

BIM, 4D Scheduling, Active Learning, & Industry Collaboration: Filling the CM Program Void

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Building Information Modeling (BIM) is gaining mainstream acceptance in the construction industry. Construction Management educators at Central Washington University have struggled to successfully implement BIM into the curriculum. However, the construction of the $37 million concrete frame building on the university's campus and the aid of an industry partner provided an outstanding opportunity for the students in the Construction Management program to develop their BIM knowledge. The industry partner aiding this effort is contracted to construct the building and developed a BIM for their own project management efforts. The faculty and the industry partner created an active learning BIM workshop and provided the students with the knowledge and skills to manipulate an existing BIM and create a 4D schedule using NAVISWORKS. Students were teamed together and tasked with creating a 4D schedule for the concrete forming, re-steel, placing, and finishing of the building. The teams presented their plans to the industry partner and their fellow students and were evaluated accordingly. Upon completion of the presentations, the industry partner presented his schedule giving students time to reflect on their respective approaches. The active learning opportunities and outcomes of creating and implementing a BIM workshop are presented.

Key Words: Building Information Modeling, 4D Scheduling, Industry Collaboration

Introduction

Over the past decade, the adoption of building information modeling (BIM) in the construction industry has grown to a level of mainstream acceptance and application. The industry has indeed progressed past the "bleeding edge" stage of early adopters. Widespread use of BIM for both medium and large sized construction firms is common. According to McGraw-Hill Construction (2013), the percentage of companies using BIM jumped from 17% in 2007, to 49% in 2009, to 71% in 2012. Additionally, in contrast to the typical cautious, resistant-to-change demeanor of the construction industry, for the first time, more contractors (74%) than architects (70%) are using BIM (Davis, 2004). A major challenge now facing the construction industry is finding talented people, capable of utilizing BIM in a meaningful way. Producing graduates that are fluent in the application and use of BIM is proposed to be the solution to mitigate the BIM learning curve (McGraw-Hill, 2013).

Traditional scheduling methodologies employ two-dimensional (2D) documentation in which schedule components are detailed over various pages of documentation. The scheduler must spend significant time working through details and elevations of the drawings to understand interrelationships between components, sequencing of elements and unique conditions of the project to formulate the most effective and efficient method of construction. Additionally, no real simulation of the sequencing is afforded to the scheduler before construction allowing for error reduction and increases in efficiencies. Four-dimensional (4D) technologies afford the scheduler with an ability to quickly review the project in three dimensions in the manner in which it will be built. Interrelationships between elements and information can be quickly aggregated, sequenced and scheduled in a fraction of the time that 2D methods require. Construction "real world" simulations may also be performed to allow for relationship error reduction and production efficiency during construction. Various what-if scenarios may also be evaluated assuring the scheduler and field personnel that scenarios are feasible and what impacts and limitations each may have. Thus the 4D element provides a "real world" scheduling opportunity.

The purpose of this paper is to provide educators insight into incorporating BIM into a construction management (CM) curriculum and the development of a BIM activity. The outcomes are geared toward enabling students to be able to virtually construct a large concrete structure using 4D scheduling software with minimal training to develop students' BIM skills and enhance their abilities to plan, schedule, and manage work flow.

Problem Statement

The CM program at Central Washington University is housed within a university that was originally founded as a normal school near the turn of the 20th century. Normal Schools across the United States were created to train high school graduates to become teachers. Its purpose was intended to establish teaching standards and norms, hence its name. Over the decades, the school grew into a college and finally into a comprehensive university offering bachelors and masters degrees across four separate colleges. Currently, there are more than twenty American Council of Construction Education (ACCE) accredited CM programs across the United States at universities whose history began as a normal school. The CM programs at these universities are typically faced with greater curriculum challenges than their "land grant" school counterparts. Land grant universities were established through the Morrill Land Grant Act, which turned public lands over to any state that agreed to use the land sale proceeds to maintain a college teaching agriculture and the mechanic arts. Specifically, normal school programs are constrained more by their respective university's general education requirements. General education requirements often requires that the curriculum for these programs to be very prescriptive and therefore, allows for little flexibility within the existing curriculum, such as, the introduction of a BIM course. This "credit hour" constraint is later referred to in the literature review section of this paper as a key reason why CM faculty are slow to adopt BIM into the curriculum. A curricula review of ten ACCE accredited CM programs (purposefully chosen to represent multiple regions) housed within historically based "normal" schools reveals that, on average, 34.2% of the semester credit hours required to earn a bachelor's degree must be general education courses (i.e. writing, communications, social sciences, arts and humanities, physical or biological sciences, reasoning, health and wellness). In contrast, curricula for CM programs for six land grant universities required only an average of 26.3% of all semester credit hours earned to be general education courses (Table 1). On a semester basis, this equates to a difference of approximately 3 - 4 classes or 9 - 12 semester credit hours allowing more flexibility in the curriculum for the historically based land grant schools. This difference allows these programs to offer specific concentrations or at a minimum, electives for students in topics without jeopardizing their general education or ACCE requirements.

