Using BIM Scheduling Simulations (4D) in an Undergraduate Construction Management Course to Assess "Means and Methods" Knowledge

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Abstract

There is a need within the undergraduate construction management curriculum for students to have a solid understanding of the "means and methods" of construction projects. Building Information Modeling (BIM) allows construcion teams to visualize the overall construction process. Furthermore, the 4D modeling aspects of BIM, which implements the element of time, presents a valuable opportunity to better teach construction scheduling to undergraduate students. This case study created a 4D modeling (schedule simulation) assignment in an undergraduate construction management scheduling course. This assignment was used to assess the students knowledge of "means and methods" of a construction project. The results from this case study demonstrated that this schedule simulation assignment was an effective assessment tool. Additionally, this case study provided a resource for implementing a 4D modeling in future construction scheduling courses.

Keywords

Construction management, 4D modeling, schedule simulations, education.

1. INTRODUCTION

Construction scheduling is a fundamental skill in construction management. Students in undergraduate construction management programs often struggle, not with the general concepts of scheduling, but with the application of these concepts to actual construction projects. Construction scheduling is often taught in a traditional classroom setting where students are not typically provided the opportunity to see and learn the actual procedures and processes involved in completing a construction project. This case study explored the use of BIM to teach and assess students' knowledge of the "means and methods" of a simple construction project.

2. BIM AND CONSTRUCTION SCHEDULING

The American Council for Construction Education lists construction scheduling as one of the key educational objectives for undergraduate construction management programs (ACCE 2009). Additionally, accurate knowledge of construction "means and methods" is a key skill required to plan, develop, and manage a project schedule (AACEI 2006). However, students often struggle

with the concepts for scheduling a construction project because of a lack of knowledge of the process of construction (Jenkins 2000). The result is that students focus on properly sequencing construction activities rather than the key concepts of scheduling.

2.1 Teaching "Means and Methods"

The terminology "means and methods" is generally used to describe the contractor's responsibility for executing the project. Typical construction contracts state that the "Contractor shall be solely responsible for, and have control over, construction means, methods, techniques, sequences and procedures and for coordinating all portions of the Work" unless stated otherwise in the contract documents (America Institute of Architects 2007). Thus, construction managers are expected to know these "means and methods" not only for scheduling purposes, but also because they actually manage these procedures and processes in the field.

However, learning and understanding the "means and methods" to complete a specific construction activity often takes field experience. This lack of field experience by most undergraduate students complicates the scheduling process. Additionally, most students are asked to create a construction schedule based upon a set of construction drawings. Previous experiments have shown that "the traditional use of 2D drawings to create a CPM limits the students' ability to understand the construction process" (Messner 2003). Therefore, there are two specific questions that need to be addressed for undergraduate students to adequately learn the specific "means and methods" to schedule a construction project:

1. How can construction management educators overcome the lack of field experience so that students can better *learn* the construction process?
2. How can construction management educators use actual construction project documents without using traditional 2D drawings so that students can better *understand* the construction process?

The increased use of Building Information Modeling (BIM) in the construction industry and in construction management education provides interesting opportunities to accomplish both of these goals simultaneously.

2.2 BIM in the Construction Industry

BIM is growing fastest among construction managers and contractors. The most recent McGraw-Hill Smart Market Report found that "71% of contractors report positive results with the use of BIM". Additionally, the report states "contractors see many of the most obvious and dramatic benefits of BIM." Finally, the report showed that contractors are adopting and using BIM faster than any other group in the industry, increasing to 50% in 2009 from 13% in 2007 (Young et al. 2009). Because of this growth contractors are looking more and more for undergraduate construction management programs to produce graduates with the knowledge and skills to use BIM on projects.

A study of the construction industry's expectation of construction management graduates' BIM skills found that using BIM for "constructability" and "visualization" were in the most demand. This study also found that about half of the respondent firms currently used BIM for 4D modeling (Mojtaba 2010). The term 4D modeling refers to the addition of the time element to the 3D model established in BIM. Typically a 4D model creates a schedule simulation that can be used by the project team. The 4D modeling aspects of BIM allow project teams to visualize construction plans, identify construction sequences, and improve communication within the team (Koo

2000). These benefits of 4D modeling greatly increase the construction manager's ability to plan and schedule a construction project.

2.3 BIM in Construction Management Education

This increase in demand for students with BIM knowledge and skills has led to the implementation of BIM within various aspects of undergraduate construction management curriculum. Some programs opted to offer full courses in BIM. Other programs implement BIM as a portion of existing courses. One instructor used BIM in a course to teach productivity. Ultimately, the instructor noted that use of BIM in teaching productivity analysis found that "BIM was most beneficial for visualizing the overall project and seeing the construction sequences." (Gier 2006)

Perhaps the best recommendation by one of the educational adopters is summarized by their statement that they "do not advocate a silver bullet course to add to an already packed curriculum, but rather promote the use of BIM as a means of better integrating a construction curriculum" (Taylor 2008). This approach of integrating BIM into the existing curriculum seems like an approach that is well suited for construction management programs since it matches the way that most construction professionals are using BIM on projects.

