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PROJECT-BASED LEARNING IN A BUILDING INFORMATION MODELING FOR CONSTRUCTION MANAGEMENT COURSE

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SUMMARY: *It is widely accepted that the evolution of Building Information Modeling (BIM) is increasingly affecting the roles of construction management professionals in the Architecture, Engineering and Construction (AEC) industry. Teaching BIM in construction engineering and project management (CEPM) curricula requires more emphasis on learning BIM as a process improvement methodology rather than only a technology. This paper describes experiences of a university course on Building Information Modeling that was developed to educate the next generation construction managers to understand BIM and effectively use an existing BIM in plan execution for construction projects. This is a project-based course where students gain knowledge on the implementation of BIM concepts throughout the lifecycle of a project. Findings and lessons learned from the teaching experience in seven offerings of the course are documented.*

KEYWORDS: *Building information modeling (BIM), Construction management, Construction education*

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1 INTRODUCTION

Building Information Modeling (BIM) is regarded as an innovative approach and integrated process that supports efficient design, information storage and retrieval, model-based data analysis, visual decision making, and communication among project stakeholders (NIST 2004, Krygiel and Nies 2008, Eastman et al. 2008). Although the various definitions of BIM have been given with different foci, most researchers and practitioners believe that BIM is not a product or technology; instead, it is a process which can facilitate project success when utilized throughout the project lifecycle (Autodesk 2003). According to McGraw-Hill's SmartMarket Report (2012), 71% of the Architecture, Engineering and Construction (AEC) industry is using BIM, a rapid growth from 49% in 2009. The biggest challenge to BIM adoption continues to be lack of adequate BIM training. As the importance of BIM is widely recognized in the AEC industry, it is essential for the next generation of construction management professionals to learn BIM while undertaking studies at universities.

This paper describes the experience and lessons learned from a university course on Building Information Modeling that was developed to educate next generation AEC professionals to understand BIM and effectively use an existing Building Information Model (BIM) in plan execution for a building construction project. BIM is cross-listed with both graduate and undergraduate-level codes. ARE 376 is an undergraduate-level elective for both Civil and Architectural Engineering majors, and CE 395R7 is a graduate-level course part of the Construction Engineering and Project Management (CEPM) graduate program in the Civil, Architectural and Environmental Engineering (CAEE) department at The University of Texas at Austin.

This course focuses on BIM as a collaborative process rather than a design tool. There was no requirement for advance modeling since all models used in course work were provided. Students were asked to use existing models to perform tasks including model-based cost estimating, scheduling and 4D simulation, and design coordination. A project-based learning approach was applied to: (1) emphasize the importance of understanding BIM as a process, and (2) provide students with active learning experiences by encouraging self-directed learning and critical thinking throughout the course. The course organization and deployed educational modules are introduced, and lessons learned to date from the teaching experience are documented.

2 BACKGROUND RESEARCH

BIM has been gaining wide acceptance and recognition in the last decade, as AEC professionals are facing a new transition from computer-aided design (CAD) to BIM. As a response to this promising technology and to industry needs for relevant skills, academic institutions are exploring strategies and approaches to incorporate BIM education in their undergraduate and graduate curricula. Researchers found that BIM is one of the most challenging and recent trends for Construction Management programs, but BIM pedagogy is not yet consolidated (Casey 2008, Johnson and Gunderson 2009, Wang and Leite 2014). In recent years, more academic institutions have started to incorporate BIM into their programs to respond to industry needs for these skills. In the United States, schools such as Penn State, Carnegie Mellon, Georgia Tech, University of Southern California, and the University of Texas at Austin have successfully integrated BIM education in their programs, some of which are design programs (i.e., integrated to Architectural Engineering or Design Studio courses). It is important to teach BIM as a design tool in a Design Studio or modeling course; however, as BIM is recognized as "the process of creating and using digital models for design, construction and/or operations of projects" (McGraw-Hill Construction 2012), it should be also taught in construction and facility management. The data-rich nature of BIM enables the model to not only be a digital representation of the design, but to also facilitate model-based quantity take-offs and cost estimating, schedule simulations, design coordination, among others. Therefore, in addition to teaching BIM in design education, it is equally important to teach students the potential of BIM application throughout the project life cycle as well as the knowledge and experience of how to manipulate, manage and make good use of the model.

