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UTILIZATION OF DRAWING MANAGEMENT SOFTWARE TO ENHANCE BIM EDUCATIONAL EXPERIENCES

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ABSTRACT

Building Information Modeling (BIM) is becoming more imbedded in Architecture, Engineering, Construction and Operations (AECO) industry workflows and as such an emerging area of concern is the transmittal of data present in the model to the field. Furthermore, the use of and navigation through 2D drawing sets, especially when developing as-built BIMs, can hinder the productivity of Virtual Design and Construction (VDC) processes. With increased expectations that college graduates in AECO fields achieve competency in VDC processes, instructors of BIM courses have the unique challenge of teaching both modeling techniques and best practices to students. In order to accomplish this, the graduate BIM course at the University of Florida, Construction Information Systems, uses both individual and group as-built modeling assignments. In both portions of the course students are expected to interpret construction drawings sets and develop a fully completed BIM model inclusive of all building systems. However, it has been found that students spend a great deal of time trying to organize and navigate disparate drawings sets, rather than spending that time to develop their VDC expertise.

This study conducted a survey to establish the approximate amount of time that students spent navigating drawings as part of the BIM development process from 2D plans. The class in the subsequent semester is provided access to an emerging drawing management software tool, PlanGrid. This tool organizes drawing sets by detecting and displaying relevant sheet identity information, along with standard drawing set navigation markers, e.g. section cuts or callout boxes. It then intelligently links these elements to the appropriate pages and allows seamless navigation between drawings on a web-based platform, accessible through any Internet ready device or PC. Students provided with access to PlanGrid were asked to evaluate their experience and provide initial reactions to the use of the software. The utilization of advanced drawing management software in the BIM classroom allows students to focus more of their time on the development of BIM/VDC knowledge, enabling them to be better prepared for their careers in the AECO industry. Furthermore, it helps illustrate the importance of organized, clean model and data management. This research provides an evaluation of a new tool for instructors to consider as they work towards the enhancement of the BIM educational experience for their students.

Keywords: BIM, VDC, PDF, Data Management, Education

1. INTRODUCTION

Data management has become one of the main areas of concern in the AECO industry. The quantity of data available to project teams continues increasing to unprecedented levels as the industry further embraces BIM and VDC processes. BIM has become a standard in the AECO industry, with McGraw Hill (2012) reporting that 71% of practitioners in the AECO use it in their

businesses. The adoption of BIM further demands the development of a strategy for the management of the multiple data streams which must be managed by a project team. Industry practitioners utilize a range of software solutions designed to aid in the management and distribution of data, with each company working to find the solution that works best for their needs. As new methods of data management are developed and integrated in the AECO industry, it is vital that students remain current and prepared for their changing roles as they begin their careers.

Education is a vital aspect of preparing students for their eventual careers and more importantly, preparing them for the ever changing technological landscape they are entering. Technology changes frequently make it difficult for educators to expose students to the BIM and VDC fields in a way that focuses on best practices and higher level concepts. Given the short timeframe that educators have to work with students any method to help students better comprehend the concepts being provided is a benefit. In previous semesters, this research team has introduced means of improving the students experience and ability to better master the advanced BIM curriculum offered, such as keystroke capture software called Screencast (Blinn and Issa 2016). That research found that such technology aided in the development of the students' modeling abilities, thus allowing instructors the ability to focus on additional important conceptual and advanced BIM topics.

Moving forward, it was observed by the researchers that the management and interpretation of the drawing sets used in the course was having an impact on the amount of time students were able to spend on the core aspects of their assignments. The goals of this study were to establish the potential causes of delays due to drawing management, e.g. drawing completeness, mode of delivery, access, and find a solution which can be used by educators to improve BIM education. Drawing management software was selected for evaluation as a potential solution and was integrated into a graduate level BIM course during this study. While drawing management technology is not a new concept, there have been great advances in its functionality and feature offerings in recent years. Many of these improvements, such as markups, RFI integration, tagging or intelligent drawing linking, are not only useful in the industry but can also aid student comprehension and development. Educators in the BIM and VDC fields constantly strive to remain up to date within the ever-changing landscape of technology in the AECO industry while providing students with the technological foundation which will have an impact on their future careers. This research provides a review of a tool that educators may potentially employ to improve efficiency and comprehension during BIM education.

2. BACKGROUND

2.1 BIM and Digital Learning Techniques in Higher Education

The AECO industry continues to rely more and more heavily on BIM and VDC, which creates a parallel demand for the development of qualified professionals. Around the world, educators work to meet this need and produce students prepared to enter the industry with a solid foundation and eagerness to learn with relation to BIM. AECO industry professionals, regardless of their role, face the reality that their jobs will, in some way, be impacted by the use of BIM and other technologies. With this in mind, instructors work to instill high level management concepts, which still require an underlying foundation of basic modeling concepts, knowing that most students will never be involved with model development in their careers (Lee et al. 2013). The majority of BIM educators focus on the development of BIM process and management knowledge, while working to avoid focusing on product based modeling skills (Wang and Leite 2014). Research has

corroborated the focus of BIM educators on higher level concepts by showing that industry professionals are looking for employees with these skills, which is especially true for students entering the industry with graduate degrees (Lee and Yun 2015; Sacks and Pikas 2013).

The desire for this sort of knowledge in the AECO industry has led to the development and integration of BIM and VDC courses at the majority of institutions with AECO related degree programs. Joannides et al. (2012) reported that 78% of the 67 architecture and construction institutions surveyed stated that BIM was integrated into their curriculum. Of these, 67% of the architecture schools and 53% of the construction schools indicated that they had at least one dedicated BIM course in the current curriculum, while 44% of the architecture schools and 37% of the construction schools reported having two or three such courses (Joannides et al. 2012). The integration and instruction of BIM occurs at three differing levels according to Barison and Santos (2012). The established levels were introductory, intermediary and advanced, which each offer different experiences to students. Introductory courses provide basic software knowledge, intermediary course introduces analysis and management tools such as clash detection and advanced courses are those with an interdisciplinary component which relies on some form of a group project to simulate real world strategies (Barison and Santos 2012). As advanced levels of BIM comprehension are continually expected, pedagogical techniques are needed which can improve the learning efficiency of lower level techniques, e.g. basic modeling or plan reading skills, thus allowing for spending more time developing knowledge of higher level concepts. The use of technology in the classroom is more commonplace now than ever and educators, especially those teaching BIM and VDC, may be in the best position to consider a range of technologies to meet this need.

2.2 Construction Information Systems Course

An elective graduate level course at the Rinker School of Construction Management, University of Florida, entitled Construction Information Systems was selected for use during this study. This course was selected for a range of reasons including the overall course content and rigor of the coursework. Over the course of a semester students are exposed to BIM and VDC processes, developing not only technical but conceptual proficiency related to how this technology impacts the AECO industry. Guest lectures and true to life examples are provided whenever possible to provide a firm basis of understanding for the best practices and methodologies taught during the class. Over the years, this course has evolved to keep up with the development of new technology and workflow practices, while relying on student and industry feedback to enact meaningful changes. These changes are a product of a constantly evolving industry segment and are vital to ensure the students develop the skills necessary for BIM and VDC use in their careers.

The course meets weekly in a three hour block and due to this format students are expected to complete a combination of both individual and group assignments outside of class. The group project and individual assignments were designed in such a way to focus on different aspects of the BIM education process. The individual classwork assignments were designed to focus on technical proficiency and development of modeling and data management best practices based on sound reasoning and advanced practices. The group project required the students to apply the skills they acquire individually to the collaborative and industry realistic BIM development process inherent in any real project. The semester starts with basic skills and gradually introduces more advanced topics, while always ensuring the focus is not on software specific proficiency but rather on best practices and underlying conceptual reasoning. The individual assignments are completed using a set of standard building plans developed specifically for the course. The use of standard

plans allow for an elimination of unknown variables and allows students to focus on specific modeling tasks intended to build their skills and modeling proficiency (Giel et al. 2012). The standard plans used for the course were most recently updated in 2015, to ensure they provide realistic challenges to students while making use of new software capabilities. The goal of this course is to provide students with the skills and underlying concepts which will be crucial in their educational and professional careers, while ensuring that they are exposed to the most current BIM technology and processes.

3. PLANGRID INTEGRATION AND EVALUATION METHODOLOGY

The course used for this study provides students with advanced BIM and VDC skills, providing a breadth of knowledge and experience in order to prepare them for their eventual careers. This study focused on the evaluation of their use of the drawing sets provided in class, as well as the associated time spent on document management. Drawing utilization was evaluated in two parts, survey Part 01 was completed at the conclusion of the semester and Part 02 involved the integration of the PlanGrid platform, and subsequent evaluation, in the following semester. Part 02 of the study was completed after the students completed their first and largest individual assignment, which was the development of an architectural model based on a set of standard plans. The individual assignments were the primary focus of the study because the plans were more modern than the group project, thus reduced uncontrollable variables and lent themselves to the technology evaluation for in this study.

3.1 Document Management and PlanGrid Integration Strategies

Prior to the integration of drawing management software, drawing sets for both the individual and group project assignments were provided as PDFs and students were given a hard copy of the individual assignment drawings. The drawings were shared on the course website and made available to the students for download and viewing on their personal computers. The researchers worked with technologically savvy industry partners to identify potential software solutions for the management and dissemination of drawings during the course of construction. The goal was to select a platform that was actively used in the industry and that would expose students to technology they may be expected to work with upon graduation. In this regard, PlanGrid was selected as the means of document management to be integrated. Beyond document viewing, PlanGrid provides increased functionality including; automatic drawing to drawing hyperlinks, markup capabilities and RFI creation. As a cloud based platform, users have access to the drawings on any web connected device, as well as dedicated apps on most mobile platforms. Figure 1 is an example of the PlanGrid GUI as seen on a PC. It shows the individual sheets, which were auto named and numbered based on the information in their title block. Figure 2 is an example of a sheet with markups and notes that were created during the class. The imbedded RFI tool was used by the instructor as the primary way that students could ask questions related to the drawings. Not only did this provide a way for students to include visuals with their RFIs, but it enabled every student to see others' questions as well as instructor responses. Using this platform the instructor worked to ensure that RFIs were responded to within one business day of the time they were posted and any questions not related to the drawings were able to be asked through standard methods.

Following the integration of PlanGrid, in the second semester of this study, access to the drawings was only made available through the students PlanGrid account. Neither digital nor hard copies were provided to the students as they were expected to use the document management

platform provided to them. Students were provided free access to the software and training during class, by a PlanGrid professional, to ensure adequate instruction was provided for the use of software. The individual assignment drawing set was 33 pages in length and was released to the student by construction discipline as needed. For the group project, each team was asked to select a leader who was given admin access to the project drawings and each group project had between 370 and 700 drawings due to the size of the project. Additionally, students were provided the ability to push notes and markups to the “master set” in the group projects so that they could use it as a collaboration platform as they worked to develop the group project models. The integration of document management software was conducted at the start of a new semester as the researchers felt that altering the mode of drawing dissemination part way through a semester would have been detrimental to the student’s ability to focus on the course content. This decision led to the two part approach used in the evaluation of student drawing management efficiency.

