correlation methodology to look at students' test scores using 2D and 3D models to increase spatial visualization skills. They found no significant difference, but noted that spatial skills were a good predictor of problem-solving abilities. 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 3D views and, therefore, do not provide opportunities for spatial 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 research area although the role of gender, age, and experience have more impact on spatial ability. One of the common elements of these studies is the need for good spatial visualization skills in subjects that require scientific thought processes. The similarities between construction management, engineering, math and other technical fields support the need to foster the CM students' spatial abilities in an effort to enhance their CM education in the absence of experiential education opportunities.

The Need to Study 3D Model use in Construction Management Curriculum

3D Models

Three dimensional models can be characterized in different ways. They have virtual depth, height, and width, x, y, and z axes that can be scaled according to user preference and requirements. While similar to an isometric (ISO) drawing that represents x, y, and z dimensions on a two-dimensional plane, a three-dimensional model has additional capacity to be rotated and expose multiple, continuous views. Regardless of the model's attributes, it is the ability of the model to show and manipulate spatial relationships that is essential. In short, a spatial model can assist a user to visualize an object.

Models, virtual and physical, are used in construction on a regular basis to illustrate a concept, explain a detail, or support a presentation. One of the more common uses of models is the mock-up wall(s) on the construction site. These are used to show the detail of connections, spatial relationships of materials, present the finishes or color schemes, and show design intent to the persons working in the field; in short, the primary function of a mock-up is to serve as a reliable and documented means of communication of design information. While 2D plans are also typically used on the job site to communicate, gaps remain due to undisclosed or missing details resulting from the limited number of views available. While virtual 3D models lack the physicality of physical mock-ups, they significantly improve the level of communication over 2D models. In addition, they have the benefit over physical models of being easily modifiable.

Building Information Modeling (BIM) recently has gained considerable attention as a valuable 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 3D (three dimensional), object-oriented, AEC (architecture, engineering, construction)-specific CAD (computer-aided design) (Davis 2003) (parenthesis added for clarification). There are two simple ideas at the core of BIM. The first is database efficiency. The goal for BIM is to allow information to be stored centrally, updated quickly, and accessed by multiple stakeholders. This reduces waste by reducing redundancy of tasks and documentation. The second advantage of BIM, and its importance to this study, is visualization. All BIM programs can represent a building with a 3D model. This visualization affords students in a given educational setting a 3D image of the project and its components. It is hoped that this visualization will enhance the students' ability to conceptualize, digest, and understand the construction concepts they are being taught. We hypothesize that the introduction of 3D BIMs in the classroom will increase the spatial abilities of students both with and without construction experience, as well as help students transition into the computer-driven world of construction management. As construction managers, students will need the skills to effectively manage information and communicate with others.

Models vs. Traditional Documents

The difference in 2D drawings (Figure 1) and 3D models (Figure 2) supports the thought that these models will help CM students develop and hone their spatial visualization skills early in their CM education. The impact this could have on the students will carry through to the industry that hires them. The image in Figure 1 is from the plan and is stationary while the image in Figure 2 (3D) can be rotated, enlarged, and made solid, all significant advantages.