Teaching BIM in construction management is challenging for several reasons. Firstly, it is critical to help students form a correct understanding of BIM. BIM is not simply new software or a stand-alone tool that supports an individual discipline. Hence, understanding how BIM streamlines the collaboration process of a construction project is much more important than mastering software. Secondly, considering the ever increasing evolution speed of information technology, it is very likely that the "content" taught in class especially the hands-on training on BIM applications will be outdated in the near future. Therefore, it is important for university educators to place more emphasis on students' ability of self-directed learning. Furthermore, as BIM is still emerging, critical thinking should be strongly encouraged throughout the teaching process. Hence, Problem-Based Learning (PBL) is the teaching approach deployed for this course.

PBL is a student-centered educational approach. The focus shifts from a method of instruction that is teacher-driven and led to one where the student is empowered to conduct self-directed learning. It is task oriented and a project is often set by an instructor or facilitator. Students integrate what is learned, and produce a solution to solve an ill-defined problem. PBL, according to Savery (2006), originated in North America over 40 years ago to help medical students become self-directed and multidisciplinary learners. PBL is also an adequate approach for engineering education, given that it resembles the professional behavior of the engineering discipline. Projects may vary in complexity, but all will relate in some way to the fundamental theories and techniques of an engineering discipline. Common elements of PBL include: (1) real-world problems are presented for investigation; (2) student's discuss findings and consult the teacher for guidance, input, and feedback; and (3) final products can be shared with the community-at-large, thus fostering ownership and responsible citizenship in addressing real-world problems.

From an engineering education perspective, PBL can be coupled with corporative learning, given that students typically work in course projects collaboratively in small groups. Researchers have been investigating cooperative learning as an alternative to competitive learning for several decades (Deutsch 1949, Johnson 1981, Johnson & Johnson 1986, Slavin 1990, Nembhard 2009). Common elements of cooperative learning methods include: (1) classes are divided into small groups with two to six members; (2) groups have an interdependent structure with high individual accountability; (3) the team objectives are clearly specified and defined; and (4) team members support each other's efforts to achieve a common goal (Nembhard 2009). Competitive learning, on the other hand, is based on a competitive goal structure in which an individual can attain his or her goal if the other participants cannot attain their goals (Deutsch, 1949). Moreover, psychologists have suggested several benefits of using cooperative learning over competitive learning in a classroom, including enhanced achievement, student attitudes, and student retention (Johnson et al. 1981, Slavin 1990).

With so much evidence on the advantages of PBL and corporative learning, why are we not implementing this pedagogical approach more often in our engineering classrooms? Implementation challenges (e.g., additional preparation time, complex logistics, access to real-world problems and related data) are often stated as the main culprits. Taking specifically the project management profession into account, ill-defined problems and team work is omnipresent in the AEC industry. Hence, it is increasingly more relevant to provide our future engineers and project managers educational experiences that can emulate real-world project work in the classroom.

3 COURSE DESCRIPTION

Building Information Modeling (BIM) has been offered at The University of Texas at Austin seven times to a total of 145 students (109 graduate and 36 undergraduate students). It was first developed in Spring 2010. This course has had high-interest from the student body. It was first offered in Fall 2010, during which time twice as many students tried to enroll than could be accommodated. Due to high demand, the course was initially offered three semesters in a row. This course has attracted students from multiple areas within the CAEE department (Construction Engineering and Project Management, Architectural Engineering, Structures, and Materials), as well as Mechanical Engineering and Architecture students. Students gain hands-on experience on various aspects of BIM as well as develop case studies on various BIM-based projects in and around Austin, supported by industry mentors. Mentors and guest lecturers for this course are recruited mainly through the Austin BIM Peer Group, an industry group that the instructor joined in 2010 as their Academic Advisor. The Group started in 2010 with 3 local companies; it has since grown to 32 companies. The Austin BIM Peer Group meets monthly to exchange information and learning experiences on BIM-based design and construction projects. Students enrolled in the course are invited to the monthly meetings and many have been able to identify mentors, internship and job opportunities through the Austin BIM Peer Group.