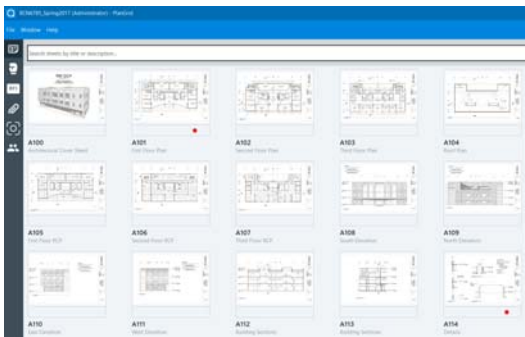


Figure 1. PlanGrid GUI

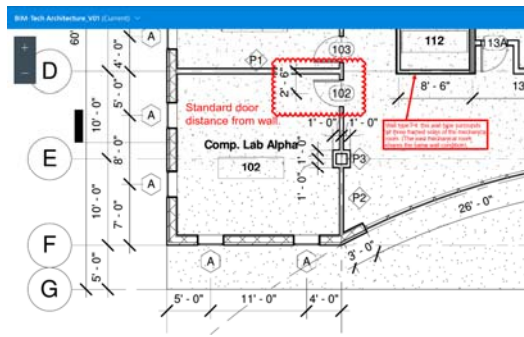


Figure 2. Markups in PlanGrid

3.3 Student Survey

The students enrolled in the course were asked to complete a survey related to their drawing management experience throughout the course of the semester. The survey was developed and distributed using the online survey platform Qualtrics, which enabled the students to complete the survey on any Internet connected device (Qualtrics 2016). The survey was distributed via a link that brought students directly to the survey page. Students were informed that their responses were anonymous and would have no impact on their grade. The surveys for both Part 01 and Part 02 begin with a series of background questions used to determine the students educational background and level of BIM experience prior to enrolling in the course. These questions were followed with two additional sets of questions, focusing on the student’s allocation of time for the completion of assignments and their use of drawings. The survey was provided over the course of two semesters, Part 01 to students at the end of a semester in which drawing sets were provided in pdf as well as hard copy and Part 02 after the students completed their first assignment using PlanGrid in the subsequent semester. The responses were evaluated and summarized using descriptive statistics.

4. RESULTS AND DISCUSSION

The Part 01 survey received a total of 29 responses and the survey completed following the integration of PlanGrid, Part 02, received a total of 18 responses. Of the Part 01 responses, 53.0% of the students had civil engineering backgrounds and an average plan reading proficiency rating of 7.22 out of 10, with a rating of ten being fully proficient and 0 being not at all proficient. The survey from Part 02 reported 66.7% of the students had a civil engineering backgrounds and an average plan reading proficiency rating of 7.12 out of 10. The Part 01 results indicated that 24.0%

of the students preferred digital copies when viewing construction drawings in general compared to 50.0% who preferred digital copies in the Part 02 results. One of the question series asked in the Part 01 survey was whether or not the students would consider using digital drawing management software if it were provided; the ability to notate and collaborate with others, automatically link between drawing pages based on standard drawing navigation markers or if it was web based and tablet compatible. Of those three questions, given the choices yes, no or maybe, the results indicated that 78.3% of the students would consider using the software with the remaining percentage providing an answer of maybe, with the exception of one response of ‘no’ being given for the web based question. In Part 02, since students were already using drawing management software, students were instead asked if they would consider using drawing management software, such as PlanGrid, outside of the class and 77.8% indicated that they would. Beyond the general use and background questions the students in both Part 01 and Part 02 were asked a series of questions related to the individual assignments in the course.

In relation to the individual assignments, the students in Part 01 rated the perceived completeness of the individual assignment drawing set, on a scale from 1 to 10 with 10 being entirely complete and 1 being not complete at all, and provided an average rating of 8.81. The students in Part 02 rated the completeness of the individual assignment drawings at 8.67. In Part 01, 32.0% of students found themselves using digital versions of the drawings compared to 61.1% of students in Part 02. Furthermore, it was found that the students from Part 01 spent an average of 11.04 hours per week on the assignments and that the students in Part 02 spent an average 10.28 hours per week. Table 1 shows the percentage of time that was spent on each aspect of the individual assignments. Table 1 and Table 2 show the percentage of time which was spent on certain aspects of the individual assignments with respect to each of the two survey groups.

Table 1. Percent of Time Allocated to Individual Assignment Aspects (Part 01 - Pre-PlanGrid)

Assignment Aspect	Min.	Max.	Mean	Std. Deviation	Count
Modeling Building Elements	0	80	45.74	21.37	27
Classifying and Naming Building Elements	0	40	15.37	8.6	27
Reading and Interpreting Drawings	0	65	20.74	13.52	27
Researching Information Found in the Drawings	0	30	10.38	7.96	26
Other (Please Specify)	0	100	8.15	19.3	27

Table 2. Percent of Time Allocated to Individual Assignment Aspects (Part 02 - Post-PlanGrid)

Assignment Aspect	Min.	Max.	Mean	Std. Deviation	Count
Modeling Building Elements	30	80	55.28	13.99	18
Classifying and Naming Building Elements	5	50	18.61	10.25	18
Reading and Interpreting Drawings	3	30	15.17	7.34	18
Researching Information Found in the Drawings	0	20	9.06	5.07	18
Other (Please Specify)	0	20	2	5.13	17

4.1 Analysis and Student Open Responses

The comparison between the responses from Part 01 and Part 02 of this study demonstrated some interesting differences given the integration of the PlanGrid drawing management platform for Part 02 of the study. Analysis of the survey results showed that that there was no significant difference in the perceived level of completeness of the drawing sets between the two semesters and that the students for both semesters reported their plan reading abilities to be within 0.1 on a

10 point scale. This provided confidence to the researchers that the results from the two semesters could be compared with no adjustments for student ability or drawing set variances, which was expected as the same drawing set was used for both semesters. Moving forward, the amount of time that students reported spending on the individual assignments reduced a modest amount, 6.9%, between the two parts, but more importantly there was a 5.2% reduction in the amount of time students allocated to reading and interpreting drawings. These categories maximum allocation percentage, as shown in Table 1 and 2, also reduced from 65% in Part 01 to 30% in Part 02. While 5% overall is not a large variance, that time appeared to be shifted to the physical modeling, classifying and naming of building elements. The most important part of BIM is information management and in this regard any approach that gets students to spend more time managing that aspect should be viewed positively and evaluated more closely.

When comparing the mode of delivery students reported preferring, digital vs. hard copy, the percentage of students who preferred digital drawings in Part 02 more than doubled going from 24% in Part 01 to 50% in Part 02. Bearing in mind that this study did not provide hard copies in Part 01 of this study, yet some students did still print the drawings on their own. In this regard, open responses cited the reasoning for this being that they felt restricted by having to switch between the drawings and modeling environment on their computer screens. Even so, the results indicated that beyond preference, the percentage of student who actually used the digital drawings for the individual assignment nearly doubled as well. Finally, the students in both parts of this study were asked which aspects of the individual assignment drawing sets were the easiest, hardest, most effective and most ineffective. Interestingly the student's responses in both parts of this study cited aspects in one of two categories, either the mode of drawing delivery or dimensions and details provided. The students in Part 01 of the study seemed reluctant to move away from the hard copy drawing format that they had become accustomed to while simultaneously stating the advantages and importance of digital drawings use in many responses. In Part 02 there was little to no apprehension in regard to moving to entirely digital drawing sets, with only a handful of comments stating that while they saw the value they found more efficiency in being able to draw on and flip through hard copies. It seemed that the apprehension toward digital drawing sets in Part 02 was largely based on the physical limitations of their screens, while Part 01 was due to the inability to mark up and navigate easily in the pdf drawing sets available to them. While the results of this study indicate changes in the attitude towards digital drawing and appreciation of the efficiency derived using digital drawings a larger sample size will be required to make any generalized claims of significant learning outcome improvement.

5. CONCLUSIONS AND FUTURE STUDY

This study focusses on a new pedagogical technique which aims to increase the students' ability to focus on the core concepts of BIM curricula while providing a more efficient means of disseminating and accessing the drawings they will use. In a course where instructors struggle to have enough time to guide students toward both technological and conceptual proficiency in BIM and VDC processes, any way to improve student efficiency and reduce time spent on secondary tasks can be valuable. The integration of a drawing management software platform has proven to be a success during this study and the majority of students have expressed their appreciation for the use of such software. There are some who still prefer hard copy drawing sets and would print them on their own, but a large majority of the students were able to quickly adapt to the digital drawings. In addition to the reduction in the percentage of time spent on reading and interpreting drawings, many students expressed that they saw this as a good thing for their future careers. One

student in Part 02 of the study stated “I will stick to digital formats as it will help me a lot in the future in my career, even though the shift is a little difficult for me now.” Also in Part 02 one student stated “The shift from hard copy to digital was a little difficult for me but it was a valuable learning indeed.” indicating that students recognized digital formats as a part of their future careers. This sentiment was also found in Part 01 where one student expressed concern over the continued use of hard-copies in an increasingly digital world, one such student stating “I think hard-copy is unnecessary. Students should get used to reading digital formats.” These statements, coupled with the findings of this study, indicate that overall students are ready for and can see an improvement in their educational experience through the integration of drawing management software.

Moving forward the researchers would like to expand the evaluation of document management software beyond PlanGrid to other software platforms and complete a more in depth review of the impact on student learning outcomes over a prolonged period of time. There are a multitude of software platforms which all have inherit advantages and disadvantages, and completing an evaluation of more would provide educators a basis to make informed decisions regarding which to use in their specific courses. Drawing management is a concern for both industry practitioners and educators alike, and this study provides a foundational evaluation of one solution that has found success in the industry leading to potential use cases in academia. As BIM educators seek to continuously improve the experiences of their students, this study provides a review of a software package with the potential to help students more efficiently manage drawings, providing the instructor more time to focus on the important underlying concepts which are so vital to the development of sound BIM and VDC comprehension.

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A CASE STUDY ON HYBRID BIM COURSE DEVELOPMENT

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ABSTRACT

The role of technological innovations is inevitable in Building Information Modeling (BIM) education. As students are often eager to take hybrid and/or online courses, faculty must review their traditional teaching methodologies and work towards combining the online and in-class assignments. One way to embrace the changes in the technology is to ease teaching BIM with hybrid courses. Hybrid courses offer both online and classroom time with flexible teaching and learning. This study focuses on a sample hybrid BIM course designed to teach BIM effectively using video tutorials, learning management system (LMS) and face-to-face meetings. The paper discusses the background of an on campus BIM course to be re-designed for hybrid learning, as well as the steps used for designing a hybrid BIM course. The findings indicate that students highly valued the flexibility and quality of online lectures and the success of achieving learning outcomes in a hybrid class setting. Various challenges and suggestions of hybrid teaching/learning are presented to benefit BIM educators.

Keywords: Hybrid learning, online learning, BIM, construction management education

1. INTRODUCTION

This study was motivated by the online Masters (MS) in Construction Management (CM) degree requirements and students' needs as identified by CM professors and previous students at Philadelphia University (PhilaU). Many students are eager to take hybrid and online courses to take advantage of the flexibility in course design and delivery. Especially students, who are working part-time or full-time want to eliminate travel times and get the most out of the class by combining both in-class and online learning methods. Additionally, with the increase in online masters in CM programs, it is now a necessity to offer online BIM courses. Due to the nature of BIM, these courses include a tremendous amount of software involvement, which may be a challenge to teach remotely. Hybrid courses help BIM educators and students in the transition from in-class format to online format in a sense to combine the best of both delivery methods. The goal of this study is to help educators develop a hybrid BIM course, which will benefit students by combining traditional (in-class) and non-traditional (online) features.