Table 1

ASC School Sample Curriculum Requirements

School	ASC Region	Major SCH	Gen Ed SCH	Total SCH	Gen Ed %
Normal Schools					
Bowling Green State	3	89	36	125	28.8%
Central Missouri	4	83	43	126	34.1%
East Carolina	2	84	42	126	33.3%
Eastern Kentucky	3	80	40	120	33.3%
Illinois State	3	81	39	120	32.5%
Northern Iowa	4	81	45	126	35.7%
Texas State	5	76	48	124	38.7%
Weber State	6	78	46	124	37.1%
Western Carolina	2	82	42	124	33.9%
Western Kentucky	3	84	44	128	34.4%
Normal Schools Averages		81.8	42.5	124.3	34.2%
Land Grant Schools					
Florida	2	89	36	125	28.8%
North Carolina A&T	2	91	33	124	26.6%
Oklahoma State	5	88	36	124	29.0%
Purdue	3	90	30	120	25.0%
SUNY ESF	1	100	27	127	21.3%
Virginia Tech	2	98	36	134	26.9%
Land Grant Schools Averages		92.7	33.0	125.7	26.3%

Consequently, for normal schools, by the time the general education requirements of their respective universities are met, there is just enough space left to fulfill ACCE minimum requirements. Any additional stand-alone course offerings in BIM would then be taken in addition to the degree requirements. Also, ACCE requires a specific number of hours to be dedicated to certain topics. To meet these requirements, it becomes difficult to find available time to incorporate BIM throughout the curriculum because learning BIM procedures takes time; time that cannot be sacrificed from ACCE requirements. For example, ACCE's Document 102 requires 45 contact hours to address construction planning and scheduling topics that includes project planning, network diagramming, critical path method, resource allocation and management, time impact analysis, and computer applications. At Central Washington University, these topics (including the computer applications requirement) consume the time allotted for the planning and scheduling course. Therefore, the introduction of BIM creates a cyclical quandary.

Literature Review

Although introducing BIM into construction education is simple in concept, it is by no means an easy endeavor. Changing from the common 2D methods used to convey construction related ideas and concepts to using three, four, and five dimensional methods requires the educator to revamp how this information is presented without sacrificing the current curriculum content. Despite the wide acceptance of BIM in the industry, BIM adoption in construction education still lags significantly behind. A 2009 survey of 45 Associate Schools of Construction (ASC) indicates that "only one institution reported that they offer BIM as a stand-alone course. BIM is incorporated in other courses in 9% of programs" (Sabongi, 2009). Becerik-Gerber et al. (2011) identified that adoption increased to "only slightly over half of all programs offer BIM courses and almost one fifth of all programs still do not have any plans to offer BIM courses." The reluctance to adopt BIM into CM programs are most attributable to the following reasons:

1. Knowledge required to use BIM software and lack of educational materials (Woo, 2007),
2. Faculty members' unwillingness to change existing curriculum for incorporating BIM (Sabongi, 2009),
3. Complexity of software tools (Johnson and Gunderson, 2009),

4. Lack of resources including (Becerik-Gerber et al. 2011):
    - Lack of experts to teach BIM,
    - Requirement to change curricula,
    - Supports of colleagues and/or administrators,
    - Credit hour constraints.

The faculty members in the CM program at Central Washington University are well versed in CM means and methods with over 40 years of industry experience and 90 years of teaching experience spread across four faculty members. Despite this breadth and depth of knowledge, there is little combined BIM knowledge. In fact, none have used BIM in the industry and any exposure has been peripheral. Based on the research conducted by Becerik-Gerber et al (2011), Sabongi (2009), and Woo (2007), this scenario is not unique. Each assert that the lack of BIM experts and educational tools are leading factors why CM programs are slow to adopt BIM into the curriculum.