ARE 376/CE 397R7 is well integrated with the instructor's research agenda. It is taught in modules, which allows flexibility of adding new content every time the course is offered, which are typically related to new research initiatives the instructor is exploring. Each module is composed of an introductory lecture, two laboratory classes and a reflective class, in which students present and discuss their work related to that specific. The three basic modules are: (1) model-based cost estimating, (2) scheduling and 4D simulation, and (3) design coordination. Additional modules taught include: (4) building energy simulation, (5) photogrammetric generation of 3D models, and (6) site layout planning. This course is entirely project-based, meaning assignments for each module are mini-projects, in which students apply the knowledge for that module to a real-world project. In addition, all teams are made up of both graduate and undergraduate students, and the team composition is carefully crafted to ensure that there is a variety in student background (e.g., modeling, estimating and scheduling experience) in each team.

This is UT's first BIM course and, through the instructor's network of industry mentors and alumni, our graduates have already been reaping the benefits of this course; several past students have been recently hired as BIM Engineers or Virtual Design and Construction (VDC) Managers by various general contractors throughout the United States and abroad. ARE 376/CE 397R7 was recently mentioned in an Engineering News-Record (ENR) article, describing how the instructor was integrating research and teaching. This was part of an article series on Women in Construction, in which Leite was featured as the sole academic of 10 women in the Construction industry in the United States (Tuchman 2013).

3.1 Course Overview and Learning Objectives

This course focuses on the skills and information needed to effectively use an existing BIM in plan execution for a building construction project. This is a project-based course where students gain knowledge on the implementation of BIM concepts throughout the lifecycle of a building, from planning and design, to construction and operations. The main topics covered in the course include: (1) model-based cost estimating, (2) construction scheduling and 4D simulation, (3) design coordination, and (4) photogrammetry-based 3D model generation.

This course is designed to provide construction management students with core concepts of BIM, the knowledge of implementing BIM as a process throughout the project life cycle, hands-on experience with various BIM software, and the opportunity to develop collaboration skills and critical thinking through group projects and individual assignments. By taking this course, students will be able to: (1) define BIM; (2) describe workflow in using BIM in the building lifecycle; (3) describe the process of model-based cost estimating; (4) perform 4D simulations; (5) apply BIM to reduce error and change orders in construction projects; and (6) evaluate and communicate your ideas related to the use of BIM in the building life cycle.

3.2 Course Organization and Educational Modules

This course is cross-listed with both graduate and undergraduate-level codes. It was designed for students interested in construction management and information technology in the AEC industry. Instructional approaches include lectures, hands-on lab-based software tutorials, team-based learning (e.g., lab-based assignments), and individual learning (e.g., reading assignments).

An innovation of this course compared to previous efforts is that the teaching approach and evaluation principle are process-oriented, which means the emphasis is placed on understanding BIM as a new construction management process as well as its impacts on project success. BIM is not only a technology but also a methodology. Especially with information technology booming, BIM products are also advancing rapidly; mastering one or more software should not be the focus in BIM education in universities. BIM courses should, therefore, encourage students to grasp the role of BIM in different project phases so that they know why this tool is used, how it improves the project performance and how it can be further improved. The evaluation mechanism of lab-based assignments is also based on the students' discussion on the process and the further understanding of the tasks based on the practice, rather than the result itself. This section describes the detailed course design and instructional approaches. There are both team and individual evaluations throughout the semester. All lab-based assignments (one per educational module) are carried out in teams. An industry-mentored case study is also carried out in teams. Individual evaluations are done through class discussions based on reading assignments, quizzes, and a synthesis report (for graduate students only). Figure 1 depicts the team and individual evaluations, as well as their connections.