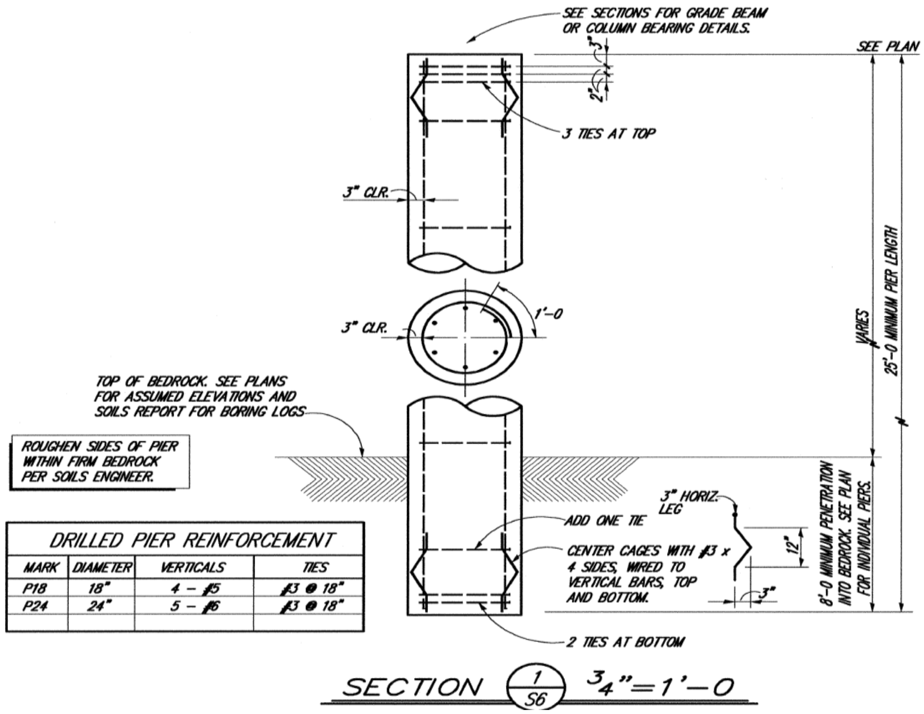

Figure 1: Typical section of a drilled pier with rebar cage and standoffs

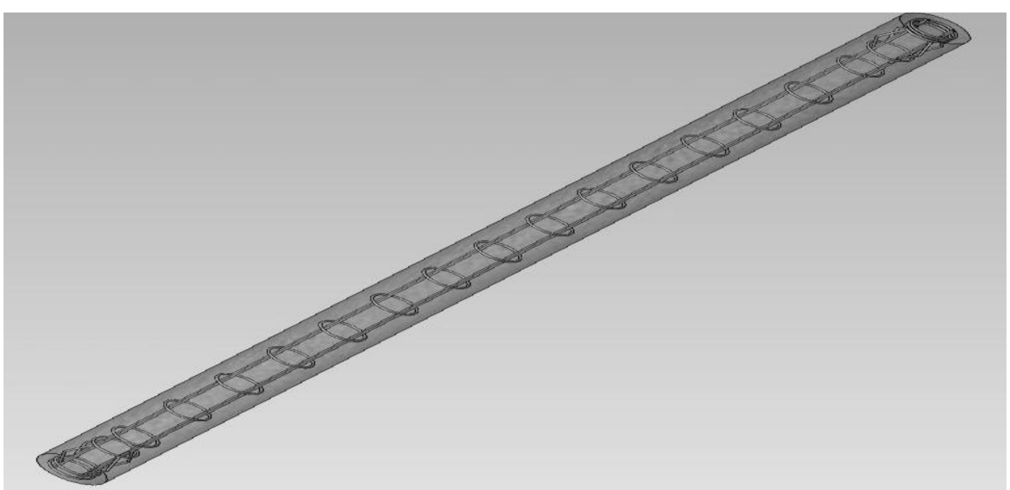

Figure 2: Three D model of pier and rebar cage as shown in Figure 1

Methodology

This exploratory case study is an effort to help determine, define, and guide possible future research in using 3D models in construction management curriculum. This 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 actual findings from this preliminary research were not available as of this writing. The following discussion is the approach to gathering preliminary data for possible direction of additional graduate work and study design.

Course Redesign Using 3D Models, Phase One

Phase one of the course redesign is the introduction of 3D models into the lectures of the Materials and Methods course. This 100-level three-hour course, with no prerequisites, was chosen since it had a lab portion prior to the fall of 2006. The elimination of wall section construction, form construction, concrete pouring, roofing, and interior and exterior finishes were observed by instructors to have had a negative impact on students' ability to learn based on student comments, and questions asked or not asked. Students are comprised of freshmen and a few upper classmen, transfers, or change of major. Teaching and communication methods in use prior to the introduction of the 3D models include written words, 2D pictorial presentations, and photographs. Instructor intuition is that the use of 3D models will serve to counteract the loss of laboratory learning. It should be noted that the time spent in class equated to about 15 minutes per 3D model concept which is shorter than the 1 hour and 40-minute lab sections.