Active Learning

Architecture, engineering, and construction education are similar because they are grounded in a constructivist approach to active learning. Nelson and Erlandson (2012) summarized that "constructivism has been defined as the idea that, learning isn't about getting a student to memorize a bunch of instructional material. Instead, with constructivism, learning is an act of building, or constructing, understanding of some content or processes from the inside out" (p. 65). Active learning has been utilized as a tool to expose students to many subjects in construction science. The idea of active learning was first established through the works of Kurt Lewin, John Dewey, Lev Vygotsky and Jean Piaget, where they defined experiential learning through "adaptive modes of concrete experiences and abstract conceptualizations and the modes of active experimentation and reflective observation characteristically resolved in different fields of inquiry" (Kolb, 1984). It is very difficult to take experiences commonly found in the ebb and flow of the construction field and simulate them in a classroom setting. Gier and Hurd (2004) suggested when students were engaged in real world scenarios they were more actively engaged in learning the concepts being taught. Similarly, Simms (1995), stated that an experiential learning approach or active learning provides a solution to three challenges in diversity education, "providing a holistic education, addressing the dilemma of individualism and equality in the classroom and providing a safe climate for learning. The dual knowledge theory of experiential learning theory depicts learning as a holistic and integrated process that attends to what learners think, feel, perceive, and do".

Architecture, engineering and construction education researchers have found that students in these disciplines learn differently. Alvarado and Maver (1999) used virtual reality (VR) in architectural education found that this type of active learning "provided a vivid experience that could result in a better understanding when compared to lectures or static images." They also found the VR provided an opportunity to demonstrate an integrated view of architecture and construction. Stein and Gotts (2001) found through a Meyers Briggs survey questionnaire of 73 undergraduate construction management students, mostly juniors and seniors that 75% of the students have a sensing/judging temperament and students like to reach conclusions through a step-by-step process and like to put what they have learned to use. Most importantly, it was found that 67% of the students preferred hands on or activity based learning. Researchers have also found that construction management students are kinesthetic learners and prefer to learn by doing, as opposed to listening to a lecture (Carns & Plugge, 2010, Gier & Hurd, 2004). Active learning models have been used to teach many concepts in construction management. Bray and Manry (2007) used a hands-on model to demonstrate active learning in a concrete design class. They found students "enjoyed the opportunity to do a hands on project and were more willing to concentrate on design issues presented in a construction management context." Carns and Plugge (2010) used a working model of a heat pump to demonstrate the refrigeration cycle. Their statistics showed through the use of a hands-on active learning model there was some association between perceived knowledge and actual knowledge when the model was used. Semih, Baur and LaBoube (2014) provide an active learning demonstration on the fundamentals of framing construction in architectural engineering education where students visited a timber framed construction site, framed a mock-up of a timber framed two story house and built a timber framed stick model of a house. What the research exposed was through activity based learning there was a positive impact over the traditional lecture learning environment. Students gained a better understanding of construction means and methods, exposure to working together in teams and provided opportunities for communication and distribution of responsibility between team members.

Methodology

The purpose of this research is to answer the question as to the best approach to incorporate BIM into the CM curriculum. The answer to this question is as wide and varied as the CM programs themselves. Currently, the most common methods used to introduce BIM into construction management curricula includes (Lee & Hollar, 2013):

1. Stand-alone courses at the lower level (often replacing an existing CAD class with a BIM class),
2. Interactive teaching modules integrated into numerous upper level courses,
3. Cross-curriculum teaching modules between different disciplines, and
4. BIM capstone course or project.

However, options 1, 3, and 4 to add a stand-alone course is not a viable option for most normal school CM programs because of their credit hour constraints and lack of BIM experts to teach the subject. The only realistic option for these schools is to select option 2; Integrate BIM through interactive teaching modules that are integrated into upper level courses (Lee & Hollar, 2013). This approach must in turn also allow students to learn the required ACCE topics through BIM. The faculty at Central Washington University with the aid of an industry partner piloted a workshop, in the spring of 2014, which helped identify appropriate implementation of BIM into the CM curriculum.

Figure 1: Artist's rendering of the Science Building.