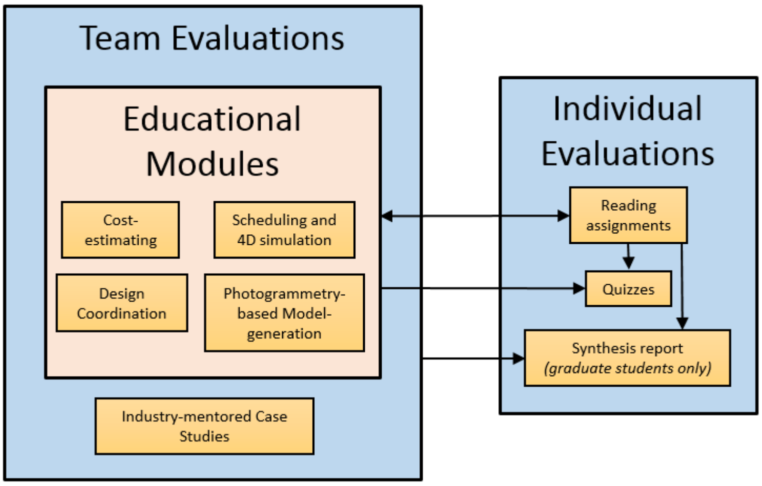

FIG. 1: Team and individual evaluations and their relationships

The course contents are organized into educational modules covering various topics such as model-based cost estimating, construction scheduling and 4D simulation, design coordination, and photogrammetry-based 3D model generation. As shown in Table 1, every module is composed of four sessions: (1) background introduction - introductory lecture supplemented by additional reading assignments; (2) lab session I - step by step hands-on tutorial led by a teaching assistant; (3) lab session II - time for questions workshop when students are free to seek help, ask questions, work in groups and interact with other groups; and (4) reflection and discussion – assignment delivery and team presentations.

TABLE 1: Structure of each educational Module

Session	Instructional Approach
1. Background/Introduction	Lecture (topic introduction) + Individual learning (reading assignment and class discussion)
2. Lab session I: tutorial	Lecture (software tutorial) + Team-based learning (hands-on exercises)
3. Lab session II: workshop	Team-based learning (time-for-questions workshop; hands-on exercises)
4. Reflection and discussion	Team-based learning (group presentations and discussion)

These modules provide students with core BIM knowledge, hands-on practice with the state-of-art BIM solutions, and multinational collaboration experience. All lab-based assignments are done in groups. At the beginning of the course, students are assigned into teams of 2-3. The teams are formed to cover a variety of industry experience levels and background. Teams are also composed of both graduate and undergraduate students. Typically, a class will have 7-8 teams of students, depending on total enrollment for a given semester.

3.3 Example Educational Module: Scheduling and 4D Simulation

The following subsections discuss the statement of alignment of an example module (Scheduling and 4D Simulation), with course objectives, lecture overview, hands-on sessions descriptions, assignment and rubric.

3.3.1 Statement of Alignment to Course Learning Objectives

As previously stated, the learning objectives for this course are: (1) Define BIM; (2) Describe workflow in using BIM in the building lifecycle; (3) Perform model-based cost estimating; (4) Perform 4D simulations; (5) Apply BIM to reduce errors and change orders in capital projects; (6) Evaluate and communicate your ideas related to the use of BIM in the building life cycle.

For this unit specifically, the learning objectives are to:

(1) Perform 4D simulations. Students will learn how to link activities to components using commercially available 4D systems to visualize and analyze construction processes. Moreover, getting students to do hands-on activities (i.e. actually mapping each activity to an object in the model to generate the 4D) will give them a better appreciation of what it takes to carry out this type of analysis.
(2) Apply BIM to reduce errors and change orders in capital projects. This unit will enable students to learn how to use 4D as a negotiation tool with owners, showing them the implications of making specific decisions during construction. In this assignment, this is specifically related to the installation of a sculpture, which the owner has suggested after the start of construction. This is the reason why they have two schedules in their deliverables: a first one with the original plan, and a second fast-track schedule, which contains the sculpture installation problem. This will help in assessing the usefulness of 4D modeling to streamline construction processes.
(3) Evaluate and communicate your ideas related to the use of BIM in the building life cycle. This unit will enable students to evaluate the promise of 4D for the construction industry (i.e. where do they see this applicable, at what level of detail and scale, for what objectives, what types of construction) and to provide an assessment of the implications in the schedule of installing a sculpture on a specified are of the building.

3.3.2 Lecture

This lecture provides an overview on 4D BIM, discussing how it began and how it has been used in both research and industry. A reading assignment is due at the beginning of lecture and, typically, the reading discussion in conducted at the start of lecture. This lecture also includes project examples illustrating the benefit of using 4D simulations for construction management. At the end of this lecture, Assignment 3 (scheduling and 4D simulation) is introduced. This lecture is presented in a 1h15min session.

3.3.3 Hands-on Sessions

This unit consists of two hands-on sessions, which are carried out in a computer laboratory. In the first session, students learn how to create a schedule and import it into the 4D modeling environment, so that each activity in the schedule can be linked to an object in the model. They practice using a simplified version of the model they will use for their assignment (only wall and slab objects in the practice model). In the second hands-on session, students will learn how to link each object in their assignment model, to each activity in their schedule. Their first (out of two) schedule is due before this hands-on session, so that they can use this schedule during the session. By the end of this session, students should have a 4D simulation based on their first schedule, so that they are able to evaluate its logic and improve it for their second schedule.