This paper presents a graduate level course, taught at PhilaU, to summarize the steps of the hybrid BIM course development. The course development will include background preparation as well as the teaching means and methods such as video tutorials, LMS, and face-to-face meetings. This study will help to accelerate the online BIM movement, and it can be used as a guideline for educators interested in offering hybrid BIM courses. The results will also benefit educators in terms of understanding anticipated student perceptions and preparedness for the online and face to face components of BIM courses.

2. BACKGROUND ON HYBRID COURSE DEVELOPMENT

Hybrid (as sometimes referred as blended) courses exchange traditional face-to-face time with non-traditional online learning experiences (Dykman and Davis 2008). Face-to-face learning is achieved via on campus class meetings, while online learning can be achieved in both synchronous and asynchronous ways.

Synchronous lectures are real-time lectures, where the instructor and students are online at the same time. Class runs as the same duration as an on campus class, and the instructor delivers the content and facilitates students to achieve learning goals. On the other hand, in the asynchronous version, the instructor records and provides class material on an LMS like Blackboard, so that students can view them whenever they want. The pedagogical characteristics of hybrid courses are defined in three groups as:

- Primary Mode of Communication: Combination of asynchronous (e-mail, threaded discussion), synchronous (virtual classroom for entire class as well as for individual groups) online, and face-to-face
- Course Delivery Method: Combination of Internet and (traditional) lecture
- Percentage of Course delivered via the Internet: Approximately 50% (Black 2002).

The readiness and satisfaction of students in hybrid courses is a major concern. In general, student satisfaction surveys reveals the benefits of hybrid learning in terms of flexible scheduling, self-paced online materials, face-to-face interaction with instructors, and the course format that gives the responsibility of learning on students (Napier, Dekhane and Smith 2011). As the responsibility of learning is majorly on students (especially on the 50% part that is online), it is really important to develop the course in such a manner that allows successful delivery of both face-to-face and online contents.

From educators perspective, it becomes a challenge to create a successful hybrid course in many ways:

- *Time to develop content.* Developing lecture material for a hybrid course is much more challenging than an in-class course. Overall class structure and schedule should be created to allow around 50% in-class and 50% online delivery. In an asynchronous version, the lectures to be delivered online must be recorded by using a suitable software. A hybrid course educator should expect to allocate more time than in-class lectures to record online lectures.
- *Additional work.* Lecture material -like lecture notes or handouts- created for online lectures will be different than face-to-face lecture material. There will be additional activities like weekly quizzes or online discussion boards to track the virtual progress of students. Creating additional lecture material as well as uploading this material to an LMS will be time-consuming.
- *Technological issues.* Educators should be familiar with the software that is used to record courses and with the LMS (e.g. Blackboard) that is used to share the content and post assigned activities. It is suggested to have technical support from Information Technology (IT) departments, especially when teaching a hybrid course for the first time (Ocak 2011).

The process of creating a hybrid course is slightly eased when there is an in-campus version of the class that is current and running. Course material from the in-campus class can be transferred to a hybrid platform by considering the pedagogical characteristics of hybrid courses and expectations of students. Current course material should be analyzed to determine how well it can fit to a hybrid version (Black 2002). Next section will discuss how we -as BIM educators- can be successful in creating a hybrid BIM course that can satisfy student expectations. A case study on a graduate course will be analyzed in detail.

3. HYBRID BIM COURSE DESIGN

An existing on campus course is used to design a hybrid BIM course at the graduate level. *MCM 602: Construction Information Modeling* is the only course in the MS in CM program at PhilaU to teach students the basics and applications of BIM. It is a core course to introduce students the aspects of the related BIM software (i.e. Revit). As the course is a prerequisite for forthcoming *Advanced Construction Management* and *Masters Project* courses, students take this course in their first or second semester upon entering the MS in CM program. Students are not expected to have any previous BIM or Revit experience before taking

this class. The course is scheduled to have 3 hours each week, which are structured as lecture and lab/workshop hours. Lecture hour is used to introduce students the topic of the week and it takes around 60-90 minutes. Following the lecture hour, lab hours are used to allow students to practice the topic of the week on their own, and it takes around 2 hours. Lab time focuses on software application rather than direct lecturing to make sure students get the chance to ask their one-to-one questions to the professor. By this way, students are instructed to develop their modeling skills using the required software through lectures and self-study.

The course is organized so that students advance the software in the first half of the semester, including architecture, structure, and mechanical, electrical, plumbing (MEP) components. Then, they are introduced to estimating and collaboration skills with Revit on the second half of the semester. Through the end of the semester, final project gives students a unique opportunity to create and deliver an actual project collaboratively as a team by using the required software. Table 1 gives the detailed Weekly Schedule for the course. The course requires students to use a textbook: Design Integration Using Autodesk Revit 2016 By Daniel John Stine (Stine 2015), and other required readings are provided by the professor as needed. Upon completion of the course, students will be able to:

- Recognize effective team-based management practices that favorably affect construction strategies
- Understand current and evolving methods of BIM software (i.e. Revit)
- Recognize the concerns of all team members including architects, engineers and owners to be a vital member of the design/management team
- Understand the materials and assembly techniques of construction systems
- Recognize the value of BIM software for Construction Managers
- Apply the required BIM software to architecture, structure, and mechanical, electrical, plumbing (MEP) components
- Practice CM-related BIM skills by using the required software
- Create an actual project collaboratively by using the required software

Table 1: Weekly Schedule of MCM 602: Construction Information Modeling

Week	Topics	Learning Outcomes (Students will be able to)
1	Course Introduction Install software	Learn to install and run Revit Start a new project in Revit
2	Ch.2 (Small Office Building)	Learn basic Architectural elements Create a Small Office Building
3	Ch.5 (Law Office: Floor Plans)	Understand the program statement for a commercial project (Law Office) Place exterior walls, interior walls, doors, windows and curtain walls
4	Ch.6 (Law Office: Roof, Floors and Ceilings)	Create different roof types Add a flat roof to Law Office building
5	Quiz 1	Apply architectural modeling skills learned so far to create a small residential building without step-by-step instructions
6	Ch.6 (Law Office: Roof, Floors and Ceilings)	Create and add floor systems Add ceiling systems
7	Ch.7 Structural Systems	Learn how to transfer standards between a structural template and an architectural project Learn to insert structural elements
8	Ch.11 Mechanical System	Learn how to transfer standards between a mechanical template and an architectural project Learn to insert mechanical elements
9	Ch.12 Electrical System	Learn how to transfer standards between an electrical template and an architectural project Learn to insert electrical elements

10	Quiz 2	Apply structural and MEP skills learned so far to create structural, mechanical, and electrical elements in Revit
11	Project Collaboration Introduction to Final Project	Learn how to start collaboration in Revit Learn to create Central and Local files with Revit
12	Creating Schedules and Takeoffs Final Project outside class working time	Learn how to create schedules and takeoffs in Revit Learn how to export schedules and takeoffs from Revit to other software
13	LOD and BIM Execution Plan Final Project in-class working time	Learn and analyze the level of LOD in a Revit project Learn the definition and importance of BIM Execution Plan
14	Final Project outside class working time	Apply the required BIM software to architecture, structure, and mechanical, electrical, plumbing (MEP) components Practice CM-related BIM skills by using the required software Create an actual project collaboratively by using the required software
15	Final Project	
16	Final Project Submission	

In its initial setting, the course was delivered solely on campus, and students were expected to attend all lectures and labs. Additionally, they were encouraged to ask their questions during lab hours and office hours to receive face-to-face feedback, and via emails to receive online feedback. When the decision was made to design a hybrid course, a Strengths, Weaknesses, Opportunities, and Threads (SWOT) analysis was performed (**Table 2**).

Table 2: SWOT Analysis for Hybrid BIM Delivery

Strengths	Weaknesses
<ul style="list-style-type: none"> Combines the best of face-to-face and online There is no travel time for online lectures Students can access lecture material through Blackboard at any time Students can watch the online lecture more than once Students receive both face-to-face and written feedback Students get to learn at their own pace during online lectures Very convenient for students who work part/full-time, as the schedule is flexible 	<ul style="list-style-type: none"> Having one week on campus one week online may confuse students, and they may miss courses Students may not easily adopt to Blackboard and its user interface Asking questions via email may be challenging for students
Opportunities	Threads
<ul style="list-style-type: none"> Online platform offer networking opportunities Construction industry is evolving and expect CM graduates to use online tools Allow to achieve transition to full online delivery 	<ul style="list-style-type: none"> Unforeseen technical issue both on Blackboard and in Revit Traditional students may not accept the idea of online/hybrid delivery

As strengths of the hybrid delivery were apparent, a step-by-step procedure was followed to revise the on campus BIM course and re-design it for hybrid delivery. The steps are as given below:

- 1) Review On Campus Syllabus (including delivery method, policies for attendance, submission of assignments, grading, and method of communication)
- 2) Revise Weekly Schedule
- 3) Create New Course Material to Introduce Hybrid Teaching (i.e. set student expectations)
- 4) Create Video Lectures
- 5) Revise Assignments and Quizzes

- 6) Revise the Method of Teaching
- 7) Format Blackboard to fit into Hybrid Teaching
- 8) Test the Hybrid Course Structure and Get Feedback from Students

3.1 REVIEW ON CAMPUS SYLLABUS

Policies for hybrid courses should be created differently than on campus courses. On campus courses have the availability to get in touch with students on a weekly basis and update or correct the information on the syllabus. For hybrid courses, a big challenge is the use of internet and web-based communication tools. In creating the hybrid BIM class, the Professor should meet with students on the first class and set the scene for hybrid delivery:

1. Explanation of the delivery method: instructional strategies should be clear to students. They should be informed about what the hybrid delivery is and what they should expect from the class setting.
2. Emphasize the use of web-based communication tools such as emails and Blackboard: students should check emails and Blackboard on a daily basis. Preferred method of communication with the Professor is via emails.
3. Policies for attendance: what is on campus attendance and what is virtual attendance, it should be clarified that they need to come to on campus courses.
4. Policies for assignments and quizzes: all submissions will be through Blackboard. For online lectures, students still need to watch the video lectures and complete assignments on time.
5. Access to video lectures: clarify how students can access to video lectures, state when the video lecture will be available (which time and date each week), and give them a demo on how they can watch them. Also, explain how the video lectures should be used. As an example, my expectation for students was to watch each exercise two times, first time to get familiar and second time to practice it themselves. This guarantees the success of learning through videos.

3.2 REVISE WEEKLY SCHEDULE

Weekly Schedule for hybrid delivery should mark on campus and online dates. In *MCM 602: Construction Information Modeling*, I assigned online lectures every other week, so that I can see students every two weeks to make sure about their progress. I try to schedule online lectures on holidays like Labor day. As they are given a whole week to watch the video lectures, weeks with holidays can be used for improving students' performance. It is also a good strategy to schedule quiz dates as online lectures. By this way, students are given flexibility to complete their quiz without physically coming to the class.