The construction of a science building on the campus of Central Washington University (Figure 1), along with the help of an industry partner that is also contracted to construct the building, presented a very unique opportunity to introduce BIM into a planning and scheduling course while maintaining the integrity of both the CM program's construction education and ACCE requirements. Also, this opportunity filled in the knowledge gap that existed in the faculty's knowledge base. The Science Building is the second phase of an already constructed Sciences Building Phase I completed in 2012. Notice to proceed for Phase 2 was April 11, 2014. The facility is a 120,000 square feet, three story plus a mechanical penthouse, concrete framed building on shallow foundations with a five story observatory isolated on a separate foundation and a domed ceiling for the telescope room. The winning bid was just under $37 million and the contract required the project to be complete in 672 calendar days to final completion.

The faculty at Central Washington University along with its industry partner Lydig Construction Co. partnered together to provide an active learning BIM workshop that lasted 8 hours with a 1-2 hour follow up presentation by the students. The industry-led BIM workshops demonstrated scheduling concepts by virtually constructing a concrete framed structure in a construction planning, scheduling, and controls course where students participated in the activity based learning exercises. The benefits and the results of the workshop were determined through a survey questionnaire to assess their experiences while scheduling the project and faculty observation. The premise is to allow students to experience both 2D and 4D scheduling methodologies.

The contractor developed a BIM of the Science Building for its own managerial purposes. The concrete portion of the BIM was broken down by each concrete structural member (i.e. footings, piers, columns, and beams) and each process for each structural member (i.e. excavation, formwork, reinforcing, place, strip, finish). Students were then tasked with creating a schedule using NAVISWORKS to create a 4D model. This workshop taught students how to manipulate an existing BIM from a construction standpoint. The outcomes of the workshop were two-fold:

1. Students learned how to navigate within a BIM environment and manipulate an existing BIM without becoming BIM experts,
2. ACCE standards were maintained as students were able to virtually build the building and identify and apply typical scheduling considerations such as the critical path method (CPM) and resource management.

BIM Workshop

The concrete foundation of the Science building posed interesting challenges for the students. Figures 2 and 3 are examples of the BIM used in the classroom providing a layout of the foundation and the first floor concrete for the structure. Although the foundation is shallow, as can be seen in Figure 3, the footings are at multiple levels of elevation and the footing forming and placement must be carefully sequenced. The general process of the workshop is designed to provide students first with traditional methodologies of 2D plans and concrete production scheduling. The students produce a bar chart schedule based on the construction drawings. Following the production of the initial schedule, students are supplied with a 3D model of the project. Training in current 4D scheduling practices is then given and students produce a 4D schedule. Comparisons are made between scheduling processes in regards to schedule sequencing accuracy and resource management. Students are evaluated on production of a sequenced model, schedule accuracy, and software skillset. Students provide follow-up discussions and written responses as to errors generated during 2D schedule, errors avoided during 4D schedule, ease of scheduling based on time, and overall experience between scheduling experiences.

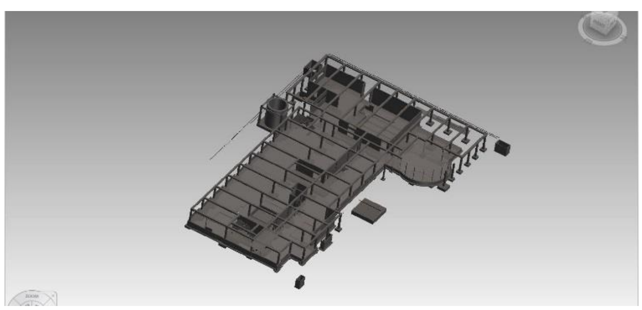

Figure 2: BIM of the Science Building first floor concrete structure.

Figure 3: BIM of the Science Building first floor and foundation.

Survey Questionnaire for BIM Workshop

The survey questionnaire (Table 2) was used by the researchers to gain insight to what students were learning in the exercises. A Likert scale ranging from strongly agree to strongly disagree was used to measure whether students felt their understanding of the scheduling and project management concepts were enhanced, identify whether the topic helped in their professional development as a construction manager, changed how they will schedule projects in the future, identify whether the workshop would help the student become a more effective construction manager and make recommendations to whether the workshop should be performed in future classes.

Table 2

Quantitative survey questions

Question	SA	A	N	D	SD
The 3D model helped me to better visualize the structure in a way 2D drawings could not.	☐	☐	☐	☐	☐
NAVISWORKS helped me to better understand the concrete construction process in a way that 2D drawings could not.	☐	☐	☐	☐	☐
This exercise added to my professional development as a construction manager.	☐	☐	☐	☐	☐
The concepts in this exercise have changed how I will manage concrete projects in the future.	☐	☐	☐	☐	☐
This exercise will likely help me to be a better project manager regarding planning and scheduling concrete projects.	☐	☐	☐	☐	☐

Qualitative questions assessed what students learned as they relate to scheduling concrete processes:

- In what way did the use of a time-sequenced, three-dimensional model either help or hinder your ability to plan and schedule the Central Washington University Science Building?
- In what way did the use of a time-sequenced, three-dimensional model either help or hinder your ability to understand the resources required to construct the Central Washington University Science Building?