3.3.4 Assignment, Rubric, and Evaluation Criteria

The objective for this assignment is less teaching students to use specific tools, but more getting them to think critically as to how these state-of-the art technologies support the decision making process of construction managers and owners.

Explicit learning objectives for this assignment are as follows:

> *"In this assignment, you will learn how to link activities to components using commercially available 4D systems to visualize and analyze construction processes (from your schedule). This will help you in assessing the usefulness of 4D modeling to streamline construction processes."*

More specifically, students will be able to evaluate the promise of 4D for the construction industry (i.e. where do they see this applicable, at what level of detail and scale, for what objectives, what types of construction) and to provide an assessment of the implications in the schedule of installing a sculpture on a specified area of the building.

There are also hidden objectives, including having students learn how to use 4D as a negotiation tool with owners, showing them the implications of making specific decisions during construction. In this assignment, this is specifically related to the installation of a sculpture, which the owner has suggested after the start of construction. This is the reason why they have two schedules in their deliverables: a first one with the original plan, and a second fast-track schedule, which contains the sculpture installation problem.

Making students reflect on these issues will help them begin thinking like professionals and learn how these tools can support real-world decision making. Moreover, getting students to do hands-on activities (i.e. actually mapping each activity to an object in the model to generate the 4D) will give them a better appreciation of what it takes to carry out this type of analysis. I also expect their evaluations to be different for each software system they used (half the teams will use one 4D system and the other half will use another). One is more user friendly than the other and it is expected that students discuss these differences by exchanging their learning experiences on presentation day as well.

The assignment description is provided below.

> *"For this assignment, you will be exploring MS Project scheduling software as well as Autodesk Navisworks Manage, a 4D modeling software. In this assignment, you will learn how to link activities to components using commercially available 4D systems to visualize and analyze construction processes (from your schedule). This will help you in assessing the usefulness of 4D modeling to streamline construction processes.*
>
> *You will develop two schedules for the construction of slabs, walls, columns, beams and windows of a section of a commercial building. The first schedule should be created assuming that there is not a major time-constraint on the job site. Your second schedule will be an improved fast-track one that aims at completing the project in minimum time frame. The second schedule will also contain activities and sequences associated with the installation of a sculpture, which is detailed below.*
>
> *You will bring both schedules to a 4D environment and analyze the construction processes generated to identify any possible constructability issues in your schedules and/or improvement opportunities to deliver the facility in a shorter duration.*
>
> *Notice to proceed with construction is November 1st, 2015. For the crew sizes, equipment selection and production rates of activities please refer to RS Means online (access instructions will be provided to you). For design specifications of the building, please refer to building blueprints and specifications. State your assumptions clearly.*
>
> *As mentioned above, in your second schedule (fast-track), you will need to include the installation of a sculpture, which was requested by the owner, who wants to place it on the 4th floor, where an executive's office will be located at. The location is shown below.*
>
> *Part of the owner's decision of where to place the sculpture depends on the implications this will have in the schedule. The owner wants to maintain the completion milestone. Assume that no structural modifications must be made to the facility in order to support the sculpture. The artist permits crane lifting for the sculpture, which will be installed on site (24 hour process, or three 8-hour shifts, using one crane) and lifted to the 4th floor once assembled. The dimensions of the sculpture that the owner plans on purchasing are approximately 6' (height) x 4' x 6'.*
>
> *Here are some general requirements and discussion points in relation to this assignment:*
>
> *(1) When you create a logical schedule with selected crews, make sure to show your calculations for durations in a separate table, develop your Work Breakdown Structure (WBS), describe your general plan of attack for each schedule, and describe some interesting sequencing constraints incorporated in the schedule. The level of detail of both schedules should be to the activity level. Hint: The more detail that you have (in terms of components, zones, etc) the better assessment that you will have about the capabilities of 4D.*
> *(2) Discuss what opportunities for improvement (if any) that you have identified (or did not identify) on this schedule and how you identified them.*
> *(3) Try to identify a way to incorporate the sculpture in your 4D model to assess the viability of installing it with the given constraints. Discuss how 4D model was/was not helpful in this.*