3.3 CREATE NEW COURSE MATERIAL TO INTRODUCE HYBRID TEACHING

Many students who start taking hybrid courses are not really knowledgeable about its definition, as well as benefits and challenges. I prepared a presentation to students to inform them on hybrid and online courses. This presentation is shown on the first day of classes. After the presentation, they are given tips to succeed in a hybrid class. Students still have the opportunity to ask face-to-face questions to the Professor. They are repeatedly suggested to email or come to office hours to ask their questions. Especially during online lecture weeks, students should demand extra help if needed. It is very important to make this clear to students, so that they do not think online lecture weeks do not include any question and answer sessions.

3.4 CREATE VIDEO LECTURES

This step is the most time consuming part of creating a hybrid course. After updating the Weekly Schedule to decide on which topics will have video lectures, a suitable software should be selected to record videos. In *MCM 602: Construction Information Modeling*, Screencast from Autodesk was selected to record video lectures (Autodesk 2016). Screencast is compatible with Revit to record videos and it has the capability to track keystrokes and show them on the video. It gives students the opportunity to see their professor's mouse movements and clicks when they are trying to create or edit an element in Revit. After recording, videos are stored in user's Screencast account. They can be downloaded or can be shared via links.

3.5 REVISE ASSIGNMENTS AND QUIZZES

As expected assignments and quizzes should be revised to fit into the hybrid setting. In *MCM 602: Construction Information Modeling*, all assignments and quizzes are collected via Blackboard. Emailed submissions are not accepted for grading, as they confuse both parties in terms of grading. There are two steps in revising assignments. The first one is the content. The content and language of assignments and quizzes should be very clear so that students will not need to ask any face-to-face questions. As they will create assignments and quizzes outside the class time, they should be given detailed instructions. Secondly, it is important to decide on the format of submissions. They can be RVT files or PDF prints from Revit. In a hybrid setting, it is not suggested to collect paper copies as on campus lectures will happen bi-weekly. Grading and returning paper copies will not give students enough time to correct their mistakes on an assignment before the submission of the next one. Additionally, as students are directed to contribute to an online setting, performing grading on Blackboard will require them to use Blackboard on a regular basis. For *MCM 602: Construction Information Modeling*, PDF files are collected for assignments and both PDF and RVT files are collected for quizzes. Blackboard gives the ability to enter feedback to students' assignments and quizzes. All feedback and comments are entered to Blackboard to make sure they are visible to both students and the professor.

3.6 REVISE THE METHOD OF TEACHING

Teaching strategy in hybrid setting should be different than in a fully on campus class. As the professor gets to meet with students on a biweekly schedule, the face-to-face time should be used effectively not only to deliver the content, but also to introduce hands-on and collaborative activities. One important item that is lacked in an online setting is the limitation on collaboration. Therefore, on campus classes should include team activities related to the content. For example, in *MCM 602: Construction Information Modeling*, Project Collaboration lecture is an on campus lecture. Students are instructed on how to start collaboration with Revit and then, asked to create their own Central and Local files. Afterwards, they get to practice requesting permissions as a pair activity. This class has a final project that requires creating the Revit model of an actual construction project. Introduction of the final project and creating the teams to work on the project are also performed in class to make sure students know the expectations of the project and exchange contact information of their team members.

When students experience issues during a hybrid class, they sent emails to the professor. Although the queries are solved via emails or during out-of-class meetings, still on campus classes should have a timeframe to discuss common issues of students. By this way, all students will be aware of common problems in Revit and they will also build upon their problem-solving skills.

3.7 FORMAT BLACKBOARD TO FIT INTO HYBRID TEACHING

Blackboard or any other LMS system should be re-designed to include all class material online. Suggested approach is to create weekly modules on Blackboard that will appear on a certain day and time each week. Consistency is very important, as students will know when they will see video lectures and other materials

on Blackboard for each week. Assignment and quiz drop-boxes should also be created with detailed instructions on what to submit and how to submit. All drop-boxes should have a due date. It is also suggested to have the same day and time as due date for each week's submissions. For *MCM 602: Construction Information Modeling*, all assignments and quizzes are due at the beginning of class and video lectures are available to students again at the beginning of class. This setting prevents students from mixing and matching due dates.

3.8 TEST THE HYBRID COURSE STRUCTURE AND GET FEEDBACK FROM STUDENTS

The hybrid BIM course was first tried in Spring 16, and since then the class is offered each semester. Students are surveyed each semester with questions about their previous Revit knowledge, assessment of student learning outcomes, and hybrid BIM course delivery. 65% of students who were taking *MCM 602: Construction Information Modeling* had none or very low Revit knowledge. 100% of students agreed that they understood the current and evolving methods of Revit and BIM better after taking this class. This percentage shows that the content of the class is 100% successful in one of the learning outcomes mentioned previously. 65% of them said they learned Revit better when they have access to both on campus and video lectures. Additionally, 55% said they watched the video first before they try to do the exercise themselves. 90% of students were agree or strongly agree on the success of hybrid BIM course design, only 10% did not find it beneficial. Actually, it is an expected results, as traditional students, who value face-to-face interactions more than any other delivery are not satisfied with hybrid or online courses. Additionally, this percentage is expected to increase when students face technical issues. All students agreed or strongly agreed that hybrid course design gave them flexibility in their schedule, which is one of the generally accepted benefits of hybrid/online courses.

Students were also asked about the content of the video lectures to be able to improve them in the future. 50% of students said the content was just enough to understand the basics of each chapter in the textbook, while 45% said video lectures included more than enough to cover the textbook chapters. There is no side effects to include more than enough information on video lectures, as students have the flexibility to fast forward if they need to skip some sections of the video. One of the questions asked students on how much outside-of-class time they spent on assignments per week, and 50% selected 3-4 hours, while the remaining 50% selected more than 4 hours. It is apparent that hybrid courses require more of students' time, as they need to watch the video and perform exercises on their own. So, on average all students spent more than 3 hours per week to successfully finish assignments.

Finally students were asked if they understood the importance of BIM and Revit better after taking this class, and 70% selected strongly agree and 25% selected agree. Having 95% ration on recognizing the value of BIM for a CM student shows the success of hybrid delivery in transferring BIM and Revit knowledge and importance to students.

A comparative analysis of the results was performed to evaluate the performance of students by comparing average assignment scores. The goal was to see if there was a significant difference between the performance of students in face-to-face and hybrid courses. The results (Figure 1) show a significant increase in average assignment grades from face-to-face to hybrid delivery styles, which supports the findings of the above survey. Possible causes of the increase in class average are the strengths of hybrid learning as given in Table 2. Especially the flexibility of watching video lectures more than once and allowing students to learn on their own pace are signature advantages of hybrid delivery over traditional/on campus delivery methods.

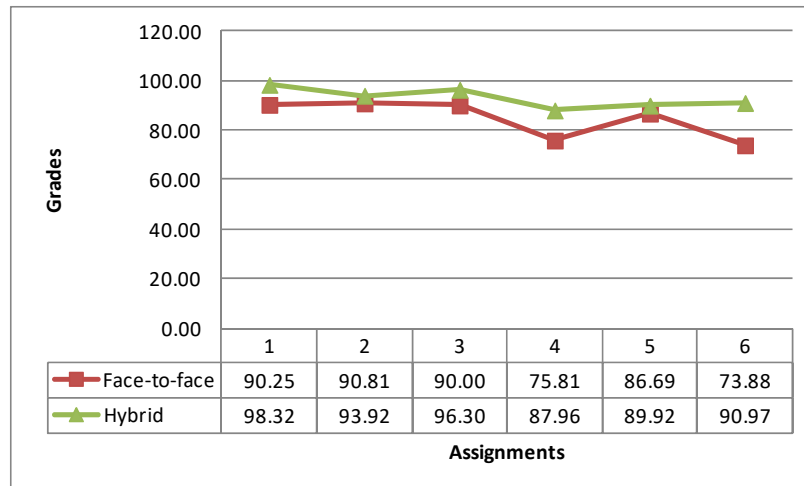


Figure 1: Comparison of Average Assignment Grades between face-to-face and hybrid courses

4. CONCLUSIONS AND FUTURE WORK

This paper addresses the design steps of a sample hybrid BIM course. The sample course effectively uses video tutorials, Blackboard, and on campus classes to achieve student learning outcomes of the class. The results show the success of hybrid delivery in terms of content and quality of video lectures. They also show that student learning outcomes are achieved successfully with an organized hybrid classroom setting where expectations from the class are set at the beginning of the semester and students are given clear instructions on every step of the course. It should be noted that the sample class is a graduate course. At the graduate level, students appreciate the flexibility that a hybrid class offers and they want to learn BIM basics and Revit as feasible as possible. Video lectures give them the opportunity to learn in their own pace whenever they are available. This is especially appreciated by students who work part or full-time.

This study shows the successful outcomes of a hybrid BIM delivery, however it should be noted that the background work on updating weekly schedule, creating video lectures, and formatting Blackboard are very time consuming steps for educators. Unless they have enough time and appropriate resources, they should not experiment with hybrid BIM delivery. Additionally, teaching a software program remotely brings its own challenges, like making sure students can run Revit outside the campus. Despite the cons, the pros of hybrid delivery are proved in this research to be applicable to BIM courses. The next step of this research is to create a fully online BIM course. Eliminating all on-campus meetings will bring additional challenges to be studied and overcome in the future.

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THE FEASIBILITY OF REMOTE INSPECTIONS BY CODE OFFICIALS

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ABSTRACT

The aging population of code officials is becoming a concern to the construction industry. For example, over the next decade, 50% of the building code officials in the state of Utah will retire. This trend is similar to other states. With this large amount of turnover, there is a concern about being able to replace the departing code officials. This problem will be magnified with the labor shortage being experienced throughout the construction industry that will most likely limit the potential replacement candidates available to fill code official openings. Solutions need to be found that will allow the limited number of code officials to accomplish their work more efficiently. This paper researches the feasibility of remote building inspections and disseminates the findings of the pilot study that was conducted. The researchers worked with code officials to perform remote jobsite inspections using cellular technology. This technology could utilize code officials in training by allowing them to aide in the inspection process while the inspector remained in the office.

Keywords: Building Code Official, Remote Inspection

1. INTRODUCTION

Throughout the construction process, buildings must be constructed in accordance with a standardized set of codes established by governmental authority that promote public health and safety. The building codes often result from past tragedies in an effort to prevent them from occurring in the future. Byrne stated that “the codes were written blood” (Byrne 2011), meaning that past deaths tend to form and shape the codes (Williams, 2015).

Building code officials are responsible for inspecting and ensuring construction meets these regulations. What is sometimes misunderstood, is that there are various certifications for building officials. A typical path for a person to become a code official is to start by inspecting single family residences. As they do this, they are gaining experience in what to look for as a code official. From there they start branching out to various other specialty areas of inspection. There is a broad spectrum of certificates that code officials need to perform selected inspections. The graphic below was created by Williams (Williams, 2015) to help explain the spectrum of certifications that are required for the various specialty inspections.