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).

The goal of introducing 3D models is to improve CM student ability to visualize spatial relationships and solve problems. Block (1971) surmises that mastery learning techniques help students with limited prior knowledge of a subject achieve a higher level of understanding than other traditional teaching methods. Unfortunately, the ability to achieve 80% or better test scores prior to moving students forward is not an option, but the goal should be to provide students with the greatest opportunity for success possible given the constraints faced in the classroom environment.

The choice of which models to introduce to the Material and Methods class was based on a review of the material previously covered in the lab portion of the course. The next step was to review the textbook for pictures that related to the topics of interest so models could be built in conjunction with these 2D pictures. By building on text pictures of systems or components, context was provided for the models, creating an opportunity for the students to see the same concept in two different forms. Allowing the students to see material in two formats would allow students to compare presentation methods at the end of the semester.

Phase One Study Format

The Materials and Methods course is taught in three sections that meet three days a week for 50 minutes each meeting. The students are assigned class readings ahead of time and have access to the instructor's baseline presentation online as well. Baseline means that the 3D slides are not included in the presentation. Coded references to the 3D models are included so the instructor knows where to insert them as appropriate. There are two instructors for this course. One teaches two sections and the other teaches one section. To control for teacher effect, the teacher with the two sections of the class is showing the 3D slides to one section and not to the other; everything else about the lectures is identical. At the end of the semester, a questionnaire will be administered to the students to gain feedback about the effectiveness of the various teaching methods used in the course. Both questionnaires solicit feedback on the use of 3D models but from different perspectives to account for the fact that one section of the students did not see them and one did. The students did not have access to the 3D slides outside of class to ensure that the sections did not share the 3D presentations.

The formation of the questionnaires was based on the literature and incorporated the most commonly identified attributes that have been shown to affect spatial cognition. The following is a list of the questions the students will be asked to respond to at the end of the semester. The questions are based on the main concepts that were identified in the review of the literature.

- Which method of course material presentation best suited your learning style? List of material provided.
- What is your level of construction field experience? Scale given.
- What is your college major? Two options listed and "other" category.
- Please identify your childhood interests. Three options and room for a list up to six.
- Identify members of your family in the construction industry. Close relatives listed and space for "other."
- Rank the divisions in order of difficulty for you to learn. List four and Likert scale measurement.
- Rank the order of the available class resources on your learning/understanding of the subject matter. List all resources and Likert scale measurement.
- What is your age?
- What type of setting were you raised in? Choices: rural or urban?
- Identify the level of impact you think the use of 3D models would have on your understanding of complex course materials. Likert scale-type rank (both groups of students)
- Out of the 3D models you just viewed, rank in order your perceived impact on your learning/understanding of each division listed below. Rank order measurement (for the students that did not view the 3D models during lecture).
- Rank the impact on your learning/understanding of 3D simulation models by division. Rank order measurement.

The students in the section that did not see the 3D models during the semester will get to see them prior to filling out the questionnaire so they can comment on the perceived impact they would have on their education, if they had access to them.

The choice to divide the students into two groups under the same instructor provides a control group from which to measure perceived impact of the 3D models during the semester and at the end of the semester. If the feedback from the students supports the initial intent of using 3D models for spatial and visualization development, then they will be made available to the students as part of the downloadable material in the spring. This will provide more information from students for future research and possible adoption in other core courses.

Course Redesign Using 3D Models, Phase Two

After Phase One of the course redesign is complete, a "BIM Thread" will be developed and integrated into additional Construction Management coursework. Specifically, this thread will consist of stand-alone teaching modules to be developed in conjunction with industry leaders. The modules will be 2-3 class periods in duration and include an accompanying assignment. The modules will use BIM as a software tool both to demonstrate state-of-the-art construction practices, and to leverage BIM's 3D visualization capabilities to illustrate class concepts. This will build on Phase One, where the value of 3D software capabilities to aid experiential learning is expected to be supported.