(4) *Project schedules and even designs get changed and updated frequently during construction. Assuming that the second schedule is a modified version of the first schedule, discuss how easy it was to recreate the 4D model. What approach to modify the 4D using the new schedule did your team take?*
(5) *Discuss the features that you liked and the things that can be improved in the 4D system that you are using. Create a wish list containing 5-10 items that you would like to have in an "ideal" 4D system.*
(6) *Discuss what some value propositions for creating a 4D model during construction are. Similarly, discuss what some impediments are. What are some characteristics of a project that would benefit the most from a 4D system?*

Deliverables: For this assignment, you will need to submit a 3-5 page report including: (1) a brief overview of the process of formulating and analyzing a schedule and a 4D model; (2) a discussion on, but not limited to, the points listed above; (3) an appendix (not counted towards the page limit) with your two schedules and screen shots of your 4D simulations. This assignment is due on October 02. Please hand in a hardcopy of your report in class on October 02 and also submit a .ZIP file to Canvas by the due date. The .ZIP file should include: (1) a PDF of your report and schedules, (2) two .AVI files of your two simulations, and (3) a PPT file of your presentation, for the teams that are presenting in class for this assignment. See presentation assignments below.

Presentation assignments are as follows:

Note to all groups: please prepare for a 10-15 minute presentation covering only your assigned discussion points. Both teams may choose to show their animations to support their discussion points. Have mostly discussion points and/or figures in your slides. Avoid wordy slides.

Group 3: Discuss some interesting features of the system and what aspects of the system need improvement. How to incorporate sculpture installation analysis in the 4D model? Compare the initial versus modified schedule and how your first simulation helped in developing your second schedule. What were the levels of detail in the schedules? Were there any challenges in generation of 4D using one schedule versus the other?

Group 4: Assuming that the second schedule is a modified version of the first schedule, how easy/difficult was it to maintain the model? Discuss in general whether there would be some issues in maintaining a 4D model in the face of changes in the 3D model as well as schedule. Discuss what some value propositions for creating a 4D model during construction are. Similarly, discuss what some impediments are. What are some characteristics of a project that would benefit the most from a 4D system. Discuss a wish list containing 5-10 items that you would like to have in an "ideal" 4D system."

The assignment rubric is provided in Table 2.

TABLE 2: Scheduling and 4D Simulation Assignment Rubric

	Competent	**Somewhat competent**	**Not yet competent**
First schedule	Logical and detailed schedule (activities considering who, what and where)	Logical schedule but not all activities are detailed as to who, what and where	Schedule not considering order of activities (e.g. columns before slab in same floor)
Fast-track schedule with sculpture installation problem	Logical and detailed schedule (activities considering who, what and where)	Logical schedule but not all activities are detailed as to who, what and where	Schedule not considering order of activities (e.g. columns before slab in same floor)
First 4D	All objects have a link to a specific activity in the schedule; objects were disaggregated in each floor to reflect the level of detail in the schedule	All objects have a link to a specific activity in the schedule; no disaggregation of objects in a single floor	Not all objects are linked to the schedule/ several objects do not show up in the simulation

Fast-track with sculpture 4D	All objects have a link to a specific activity in the schedule; objects were disaggregated in each floor to reflect the level of detail in the schedule	All objects have a link to a specific activity in the schedule; no disaggregation of objects in a single floor	Not all objects are linked to the schedule/ several objects do not show up in the simulation
Report – schedule discussion	Discussion regarding selection of level of detail of each activity, stating assumptions and information used from estimating assignment. Discussion on resource balancing for fast-track schedule.	Limited or no discussion regarding selection of level of detail of each activity. Some assumptions discussed. Some discussion on resource balancing for fast-track schedule.	No discussion regarding selection of level of detail of each activity. No assumptions discussed. No discussion on resource balancing for fast-track schedule.
Report – 4D discussion	Discussion on possible ways of keeping track of an as-built schedule aligned with an as-planned schedule. Discussion on mapping process and limitation of the 4D system they used.	Mention that it might be possible to keep track of an as-built schedule aligned with an as-planned schedule, but no discussion on how. Only discussed mapping process.	No mention that it might be possible to keep track of an as-built schedule aligned with an as-planned schedule, but no discussion on how. Did not mention mapping process.
Report – sculpture problem discussion	Provide an assessment of the implications of installing the sculpture on the 4th floor area; discuss how to use 4D as a negotiation tool with owners, showing them the implications of making specific decisions during construction.	Discussion limited to how the sculpture installation impacted the schedule.	No discussion on the sculpture installation problem.
Report – impact to construction industry discussion	Evaluate the promise of 4D for the construction industry; where this is applicable, at what level of detail and scale, for what objectives, what types of construction	Vague discussion on evaluation of 4D promise for the construction industry	No discussion on evaluation of 4D promise for the construction industry
Presentation	Active participation during presentation, by asking questions to other groups, comparing and contrasting their experiences with different software systems; presentation discussing points which their groups were assigned to focus on for presentation day.	Presentation missing some points which their groups were assigned to focus on for presentation day. Little or no participation in exchange of ideas with other groups.	No presentation or presentation missing most points which their groups were assigned to focus on. No participation in exchange of ideas with other groups.