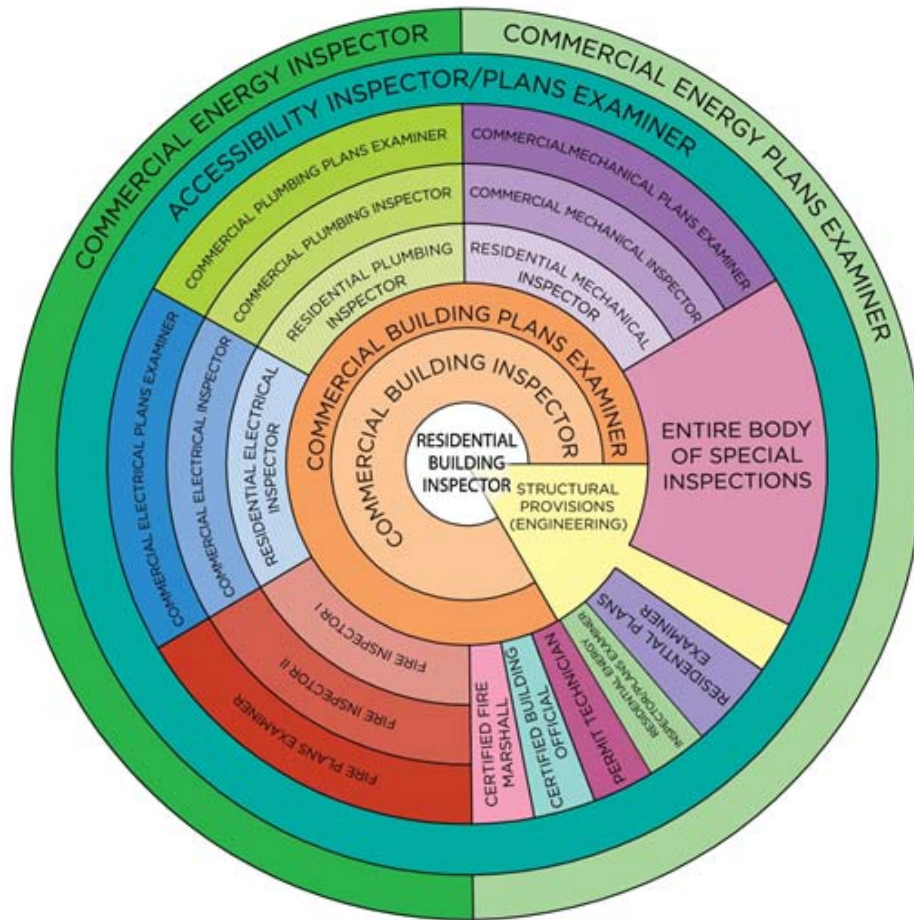


Figure 1: This diagram displays the various certifications building code officials can acquire. As code officials progress in their career, they often become specialists in certain areas of inspection. This graphic provides a visual of these specialties.

In a study conducted by Williams in 2015, it was found that over the next decade, more than 50% of Building Code Officials in the state of Utah will retire. A similar study on a national scale was also conducted and found similar results at the national level (NIBS 2014). As these experienced code officials retire, there may be insufficient replacements to fill their vacant positions. The general construction industry is experiencing a labor shortage. Many code officials have come from the construction industry trades. This labor shortage may be compounded for code officials as studies have found that younger professionals are not entering the industry at a significant rate (NIBS 2014).

This loss of experience could also pose a problem when training new code officials. Without experienced code officials, there will be a lack of individuals available to train\mentor the new generation of code officials. Additionally, the work load of the remaining code officials is not expected to decrease, therefore a solution needs to be found which will increase the productivity of the code officials while allowing them to train\mentor the new code officials. Performing remote inspections could be one method to increase the productivity of the remaining workers while simultaneously training the next generation of code officials in the industry.

Remote inspections allow code officials to remain in an office setting while less experienced individuals are located at the construction site. These less experienced individuals connect to the code official and live-stream video between them. The video allows the code official to guide the individual around the site

to perform the inspection. This method focuses the code officials' time on productive work saving the travel time to the various sites allowing more inspections to be performed per day. Additionally, the less experienced individual is gaining experience of how to perform the inspection. The process allows for one on one training\mentoring while increasing the number of inspections performed by the code official. Through this process, several less experienced individuals receive instruction from a single code official in the same day, maximizing the time of both the official and those in training.

Previous to this research, an application known as VuSpex was introduced that allows companies to perform these remote inspections. A fee of \$29.95 is required of contractors for each inspection session. This application includes features such as location data, inspection groups and types, and permit numbers. Along with these features, VuSpex allows contractors to record the inspections and store them for later reference.

Many of these features would be beneficial for remote inspections. One concern with this application, however, is the cost. The researchers' intent of performing remote inspections is to make it more convenient and cost effective. Requiring a fee for each use eliminates some of these benefits. Inspections are critical for the integrity and safety of buildings. Charging a fee could be a deterrent to implementing this approach to performing inspections remotely.

Another potential shortcoming of this approach is that it relies on the contractor to operate the remote video stream which creates the potential for the contractor to avoid showing areas of the project which may contain code violations. This approach is a little like the fox watching the hen house.

2. MATERIALS AND SOFTWARE

This research was completed by a professor at Brigham Young University (BYU). He was assisted by a freshman in the Construction & Facilities Management program along with a building code official currently in the industry who provided background knowledge and aided in the research process.

For this research a smart phone (iPhone 6) was used to live-streaming the inspection to the office where it was received by a Windows Surface Pro 3 & 4. To allow for clearer communication, Bluetooth headphones were used by the student on site that had a microphone attached. A headlamp was used to light dim rooms and a selfie stick was used as an extension implement to reach greater heights and maneuver the smart phone into difficult areas.



Figure 2: The headlamp, selfie stick, and Bluetooth headphones with a mic were used in the research.

Throughout this research two video applications were used: Skype and Zoom. Zoom was used the majority of the time because it allowed for video recording while Skype for Business was needed to record the video. The researchers chose to record the inspections so they could refer back to the inspection to identify what would help the process. However, in actual practice, it may not be necessary to record the inspections.

3. EXPERIMENTATION WITH REMOTE INSPECTIONS

Once the researchers had established a working system, they began to experiment on actual construction sites. The first site was a 3-building, steel-framed, multi-story commercial project located in Provo, Utah. The goal of this visit was the following:

- Determine what connectivity issues might exist on a working construction site,
- If the image quality would be satisfactory to perform an inspection remotely,
- How the dynamics would function with a code official guiding a person around a project to perform an inspection.

The student researcher was accompanied on site by a representative from the contractor while the code official and the faculty researcher were remote and provided guidance to the student researcher and the contractor representative.

From this experience, the researchers discovered that more equipment would be necessary to successfully execute remote inspections. While being guided through areas under construction, it was difficult for the student researcher to hear the directions given by the remote code official. A second problem also experienced was that it was difficult to climb a ladder while holding the cell phone. Other concerns that arose during this visit included a loss of signal in the basement of the building, drainage of the iPhone 6 battery, and insufficient lighting that caused visibility issues in the image received by the remote code official.

Solutions to the above problems were as follows:

- Bluetooth headphones were purchased which provided clearer communication during inspections.
- A selfie stick was purchased which allowed for the device to be extended to greater heights, eliminating the use of a ladder.
- The contractor had purchased a smart phone amplifier device for the project. The student researcher used a different smart phone carrier and was unable to take advantage of the amplifier. Using the contractor's Wi-Fi may also be an additional solution.
- An external portable battery could be used to provide additional power for the inspection.
- A headlamp was purchased for additional lighting. The researchers discovered that the light on the smart phone could not be accessed while using Zoom. The headlamp provided sufficient light and was a hands-free solution.

The second site visit was to a single family residence projects in Bluffdale, Utah. The purpose of this visit was for the student researcher to accompany an inspector to gain an understanding of what code officials are looking for during an inspection. This provided the researchers with a chance to gain experience with the inspection process. There was additional time available for the visit, so the student also accompanied the inspector to multi-family project and shadowed the inspector on a framing inspection of a multi-family project as well as a footing inspection of a single family residences.

The purpose of this visit was primarily for the student researcher to observe an experienced code official during an actual inspection. From this she learned that inspections become almost instinctual to the individual the more they are performed. With the first residential house, the code official was able to move through the tasks at a fairly quick pace. He knew what to look for and how to use his time effectively. Realizing this, it would take time and experience for the remote worker to become comfortable with each type of inspection. This is one benefit to having a licensed code official directing them through each project. While it does require practice, the less experienced person being trained could benefit greatly from the opportunity to participate in these remote inspections.

On the third site visit, located in Eagle Mountain, Utah, the student research was sent to the inspection site and met a contractor representative there to perform a mock 4-way inspection. The official 4-way inspection was actually performed the day before by the local municipality. No additional work had been performed on the jobsite between the time that the official 4-way inspection had been performed and the student researcher's visit to the site. The student researcher and the remote code official did not have access to the official inspection report prior to the mock 4-way inspection being performed. The remote code official had access to the plans and specifications for the project. This allowed the inspector to know where to guide the student researcher to verify that what was built was in compliance with the documents for the project. The student researcher was guided remotely around the job site and performed the mock 4-way inspection. The inspection completed by the researchers was then compared to an inspection completed by another Code official the previous day.

When compared, the two reports showed several differences. Each inspection referenced unique items in need of correction and follow up. As an example, the first inspector made a note to ensure there was a 15” attic access depth while the remote inspector noticed a double stud was required beneath the double truss by the stairs in the living room. This difference could be a result of the difference in code officials. Throughout their career, building code officials have different experiences. The code officials also may develop preferences in which items they feel are more important in the code than others aspects of the code. Therefore, code officials may have different things they look for when inspecting a project. Because of this, different code officials doing the same inspection, may find different items to be corrected. When asking a code official for their reaction between the two inspections, he was not surprised at all and said that was a typical outcome.

Through the third mock inspection, the researchers were able to experiment with the additional gear they had purchased. The headphones provided clearer communication between the student researcher on-site and the remote code official. The selfie stick provided a way for the student to maneuver the device through some of the ventilation ducts allowing the remote code official to view the manufactures labeling to ensure the correct size had been used. This would not have been possible without a ladder had the selfie stick not been used.

The image quality during this mock inspection was a concern. Maneuvering the smart phone too quickly around the project caused the video to come across pixelated. If held steady, the image would focus and become clearer, however it required slow steady movements. Further research was performed to determine whether a higher quality camera could provide a clearer image. The researchers found, however, that the Zoom application could only support up to a certain number of mega-pixels. However, the imagery was clear enough that all the small print on the labels were readable. An additional benefit to the remote inspector was that they could zoom-in on the imagery and could read text that may have been too small to read in the field.

4. REFLECTION AND CONCLUSION

From each on-site experience the researchers discovered ways in which they could better their methods. More equipment was acquired with each inspection. It was found that the Bluetooth headphones, with a mic, greatly improved the communications between the remote code official and the on-site person. The selfie stick allowed for the inspection to be completed without the use of a ladder. A headlamp provided additional lighting while maintaining a hands-free environment.

With the Zoom application, the live-streamed inspection has the potential to be recorded. A recording of each inspection would consume large amounts of storage space, however it could be beneficial to have the information documented and saved for future reference. How long the video could or should be stored as well as whether still images should be saved will be the subject of future research.