Despite the increasing demand in the industry, inclusion into undergraduate construction management curriculum has been slow. A recent study of 45 institutions affiliated with the Associated Schools of Construction found that "BIM is currently being addressed in only about 10% of undergraduate programs". The study noted the following barriers for inclusion in courses: (a) no room for new courses in existing curriculum (82%); (b) Faculty time and resources required to develop new courses (86.7%); and (c) Lack of textbooks and other educational resources for students (53.3%) (Sabongi 2009). This final factor is the most significant hurdle for adding BIM topics into existing courses.

2.4 BIM as a Tool to Teach Construction Scheduling

Many experiments have been conducted on using 4D modeling and schedule simulations in higher education. One such experiment found that "4D model when combined with a schedule offers a clear picture of construction processes and its duration." Interestingly, the researcher also states that the interest of gaming animation by today's younger generation would "develop a lot of interest … and will motivate them to try to better understand and retain important concepts of construction" by using schedule simulations in class. Ultimately, these simulations also "lead to a better understanding of the construction processes and to help identify any problems or issues that might occur during the actual construction." (Haque 2007)

Despite the many experiments demonstrating the positive uses of BIM, there remain few resources for implementing BIM into undergraduate construction scheduling education in a manner that is easily repeated on a wide scale basis. Most experiments used high-end virtual reality systems that are not available to most educational institutions (Messner 2003). Additionally, the lack of interoperability of BIM software systems remains a key barrier for adoption across the industry and within education settings (Young et al. 2009).

3. CASE STUDY

The basis of this case study was to create an assignment that allowed students to use BIM to demonstrate their knowledge of the "means and methods" of a simple construction project. In previous courses, this exercise was a team assignment that utilized an existing scheduling simulation. However, this new assignment would have individual student actually create the schedul-

ing simulation to demonstrate their knowledge of the overall construction process of the project. The addition of construction management courses in an intersession provided a unique opportunity to add this BIM 4D scheduling assignment and test it on a smaller group of students.

There were five main goals of this case study:

1. Develop a process for selecting a project that provided adequate complexity to teach various "means and methods", but simple enough that a minimal number of construction activities would be used in the schedule.
2. Implement this project throughout the course curriculum so that students would have a good knowledge of the construction project prior to the final assignment.
3. Identify the BIM software that was best suited for creating 4D simulations in undergraduate construction management education.
4. Create a "schedule simulation" assignment that would require students to understand the overall construction process of the project.
5. Create a "schedule simulation" assignment that was easily repeated for future classes.

3.1 Pedagogical Model

A problem based learning model was used throughout this course. The students were tasked with creating various levels of schedules for a "real" construction project. The same construction project was used throughout the term in order to allow the students to gain an understanding of the project in greater detail. Additionally, because of the "real" nature of the project, students were challenged to discover creative ways to solve the problems that actually existed in the project.

3.2 Alignment of Course

The course was aligned such that each assignment would build upon the previous assignment. The students first created a "milestone schedule" for the project. Students then created multiple CPM schedules for various phases and ultimately for the overall project. Each new assignment added more complexity and detail. This process also provided a method to focus on various "means and methods" specific to the project.

The assigned project was the construction of the core and shell of a two-story medical office building. The building was a steel and precast concrete structure with numerous exterior architectural features. Most notable was a glazed curtain wall system on the entire south side of the building, which added some complexity for sequencing the overall project.

3.3 Framework of Assignment

The basis of the assignment was to create a 4D model or schedule simulation by utilizing the construction schedule established in the previous exercises. The student would then be able to visualize the construction schedule as they had developed it. The use of schedule simulation to identify potential schedule errors has been demonstrated as a highly effective learning tool in previous experiments (Messner 2003). Also, the schedule simulation had the potential to make "the learning activity more interactive by allowing students to review and critique different solutions" (Wang 2007).

In the previous assignment, the students were provided 30 construction activities for the project. The students were tasked with creating a CPM schedule for these activities based upon the 2D drawings and specifications provided. The CPM was assessed based upon the calculations of the CPM schedule and if any significant logical errors were made. However, several minor logical

errors were not identified during this assessment so that the students would have the opportunity to “catch” these errors in the schedule simulation assignment.

The software selected for this assignment was the 2010 version of Autodesk Navisworks. This software was selected for two reasons. First, the software provided a platform to easily import a Microsoft Project schedule and link it to a model. Second, the software was available for students to download for free. The software was also provided in the university student computer lab for activities in and out of the classroom setting.

An Autodesk Navisworks 2010 model of the project was provided to the students. The model was a modified version of the actual project model in order to simplify the assignment. The students were then walked through an exercise that demonstrated how to import a schedule (Microsoft Project), link the schedule to the model, run a schedule simulation, and export the simulation to a movie file (.avi). Upon completion of this exercise in class, students were tasked with linking their schedule from the previous assignment to the model of the project. The students were told that the schedule simulation would be assessed based upon the following factors:

- Creation and submission of the schedule simulation movie (.avi)
- All construction activities were “linked” to elements within the model
- Identification of any changes that were or would be made in the sequence

Students were not required to make changes to their schedule simulation, but were asked to identify any errors and logic and provide a solution for the errors.