The evaluation criteria, mapped to the rubric, is provided in Table 3. Each team was evaluated based on each of the criteria listed in the rubric, which carried different weights. Teams could possibly show competency in several criteria, while not yet being competent in others.

TABLE 3: Scheduling and 4D Simulation Assignment Evaluation Criteria

	Total Possible Points	**Competent**	**Somewhat competent**	**Not yet competent**
First schedule	20	20	10-15	0-10
Fast-track schedule with sculpture installation problem	20	20	10-15	0-10
First 4D	10	10	5-8	0-5
Fast-track with sculpture 4D	10	10	5-8	0-5
Report – schedule discussion	10	10	5-8	0-5
Report – 4D discussion	10	10	5-8	0-5
Report – sculpture problem discussion	5	5	2.5-3.5	0-2.5
Report – impact to construction industry discussion	5	5	2.5-3.5	0-2.5
Presentation	10	10	5-8	0-5
	100	**100**	**50-77**	**0-50**

3.4 Industry Involvement

Guest lectures and the industry-mentored case study assignment provide students a good chance to connect and communicate with industry professionals, learn from the practical experience and strengthen the knowledge learned in class with real world practice.

For the case study assignment, students are asked to directly contact, with the support of the course instructor, one company and develop a case study on a project that utilized BIM in any way. The questions they need to discuss include, but are not limited to: what challenges the project team faced which led to the use of BIM, what technologies were used, why were these technologies pertinent to the problem they were addressing, how was BIM implemented in the project and in which phase of project lifecycle, how did these technologies facilitate project success, were there any measurable improvements, and what challenges were faced in BIM implementation. The teams will address these questions by interviews, site visits, and project document analysis. At the end of the semester, the teams present their case studies in a seminar-type environment (see Figure 2). Mentors are invited to attend and, when they do attend, they provide enthusiastic feedback to students throughout the seminar.

FIG. 2: Team of students presenting industry-mentored Case Study

Besides mentoring students in case studies, industry representatives get involved in various other ways in the BIM course. Typically, each semester will include 4-5 guest lectures. Each guest lecturer will come from a different company and talk about BIM implementation in their experience, illustrated by projects they worked on. Figure 3a illustrates a guest lecture that is connected to the Design Coordination module. This specific guest lecture started with an overview of BIM implementation in this company, followed by a mock design coordination meeting, led by two BIM Engineers that perform design coordination as part of their job duties. Figures 3b and 3c illustrate a class exercise developed by a guest lecturer that was deployed after his lecture and was meant to illustrate how 3D representation can enhance multidisciplinary team collaboration.

(a) (b) (c)

FIG. 3: Students in mock BIM-based design coordination meeting (a), and 3D hands-on class exercise (b and c), both with industry mentors

4 COURSE ASSESSMENT

For each lab-based assignment, an objective was stated in the assignment description and a rubric was used for grading. An example rubric was shown in Table 2, and an example evaluation criteria, mapped to the rubric, was shown in Table 3. Teams also performed peer assessment for each lab-based assignments. Overall, two methods were used to assess the course: the Comprehensive Assessment for Team-Member Effectiveness (CATME) peer evaluation and the end-of-semester course evaluations. CATME, a team building and peer assessment tool, was developed at Purdue University and is currently maintained with support from the National Science Foundation. CATME can build student teams based on instructor-specified criteria, as well as gathers peer evaluation data as well as self-evaluations to assess how effectively each team member contributes to the team and gives feedback to the team members and to instructors (Ohland 2016). For this course, CATME was used for peer-assessment only. End-of-semester course evaluation were conducted using existing course instructor surveys.