Through the three site visits that were conducted, it appears that remote site inspections could help alleviate some of the conditions created by the retirement of code officials. Since code officials rely so heavily on certifications coupled with experience, remote inspections allow for experienced code officials to inspect more projects while providing on-the-job training to individuals that may become future code officials. The hardware needed to do this (smart phone, Bluetooth headphone with mic, and selfie stick) is readily available, widely accepted, which should make implementation in industry easier.

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CURRICULUM TO PREPARE STUDENTS FOR BIM-ENABLED GLOBALLY DISTRIBUTED TEAMWORK

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ABSTRACT

Globalization and the increasing adoption of BIM and other technologies in the AECO industry have changed the way we prepare our graduates for the digital workplace. Social skills and professional interaction cannot be taught in traditional lecture-based classes. Social skills are learned by interacting with others. This paper presents curriculum design where students from five different universities worked together in teams both in real-time and asynchronously to develop design and construction proposals. The curriculum innovations here addressed some of the challenges these universities found in working together, namely coordinating semester start and end times as well as time zones. The East Asian universities typically start in March, while the US universities start in January and the Indian universities start in February. The result of these staggered starting dates was that the courses only had a 2 week overlap, where some students were wrapping up their course while other were just starting theirs. The solution was to create a collaborative project that occurred in two phases. Phase 1 included University of Washington in Seattle, WA, USA, and IIT-Madras in Chennai India. Phase 2 included Washington State University in Pullman, WA, USA and National Taiwan University in Taipei, Taiwan and National Cheng Kung University in East District, Tainan, Taiwan. The course provided the opportunity for students from these global universities to work together on a multi-disciplinary, interdependent project where teams created BIM models and developed 4D simulations of the construction sequences. In this paper, we describe the evolution of the course, learning outcomes and evaluative criteria, lessons learned based on faculty and student feedback, and proposed course design moving forward. We found that these projects impressed upon the students how important BIM Execution Planning is for distributed teams, and how challenging communication and coordination can be across time zones and cultural differences. Along side of practicing with technology, and working through technical challenges of exchanging BIM data and using models created by others, the students learn and practice leadership and coordination in globally distributed team environments.

Keywords: Building Information Modeling, Global Collaboration, Digital Literacy

1 INTRODUCTION

With current communication technology, distributed teams are becoming more common in the construction industry. Distributed teams and the increasing adoption of building information modeling (BIM) have changed the way we prepare construction management graduates for the current workplace. In the 2014 SmartMarket Report, 75% of global contractors reported a positive return on investment in BIM with the number one reported benefit being reduced errors and omissions and the second highest reported benefit being the ability to collaborate with owners and design firms (McGraw Hill Construction, 2014). As a

result, contracting firms are increasingly expecting new hires to be prepared to work with BIM technologies. Additionally, because improved collaboration technologies allow firms to reach out to talent across the globe, much of the collaboration in the AECO industry takes place in distributed teams (Harty & Whyte, 2009; Nayak & Taylor, 2009; Rezgui, 2007). Therefore, there is an increasing need to prepare construction management students for a BIM-enabled workplace where they will be expected to work in collaborative environments (Ahn, Annie, & Kwon, 2012; Zhao, McCoy, Bulbul, Fiori, & Nikkhoo, 2015).

Construction and engineering accreditation bodies have acknowledged this need for change with recent updates to accreditation requirements emphasizing coursework in collaborative teams and use of technology to accomplish work. In order to meet accreditation requirements of the American Council for Construction Education (ACCE) and the Accreditation Board for Engineering and Technology (ABET), undergraduate construction management and construction engineering programs, respectively, must develop curriculum that incorporates application of technology to manage the construction process and apply construction management skills as part of a multi-disciplinary team (ACCE), and understand the impact of engineering solutions in a global, economic, environmental, and societal context (ABET). Construction management programs are tasked with developing curriculum that teaches students how to work collaboratively and develop technological skills. This paper describes a project that incorporates these elements and outlines the challenges of implementing these goals in the context of a global team project.

2 BACKGROUND

Construction management (CM) programs are increasingly adopting BIM courses into their curriculum (Abdirad & Dossick, 2016; Becerik-Gerber, Gerber, & Ku, 2011). In 2012, a survey of construction schools indicated that 53% have a BIM-dedicated course as part of their existing curriculum and 40% offer two or three classes that implement BIM (Joannides, Olbina, & Issa, 2012). Because BIM is often used in collaborative functions such as 3D coordination and site logistics planning, many programs are developing courses that incorporate a multi-disciplinary collaboration element (Fruchter, 2006; Soibelman et al., 2010). Few institutions, however, incorporate both BIM and collaboration in a single course (Zhao et al., 2015).

The literature emphasizes advantages of colocation such as the ability to engage in impromptu sidebar conversations or discovery and discussion through pointing or sketching, resulting in a trend in the industry to collocate project teams (Boland Jr, Lyytinen, & Yoo, 2007; Dossick & Neff, 2011; Ewenstein & Whyte, 2007; Kemmer, Koskela, Sapountzis, & Codinhoto, 2011; Staub-French & Khanzode, 2007). However, members of AEC teams are often involved with several projects simultaneously (Rezgui, 2007) and with the increasingly global nature of project teams, it becomes impractical to meet face-to-face. Because the construction industry is heavily reliant on visual media for the communication of ideas, globally distributed teams are challenged with finding an effective way to communicate with models and drawings over distance, mediated by technology, but this becomes difficult when collaborating via e-mail, for example. As the use of both BIM and global collaboration become more prevalent in the industry, there is a need to further understand how to manage global work and associated challenges.

This paper describes a globally distributed course project in which students learn to work collaboratively with multicultural and multidisciplinary teams using BIM tools and various digital communication technologies. The project was designed to replicate a collaborative and BIM-enabled scenario they may encounter upon entering the AECO industry. In this paper, we present the evolution of the course, project objectives, lessons learned based on student feedback, and proposed course design moving forward.

3 COURSE DESIGN AND PROJECT DESCRIPTION

The Global Team project was part of a 3-credit undergraduate (400-level) construction management course at Washington State University and a 3-credit graduate construction management course at the University of Washington. Students at the non-U.S. schools were also graduate students. Students in the U.S. were asked to meet with their global teammates outside of scheduled class time, typically late in the evening due

to the time difference between U.S. and non-U.S. schools. Students from non-U.S. universities took the lead in setting up initial meetings as part of their project management responsibilities and the U.S. students were responsible for developing a BIM Execution Plan, resulting in all students ultimately taking responsibility for producing work and meeting deadlines. The intent of the project design was for students to work collaboratively and interdependently.

The objectives of the global team project were as follows:

- To give students an opportunity to increase their understanding of the practice of distributed team project management and BIM execution planning in the context of a global team,
- To expose students to advanced tools for project collaboration and planning, and
- To help understand how global virtual design teams can work together effectively.

This project built on lessons learned from a similar course offered in the spring of 2015 in which students from seven global universities were participants (Dossick, Homayouni, & Lee, 2015). With each university having different academic start dates and holidays, faculty encountered challenges when trying to coordinate their schedules. As a result, some universities joined the project later than others and students found it difficult to integrate their roles because they had little familiarity with the project and no input in the early stages. Faculty revised the global team project schedule and format the following year, Spring 2016, to resolve the issue of conflicting academic schedules – that is, rather than having one common starting date that forced some universities to join the project late because students were still on break at the start of the project, the new format staggered the start date such that two universities started early and the remaining three universities started on a separate project several weeks later. The result was a project with two parts (Part I and Part II) that were loosely coupled. The results described in this paper focus on Part I of the project, but a description of both parts is provided below.

3.1 Part I Project Description

Two universities, Indian Institute of Technology Madras (IITM) and the University of Washington (UW), participated in Part I of the project. For a total of 15 teams, 2-3 UW students were paired with 3-4 IIT students. Part I was divided into two modules. In the first two-week long module, IITM students modeled an addition to a residential house located in Chennai, India, using Autodesk Revit while UW students developed a construction schedule. UW students then integrated the model and schedule to create a 4D model. At the end of the first module, the entire team reflected on what they would do differently if they had to do it over. The second module was a more complex four-week project. UW students developed a BIM execution plan, IITM students modeled a new structure in Revit, and UW students used 4D modeling tools to develop a schedule and determine ways to reduce cost. After analysis, the 3D and 4D models were optimized and resubmitted.

Table 1. Module 1 Schedule of Tasks

Week	Week Of:	Task	Deliverables
1	Feb 1	First Virtual Team Meeting 3D Model (3 room addition) Construction Schedule	3D model (revit) Construction Schedule (excel, MSPProject, or P6)
2	Feb 8	4D Model Project I Debrief Meeting	4D Model (NWD + .AVI) Debrief Memo

Table 2. Module 2 Schedule of Tasks

Week	Week Of:	Task	Deliverables
3	Feb 15	Project II Kick-off	Draft BIM Execution Plan

Week	Week Of:	Task	Deliverables
4	Feb 22	3D Model Construction Schedule	3D model (Revit) Construction Schedule (excel, MSProject, or P6)
5	Feb 29	4D Model	4D Model (NWD + .AVI) Debrief Memo
6	March 7	Presentation Prep	Final Presentation
7	March 14	Presentation to Part II Teams	Recording of Presentation

The 2nd module design was used to allow the teams to "learn the hard way" in Module 1 and immediately apply those lessons learned in Module 2 through a guided BIM Execution Planning process. The learning goals included global team collaboration (e.g. setting expectations across the team for deliverables) as well as exploring the use of 3D and 4D modeling analysis to design and construct the example projects.

The Part I universities completed their portion of the project in mid-March and as a final deliverable developed a presentation that described their portion of the project and lessons learned. As the project transitioned from Part I to Part II, an all-team meeting with students from the five participating universities planned to meet in Sococo where the Part I teams presented to the Part II teams. The Part II universities, National Taiwan University (NTU), National Cheng Kung University (NCKU) and Washington State University (WSU), then commenced their portion of the project.

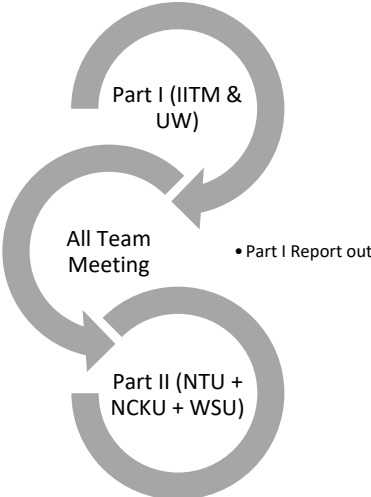


Figure 1. Global Team Project Structure

3.2 Part II Project Description

Fifty graduate and undergraduate students participated in the Part II portion of the global collaboration project: 25 students at WSU, 9 students at NTU, and 16 students at NCKU. Students from the participating universities divided into 15 teams to match the number of teams from Part I. At WSU, the 25 participants were placed on teams of either 1 or 2. NTU placed 3 of their 9 students on each team, meaning that each student was assigned to meet with 5 different teams. NCKU had 1 or 2 students on each team. The total number of students on each team, therefore, was either 5 or 6. Among the 25 students at WSU, there were 21 seniors, 1 junior, and 3 sophomores. The sophomores and junior were paired with seniors so at least one senior was on each team at WSU.