Results and Discussion

In addition to class discussions, students were also assessed through a survey instrument providing both quantitative and qualitative feedback to the authors on the activities that took place in class. Qualitatively the authors were interested in discovering the specific lessons each student learned from the workshop, allowing students to reflect on the implications the workshop would reveal about the construction industry as a whole and identify how the lessons learned in the workshop would affect how the student would manage projects in the future. Although the number of survey responses was relatively low, information on the effectiveness of using the workshop as an activity based learning tool could still identify trends within the workshop. The results of the questionnaire are shown in Table 3.

From the responses of the self-evaluation questionnaire, students who participated in the workshop felt the workshop added to their understanding of concrete construction processes better than two-dimensional drawings with a relatively high mean (M = 4.06, SD = 0.97). It should be noted that the student that gave a score of 1 had trouble with a corrupted thumb drive and lost all of his data. Students also felt the workshop will help them become a more effective project manager regarding planning and scheduling (M = 3.78, SD = 0.53).

Table 3

Descriptive statistics for BIM workshop

Question	Minimum	Maximum	Mean	SD
The 3D model helped me to better visualize the structure in a way 2D drawings could not.	4	5	4.83	0.39
NAVISWORKS helped me to better understand the concrete construction process in a way that 2D drawings could not.	1	5	4.06	0.97
This exercise added to my professional development as a construction manager.	3	5	4.11	0.60
The concepts in this exercise have changed how I will manage concrete projects in the future.	3	5	3.67	0.59
This exercise will likely help me to be a better project manager regarding planning and scheduling concrete projects.	3	5	3.78	0.53

(N = 18)

Conclusion and Future Work

The 4D environment allows students to view and schedule the project in an environment that is "real" with regard to field conditions and spatial consideration. Elements from differing elevations require specific scheduling not always visually evident in 2D drawings that are quickly evident in the 4D environment. Simulations allows for error correction and refinement not found in 2D scheduling. The 2D approach often only allows for a field refinement or a historical review. Missing elements, timing of various interconnected elements, sequencing of building phases and components, introduction of outside components can be easily corrected, refined, revised quickly and efficiently allowing for the most effective schedule for the project using a 4D approach.

Students generally commented favorably towards the concept of using the workshop to learn scheduling concepts and how to use BIM for construction management purposes. The students felt the workshop enhanced their understanding of planning and scheduling and resource management. One student answered the first qualitative questions of the questionnaire stating “It really helped to visual[ize] how each piece comes together. It also made a huge difference in visualizing how some pieces conflict with each other and what things must precede each other.” Another student answered the second qualitative question stating “It helps you visualize where your crews and resources are so you can better see when you can move your crews from east to west.” These statements validate the intended effects of learning the ACCE requirements of precedence diagramming, CPM methods, and resource management. In effect, the BIM became an activity based educational tool that maintained the integrity of the ACCE education requirements. It has been the authors’ experiences that students frequently depart from planning and scheduling classes not knowing the “real life” sequences of construction activities. Another unanticipated benefit is that the students, through the 4D model, gained a better understanding of how to sequence construction activities in a real life application by affording students the opportunity to virtually construct the building.

However, despite the students’ positive responses, the measure by which students’ knowledge of scheduling and BIM was increased is primarily anecdotal and no empirical measure was employed to gauge the level of knowledge gained and/or propensities altered due to these experiences. In future work, it is planned to establish a baseline mechanism to determine the students’ knowledge prior to the workshop and then follow up with similar measures to compare with the baseline. In addition, this study was limited to 18 students. To develop a statistically sound analysis, the sample size will need to increase. BIM’s use as an active learning tool is a good way to introduce and reinforce scheduling topics. BIM uses a hands-on visual application providing students opportunities to learn core concepts such as CPM, planning, construction means and methods, exposure to working together in teams and resource management. An additional benefit to the activity based workshop was that it showed the authors how BIM can be integrated into and enhance the content of the CM curriculum at Central Washington University.

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