4.1 Peer Assessment

Peer evaluation surveys were conducted at the end of every lab-based assignment. The goals of the CATME survey was to alert the instructor regarding issues teams might have been experiencing, as well as assess overall team performance, from the teammate's perspectives. Each student received a unique link to the CATME surveys. Students were asked to select the category of behaviors that most closely matched the actual behavior of each student on their team (including themselves). The primary CATME instrument is a behaviorally anchored rating scale (BARS), which measures performance in five areas of team-member contributions: (1) contributing to the team's work, (2) interacting with teammates, (3) keeping the team on track, (4) expecting quality, and (5) having relevant knowledge, skills, and abilities. Students were asked to rate each of their teammates (including themselves) on each of these five categories by using a likert scale (from 1 to 5, five being strongly agree). Students were also given the opportunity to provide their comments in an essay box. This peer-assessment was a valuable instructional tool, as it allowed the instructor to detect any team issues throughout the semester and adjust the course accordingly. It also allowed the instructor to identify students who were not actively contributing to the team and, hence, adjust any individual grades.

4.2 Instructor's Assessment

The Instructor was evaluated by students through the university's standard course instructor survey. The end-of-semester course evaluation and students' learning outcomes both demonstrate the benefits of this approach. Over the seven offerings of this course, the average course instructor rating was 4.7 out of 5.0, ranging from 4.5 to 4.9. The average course rating was 4.6, ranging from 4.2 to 4.8. Positive written feedback provided by the students include: "Fantastic, passionate professor who cares deeply about her students and the industry progress." "Professor has the utmost interest in the subject and is very accessible and easy to talk to." "Very valuable course that has provided me terrific hands-on skills." "Excellent course organization." "Dr. Leite is a fantastic professor. One of the best classes I have taken at UT." "Best course I've taken in CAEE." "My favorite course at UT."

5 LESSONS LEARNED AND CONCLUDING REMARKS

This course emphasizes learning BIM as an integral process which influences the overall project success from various aspects. Understanding the core value of BIM and its far-reaching influences with specific training on innovative and critical thinking is much more important than mastering a piece of software. Reflecting on the course over six semesters, the main lessons learned include: (1) project-based learning, (2) modular structure of the course design, (3) industry involvement, and (4) constant tracking of learning outcomes. For further information on learning outcome tracked in this course, see Wang and Leite (2014).

Project-based learning provides students with real-world problems and active learning experiences by encouraging self-directed learning and critical thinking throughout the course. A combination of lectures, team-based learning and individual learning not only provides students with well-structured knowledge but also enables them to practice working and learning in a collaborative environment supplemented by self-reflections. For emerging technologies and trends as BIM, university education should put more emphasis on "why" and "how" in addition to "what" (e.g., Why is the BIM process better than the traditional process? Why is the software application good or not good? How can you improve it?). Students would benefit more by knowing how to learn and think with a tool than simply knowing how to use it.

The modular structure used in this course establishes a standard format for each educational module but also enables flexibility in terms of course content. Students receive adequate training in each module through lectures, readings, lab tutorials, lab-based exercises and reflection and discussions, while the content of educational models can be updated as required. The three basic modules that are always taught are: model-based cost estimating, scheduling and 4D simulation, and design coordination. Additional modules that have been taught throughout the semesters include: building energy simulation, photogrammetric generation of 3D models, and site layout planning.

Familiarizing students with industry practice and expectations is also important. In addition to a well-directed course, case studies and guest lectures were also good ways for students to expand their vision and stimulate innovative ideas. This is this university's first BIM course and, through a network of industry mentors and alumni, graduates from the program (both undergraduate and graduate students) have already been reaping the benefits of this course; several past students have been hired as BIM Engineers or Virtual Design and Construction (VDC) Coordinators, by various general contractors throughout the United States and abroad. Several have already given back, serving as BIM course mentors and/or guest lecturers.

In summary, this course can be considered a successful educational experience for teaching BIM in construction management programs. With continuous modification and improvement over seven semesters, the proposed project-based learning approach was successfully implemented and well-received by students. The project-based learning approach, the modular structure of course design and lessons learned described in this paper can provide useful insights for educating the next generation AEC professionals on emerging information technologies, such as BIM.

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