In Week 1, the Part II students were asked to meet in Sococo, a commercially-available 2D collaboration environment that allows users to video chat, text chat, and share screens. Students from NTU

were given the role of project managers and meeting facilitators. During this meeting, they were to decide on a regular weekly meeting time and be introduced to the Virtual BIM Reviewer (VBR), a 3D virtual world developed at NTU in which students could import their 3D models and explore them as avatars.

In Week 2, WSU students were tasked with developing a BIM Execution Plan modeled after the Penn State BIM Project Execution Planning Guide (Messner et al., 2010). As part of their plan, they had to determine (among other things) participant roles, project milestones, deliverable due dates, meeting procedures, model structure, and file exchange protocols. NCKU students developed Autodesk Revit models for structures to be placed in southern Taiwan (Shanlin, Kaohsiung) on a piece of land at the base of a mountain. The team was to assume modular construction with as much of the structure as possible being prefabricated off-site for rapid assembly on site. Local labor, materials, and off-site facilities were to be used.

In Week 3, the team was tasked with reviewing the 3D model and discussing the schedule. WSU used this information to develop schedules in Primavera P6 for off-site prefabrication and on-site assembly.

In Week 4, WSU developed a 4D model in Autodesk Navisworks using the Revit model developed by NCKU and their own construction schedules. Running the construction simulation allowed them to visualize errors in the model or schedule and identify potential optimizations, which were to be incorporated into the next iteration. NTU also performed a structural analysis and shared the results with the team.

In Weeks 5 and 6, the models were optimized and re-analyzed. Teams prepared a 15-minute presentation for delivery in Week 6 describing the project and lessons learned regarding global collaboration.

4 METHODOLOGY

Both direct and indirect assessment methods were used to evaluate the success of learning outcomes. This paper reports on the indirect assessment methods of collecting survey data from the UW participants. Student participants submitted surveys at the end of Module 1 and Module 2, as well as addressed what they learned in terms of teaming and project execution in their final presentations. We followed human subjects procedures, and 9 out of 15 student teams consented to be part of the research.

The survey included:

- Meeting date, start time, and end time
- Communication methods used (e.g. Sococo, e-mail, Google docs, VBR)
- [Likert Scale] Satisfaction Level (1-7, 7 being very satisfactory)
- [Open-ended question] Things you liked about the global team project
- [Open-ended question] Difficulties: Project issues, Communication issues, Tool issues, Other issues
- [Open-ended question] Lessons Learned
- [Open-ended question] Suggestions for next year's class

The results were analyzed both as a general pool as well as on a per team basis.

5 FINDINGS

Overall, the level of satisfaction of most of the teams was high. Although, satisfaction decreased from Module 1 to Module 2 from a total of 76% to 64%. Many of teams shifted from an extremely high satisfaction level to a neutral. Main reasons of this shift were frustrations due to a lack of on-time delivery of models and promptness of correspondence (E-mails and messages). There were a lot of last moment meeting schedule changes, which was mainly due to the time zone difference and the daylight saving time change. Also, collaboration on Sococo was problematic because of bandwidth/internet issues on the IIT side. Screen sharing feature was under utilized and many teams resorted to texting or voice over IP (VOIP)

interactions. Miscommunication was another reason of this shift. A lot of teams reported that many a times all the team members were not included in the email thread leading to loss of information and communication. This is also reflected from the data where there is an increase in the low level of satisfaction from 4% to 8% while transitioning from project one to project two. Few of the teams were seen to move from high to very high level of satisfaction. This was mainly due to higher collaboration through more number of meetings, usage of other communication technology (WhatsApp) and rational division of work. In summary, some teams were able to overcome the technical challenges with communication and became more satisfied with their project, while others struggled with logistic (setting meeting times), communication (finding tools that worked for everyone), as well as setting and meeting expectations in terms of the model development.

Three primary themes emerged from analysis of the open-ended responses to survey questions:

- Teaching students how important a comprehensive BIM Project Execution Plan (PxP) is for the success of a project.
- Working in multi-cultural teams was beneficial to students
- Large time differences and poor connectivity discouraged synchronous communication.

The students conducted Module 1 without a formal BIM PXP. They then had the opportunity to create a plan for Module two and work with that plan. The learning goals here are to have the students learn through the challenges of coordinating with their IIT counterparts in Module 1 and then apply these lessons in Module 2. From an instructional design point of view, the authors found that in prior years, students did not know what to ask for in terms of model requirements until after they had created a model. This two-module design allowed the students to learn the "gotchas" of using a 3D model created by someone else, and then apply this knowledge in the creation of the Module 2 plan.

6 DISCUSSION/COURSE DESIGN MOVING FORWARD

Exploring multi-cultural teams was a main theme in the survey results. The global team design allowed the project to feel more real and applied. This increased the general engagement in the students. As one student reported: "Getting new friends and working with people with different culture helped me learn many things." Another student reflected that an impact of a diverse team provides a benefit for bringing in new perspectives to the design problems at hand: "It was fun interacting with people who had their own sort of creativity. For example, if we had made the Revit model, we would have thought of the room additions differently as opposed to our Indian counterparts. So creativity was enhanced in the process and also evoked a sense of responsibility and excitement especially implementing what you just recently learnt in class on an actual small scale real time project." From the instructors' point of view, once the global team starts, the energy of the classroom increases significantly. Students are engaged, sitting up and paying attention because they are working to address a complex project in the global team and are excited about the opportunities of the technology.

In the survey, we asked what they liked about the project. Figure 2 is a summary of the answers for this question with working with an international team most often mentioned:

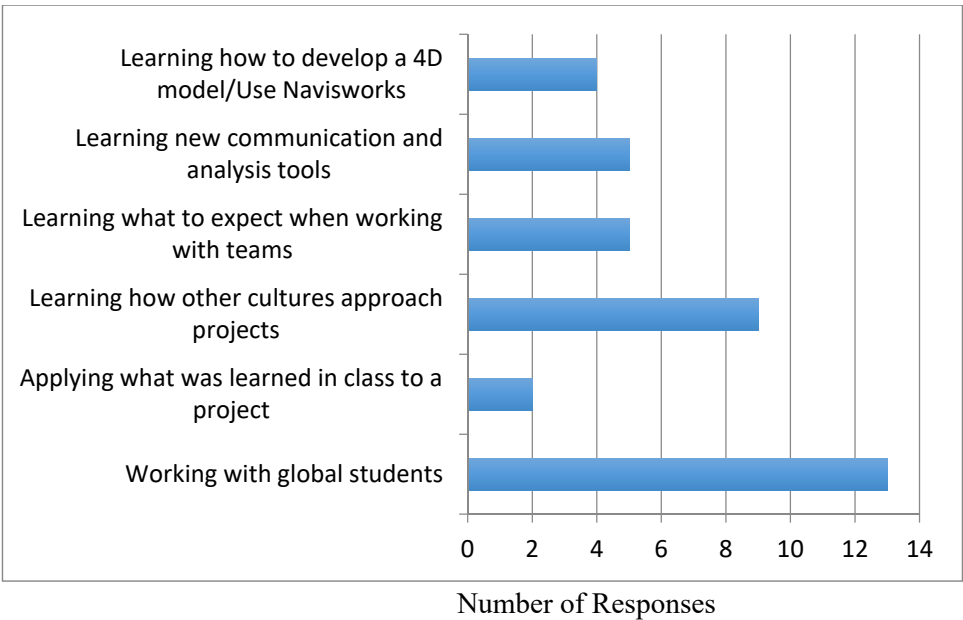


Figure 2. Responses to Survey Question: What did you like about the project?

Another primary theme included learning about technological leadership. For all of the teams, large time differences and poor connectivity discouraged synchronous communication. Many of the teams became creative with new ways of connecting. As one student described the challenges with the technical communication platform we provided "The main issue we had was using Sococo. It was ineffective for our group meetings. There was an issue with a model where the railings were flickering during the video, but we figured out a way to mitigate the effect." Another student reported challenges with "the time difference between two countries." But many teams overcame these challenges with using Whatsapp messaging applications as well as file sharing technologies such as Google Drive, Dropbox, and Google Docs. Figure 3 provides a summary of the common technologies the students used in this project. Finally one student observed the learning opportunities by describing the global team project as one that "improves one's creative skills, facilitator skills as well as technical skills considerably."

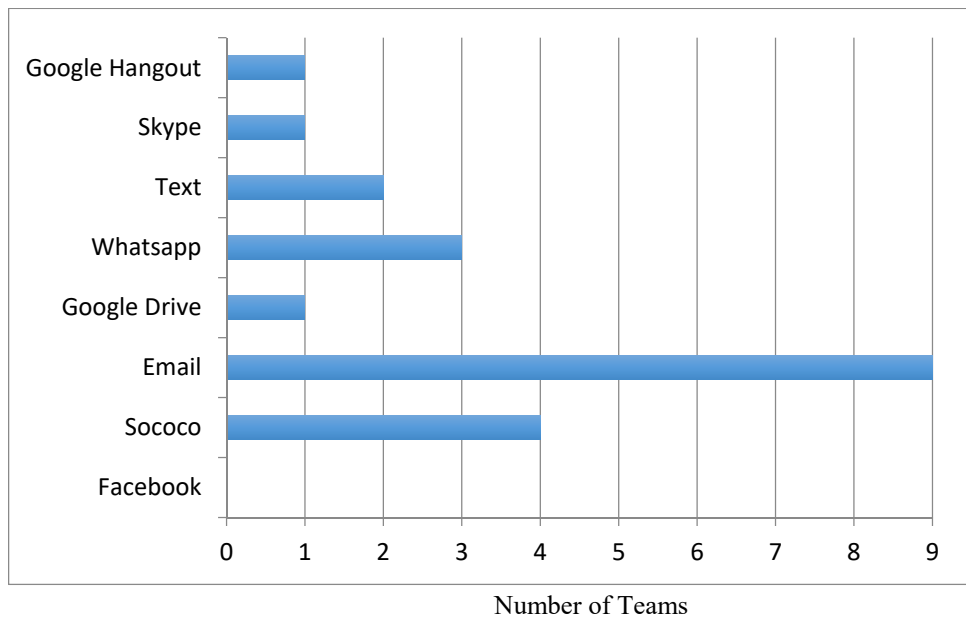


Figure 3. Communication Methods Used by Part I Global Teams (Weeks 1-6)

Student feedback, both positive and negative, indicated they learned critical lessons about the importance of planning and developing a comprehensive BIM PXP. Part I of the project, at UW and IITM, is divided into two modules where the second module builds on lessons learned from the first module. Moving forward, this model may also be adopted in Part II so WSU students had an opportunity to first learn the importance of developing a comprehensive plan, then apply that lesson in the second module.

When students were asked for suggestions regarding next year's class, the most common response was advice for students who will be taking the class next year: the importance of communicating deadlines to teammates. The most often recommendation related to collaboration and communication, as one student suggested: "I advise them to dedicate themselves to the team work involved in Global team projects; this would help them learn many things beyond just 3D/4D modeling" Other suggestions included using better communication tools, using the BIM execution planning strategies, communicate early and often and cultivate a learning environment (see Figure 4).