3.4 Learning Objectives

The learning objectives for this assignment were: (1) to demonstrate the knowledge of the “means and methods” required to build a small project by creating a schedule simulation and (2) to demonstrate the ability to use BIM for schedule visualization.

4. RESULTS FROM ASSESSMENTS

Several direct and indirect assessment methods were used for this assignment and for this class.

4.1 Direct Assessments

The direct assessment for this assignment entailed reviewing the schedule simulation for accuracy. There were approximately 50 BIM elements that could be linked to 30 activities in the schedule created in an earlier assignment. Each schedule simulation was grade on completeness and accuracy.

An average grade of 86% was achieved for the BIM exercise. Only one student was unable to fully complete the assignment and submit the proper file. All other students successfully linked the construction activities with the elements in the model. These students were also able to identify nearly all of their previously missed logical errors in the schedule. The most common logical errors that were continually missed in the schedule simulation were: (i) not linking all of the slabs to the schedule, (ii) installing curtain walls prior the roof, and (iii) not installing the parapet walls prior the roof.

The informal feedback after the assignment was generally positive. Students enjoyed learning BIM and many thought that it was the best class period of the term. Most importantly, many of the students were excited to learn more about BIM. Several students stated that they would have liked to work with the original project model, which was much more complex than the model utilized in the assignment.

4.2 Indirect Assessments

A survey was conducted at the completion of the course in order to gage the students' perceptions of the course and of the BIM assignment. Here are the most significant findings:

- 71% Strongly Agreed and 29% Agreed with the statement: "I better understand construction 'means and methods' after taking this course"
- Only 14% selected the BIM assignment as most beneficial in understanding construction "means and methods" (Individual Report was the highest at 43%)
- 57% selected the BIM assignment as most beneficial in being able to visualize the construction process (Field Trips were next with 14%)

Here are some comments that were provided in conjunction with this survey:

- "BIM was the most helpful"
- "I believed the field trips were beneficial"
- "The field trips were extremely important when it came to seeing the actual application of the schedule and learning how changes affect it."

4.3 Lessons Learned and Recommendations

Several key lessons learned were discovered through this case study. These lessons learned are summarized in reference to the five goals established for the case study.

The first goal was to develop a process for selecting an appropriate project for the course. The project selected for this assignment provided a good balance of simplicity (core and shell only) and complexity (several exterior architectural features). The most challenging aspect was to keep the model as simple as possible without sacrificing realism. Linking the schedule to the model can become very tedious when there are several hundred elements in the model. Searching for elements can become very time consuming. One lesson learned was to hide any elements that are unnecessary for the assignment. Another important lesson learned was to work with the model prior to assigning it to the class.

The second goal was to implement this project throughout the course. This was easily attained by structuring the course in such a manner that each assignment built upon the previous assignment. Although easy to attain, this took a considerable amount of time to ensure that each assignment adequately met the learning objectives of the course. Furthermore, ensuring these assignments provided an avenue to learn the "means and methods" necessary to adequately create the schedule simulation provided a unique challenge. In the end, the additional effort of structuring all assignment provided students with a firm foundation for creating the schedule simulations.

The third goal was to select the BIM software best suited for this course. As stated previously, the 2010 version of Autodesk Navisworks was selected because of its availability and ease of use. One recommendation is to ensure that all available software is reviewed for application within a course. There may be other software that better meets the needs of a specific project and course.

The final goals were related to the schedule simulation assignment. There were a couple of lessons learned for the assignment. The first was to better align the number of elements in the model with the number of activities and use this as a method to assess the students' knowledge. For instance, the steel column activity should be linked to all 24 steel columns in the model. This

method could better "quantify" the knowledge of construction sequencing and provide more detailed feedback in the assessment.

The other lesson learned was to not overestimate the time that it would take to walk through the initial exercise. These students were very tech-savvy and easily learned the software. Autodesk Navisworks 2010 is surprisingly user friendly for schedule simulations and nearly every student was able to link the activities to the elements within 15 minutes. (The initial exercise has been planned for approximately 45 minutes.)

5. CONCLUSIONS

Overall the inclusion of BIM assignment in the re-structured construction scheduling course was successful. All of the goals for the case study were met. Specifically, the goal of creating a 4D modeling assignment to assess students "means and methods" knowledge was adequately met. Additionally, the student thoroughly enjoyed the assignment and work with BIM. Additionally, the schedule simulation was extremely successful in allowing the students to visualize the construction process. The schedule simulation exercise proved to be an effective tool for achieving the learning objects established for this assignment. This case study also provided a resource for implementing the 4D modeling aspects of BIM in future scheduling courses. The development of this assignment provides an example of a way to add BIM into the construction management curriculum in a meaningful and efficient manner.

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