An important distinction exists between the introduction of 3D models into the classroom and the introduction of BIM processes. When an instructor shows a 3D model, the model itself is complete. As previously discussed, it serves as a complementary and robust form of illustration. A BIM process, on the other hand, is not static, but is a collaborative and function process. While a viewer interacts with a 3D model by panning or rotating the model, promoting a level of spatial understanding not possible from 2D drawings, the representation or model itself does not change. BIM when shown to students as a function process requires dynamic change and development.

Applying BIM in the classroom, therefore, may require a higher level of sophistication and commitment from the instructor. This may potentially be the biggest hurdle to the introduction of BIM into the classroom.

To date, the creation and adoption of 3D models into the classroom as teaching tools represent significant work on the part of the educators. The development of an illustrative exercise using BIM, along with accompanying student homework represents a huge undertaking for someone not well-versed in BIM software. Educators in the field of Construction Management, as in many others, are already stretched thin. For this reason, a core component of Phase Two of the course redesign involves industry participation. Professionals, who use these softwares everyday, have a distinct advantage over educators in their level of proficiency. Phase Two calls them into the classroom to develop and deliver the 2-3 day stand-alone teaching modules. This is a win-win-win for the educators, the professionals, and the students. The educators benefit because the course is enriched using state-of-the-art illustration. Professionals benefit because they get to highlight their company's capabilities before students and potential recruits. Finally, students benefit by learning emerging and innovative technologies from the experts. Initial discussions with industry about using BIM in the classroom have been met with significant enthusiasm and interest. The plan is to form a task force consisting of faculty, industry leaders, and perhaps a few interested students to oversee the development and implementation of these teaching modules. Pilot applications and students' feedback will be tracked in a similar manner to Phase One.

Funding Course Redesign

The redesign of this course was made possible by an internal grant competition process within the University system. This grant funded a graduate student to learn the modeling software along with the faculty members of the research group. In addition the graduate student is pursuing this topic for a master's thesis and potentially PhD dissertation work as well. Without the funding awarded through the internal grant process, this course redesign would be much harder due to the time commitments to learn software, create models, and integrate them into a course presentation format. Additional time requirements were needed to develop the survey instrument and get approval from the institutional research board. Once the surveys are administered, the results will need to be analyzed to determine the future course of research on this topic.

Additional funding will be sought to cover remaining expenses, and to fund the start of Phase Two. Significant opportunities exist to turn such course development into a forum for collaboration with industry. It is hoped that industry will be interested in funding some of the course development for Phase Two of the research if it appears to be a viable topic.

Conclusion

The desired outcome of this research would be a scenario where significant grade improvement is observed as the result of adoption of 3D models. The goal is to engage and challenge the students to become involved early in their education by providing multiple presentation methods of course materials in a manner that interests them and provides a personal understanding element to their education. We hope to continue to encourage drive and commitment to their education by introducing BIM and 3D models throughout their coursework. Quite often we hear from students after they come back from their internships that they wished they had been more serious about coursework in their first 2-3 years of school. Another outcome would be a case where the students get so involved in learning 3D modeling software that they learn the subject matter, despite themselves. The first day the 3D models were presented in class, several students commented that they wanted to learn how to make them, a hopeful indicator that this high-tech approach to spatial visualization will have an impact on CM students and their learning methods.

From the future employer perspective, students that have well-developed spatial and visualization skills tend to be better problem solvers. The addition of a technically proficient employee that can problem-solve is highly desirable from the employer perspective. As the construction industry becomes more competitive and technology dominates building systems, the need for these types of employees will grow. The addition of a teaching method that may simulate experiential education will also impact employers' ongoing efforts in quality control, safety, jobsite management, and productivity.

Future research will be directed by the results of this investigative study. If the results from Phase One indicate that the use of 3D models helped students learn to visualize components and spatial relations of system components, we will work with industry and begin to integrate Phase Two teaching modules into the curriculum. Similar to Phase One, we hope to set up a control to measure and evaluate the impact of these changes on student learning. We hope to be able to perform follow-up studies to see the type of impact the course development has on students when they enter the workplace.

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