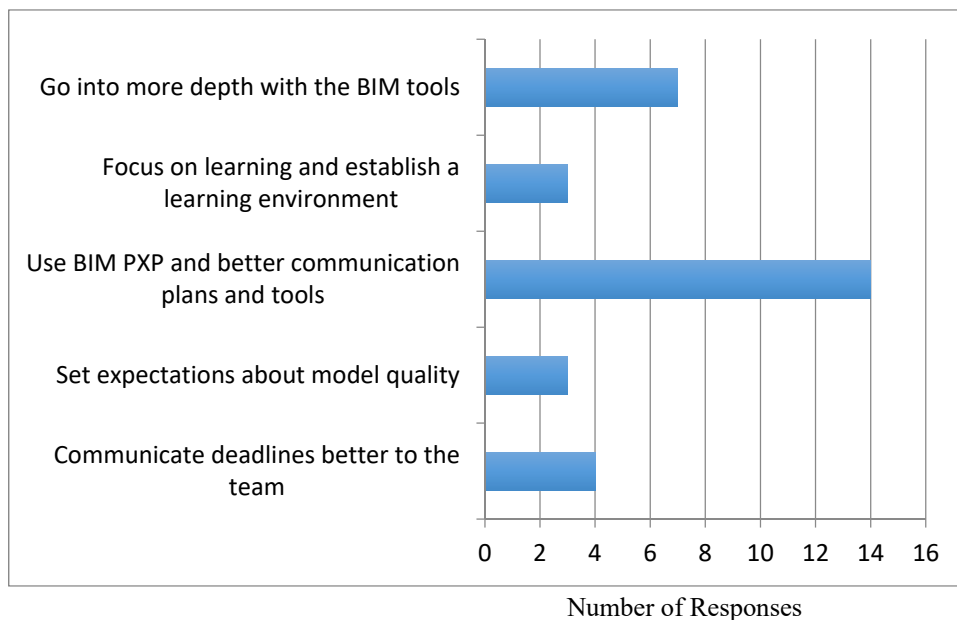


Figure 4. Responses to Survey Question: Suggestions for next year

7 CONCLUSION

Results indicate that students learned the importance of developing a BIM Execution Plan, discovered the value of various tools for collaboration (some were more useful than others), and developed an awareness of different cultural practices in the construction industry. However, further research is needed to understand how the challenges of larger time differences can be addressed while maintaining advantages of synchronous collaboration. Considering that students chose to communicate primarily through Whatsapp (Figure 3), we would like to explore the role of social media as a collaboration platform and possibly as a course delivery method. Next year's survey will ask students to reflect on their own role in improving communication among the team and how technology (both BIM tools and collaboration platforms) affected the collaboration process.

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STUDENT-DRIVEN ACTIVITY FOR FM-BIM MODELS CONTENT DEFINITION

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ABSTRACT

This paper presents a review of different approaches taken over the last ten years in developing Facility Management BIM models for educational as well as for practical implementation purposes. It also draws lessons learned that are currently being applied in contemporary educational activities at the Worcester Polytechnic Institute (WPI) and at the Universidad Autonoma de Yucatan (UADY) under their respective academic curricula.

Keywords: BIM, Facility Management BIM Modeling, BIM-based Educational Activities

1. INTRODUCTION

The benefits derived from the use of Building Information Modeling (BIM) increase as this enabling technology is integrated into a collaborative environment not only during design and construction but it is also extended over the lifecycle of the facility. As the adoption rate of this technology continues to increase within the Architectural/Engineering and Construction industry more owners of public and private projects are also incorporating BIM requirements into their Request for Proposals and contracts for design and construction services with clearly defined extensions for the use of BIM models into the future operation and maintenance of their facilities as well as for asset management and space utilization.

Some large government organizations as well as academic institutions have led the way in defining those BIM requirements and have well-established practices in this regard. There are however many more owner organizations still trying to understand more specifically where and how the use BIM can benefit them.

WPI project-based educational program allows for experimentation of new ideas through a collaboration of industry and academia in which student and faculty partner with industrial sponsors in the development of these project. These projects include junior Interactive Qualifying Projects (IQPs), senior Major Qualifying Projects (MQPs) and graduate theses and project research (Salazar, et al, 2013). The extended use of BIM models from design and construction into facilities management has been explored for many years now through these projects to the point in which some of these concepts are now being gradually implemented during the design and construction of the new Foisie Innovation Studio facility currently under construction. At the same time the lessons learned over these years at WPI are now being implemented at UADY through a research study in which low-cost laser 3D scanning technology is being used in the generation of BIM models for existing buildings. These concepts are

gradually incorporated into the class material for undergraduate and graduate courses and to some extent becoming part of the operational information practices at the academic institutions.

2. BIM & FACILITIES MANAGEMENT

The Facility Management process (See Figure 1a) covers a wide variety of tasks going beyond the performance of operation and maintenance of the buildings and grounds and keeping records and inventories of facilities and their maintenance schedules at operational level. It can be considered a total process that operates at three levels: strategic, where key planning decisions are made; tactical, where analysis and design processes take place; and operational, where implementation and day-to-day running of facilities processes are handled. A key element for the success of effectively managing the maintenance of the assets is to have continuous and reliable information about the asset inventory, condition, and performance. Quality information comes with a price, therefore organizations should consider the approach of acquiring the information and the potential for the sub-utilization of such information (Alvarez 2014).

The use of Building Information Modeling (BIM) technology has been widely adopted and well-used

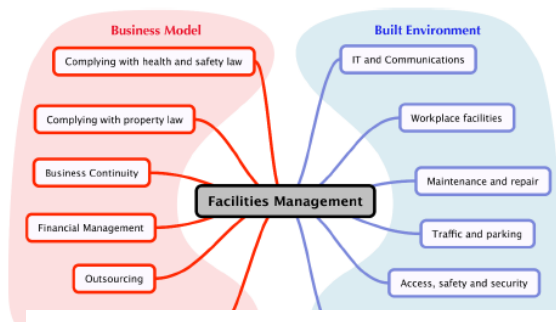


Figure 1a Facilities Management;

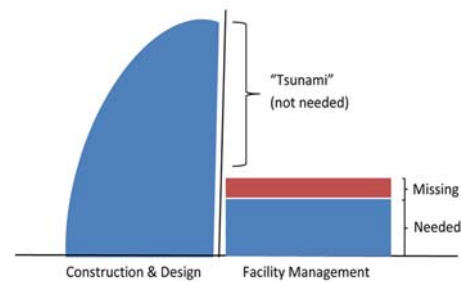


Figure 1b BIM and the “Tsunami” effect

by the architecture, engineering, and construction (AEC) industry through all stages of design and construction, however, the same is not necessarily true during the operation and maintenance (O&M) stage. A BIM model has the potential to reduce and simplify the collection of information needed by Facilities Management staff since a significant part of it has already been gathered and stored in the model (Nawari, 2012). Nonetheless, is not clear how much of the information generated at early design stages of the project through construction and commissioning is useful for the FM staff (this is known as the “Tsunami” effect, see Figure 1b). Also, one needs to determine the way in which the model should be prepared so it has only the required information by the FM staff to properly support O&M operations. As a consequence owners need to determine ahead of time how and to what extent BIM is going to be used for FM in their projects.

The adoption of BIM models for FM processes is a challenging issue for owners because FM staff does not necessarily have the knowledge and skills to implement BIM or either manipulate the model for FM operations or because the owner does not have the experience in using BIM during O&M. On the opposite side, designers and contractors are not always familiar with the FM information and requirements that the 3D model must have to be useful for O&M activities (Giel et al., 2015; Liu, et al. 2015). Much work has been done addressing this issue, (Becerik-Gerber et al. 2012; Alvarez, 2014; Shalabi et al., 2016), to assist owners in this task. The National Institute of Building Sciences has recently published the National Building Information Modeling Guide for Owners document (NIBS, 2017) with the purpose of guiding building owners in developing and implementing their goals and requirements when BIM applications are used internally or externally as well as in explaining how to include these goals and requirements in contracts for design, construction, and operation of buildings. However, each owner needs to customize this information according to their own needs and context. These are the cases of WPI and UADY. Their experiences in adapting and adopting these guidelines are discussed next.

3. WPI EXPERIENCE

Over the last twelve years several educational initiatives at WPI have been coordinated with the Facilities Management (FM) department in order to explore efficient ways of incorporating the continuous advancements in information technology and BIM modeling into their information management practices. In all this work there are a few fundamental questions that are critically asked in order to identify the value added of BIM technology. These are:

- What information is essentially required by FM?
- What information that is created in the BIM model during design and construction can be effectively used by FM?
- What information that is needed by FM but not currently created in the BIM model can be added to the BIM model during design and construction?
- What are the most efficient ways to organize the transfer of information to the owner at the completion of the project?
- What is the most efficient way for the end user to have access to this information
- How should the information be maintained and updated during the project lifecycle?

The material herein presented addressed these questions in different ways and to different extents.

The E-Campus Project. A series of undergraduate Interactive Qualifying Projects combined with a couple of MSc research projects were conducted by several groups of students between 2004 and 2010. In these studies Geographical Information System (GIS) and Building Information Modeling (BIM) were first combined in an attempt to produce integrated site-building models for the WPI campus (Salazar et al, 2016). Among other objectives, these studies collected information and developed a common database to support grounds and buildings operation and maintenance (Currier, et al, 2004; Pestileo, et al, 2005). More specifically information related to parking areas (Dumas, et al, 2004), trees and planting beds on campus (Ahmed, et al, 2006) was stored in the GIS database whereas building-related information to track environmental hazards and fire safety equipment on five campus buildings (Samdadia, 2004; Brault, et al, 2005) were created and stored within the BIM model database. The information from two database systems was then combined into a relational-database system. See Figure 1 below.

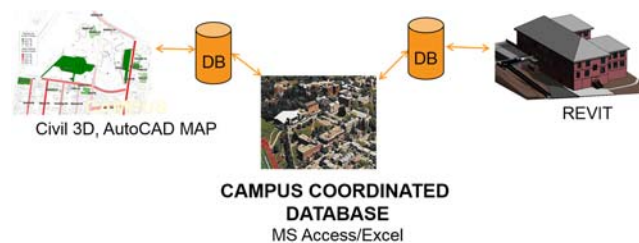


Figure 1 GIS-BIM Campus Coordinated Base

The above effort was conducted with a global and conceptual view in mind but through separate efforts in terms of time, facilities and systems, The question of how to make the information accessible to the end user in a simple way was addressed by MSc research using the Internet (Mendez, 2005) and it is presented in the next section. At about the same time, an IQP project (Halilaj & Mills, 2006) proposed a conceptual Graphic User Interface (GUI) to coordinate and facilitate access to all 100 buildings information on campus, see Figure 2.

This proposal presented a complete concept and was implemented through a PowerPoint file having hyperlinks pointing to specific slides within the PowerPoint file containing information for a only a couple of buildings. A later research project (Liu, 2010), worked close with the operations group of the FM department and further elaborated on the content of information for the Kaven Hall BIM model leading to the inclusion of including objects for some mechanical components and adding a sample of

inter-connecting building systems, including water, sewer, fire, steam systems. It also proposed a procedure to coordinate student activities with the FM department for future development and update of BIM models on campus.

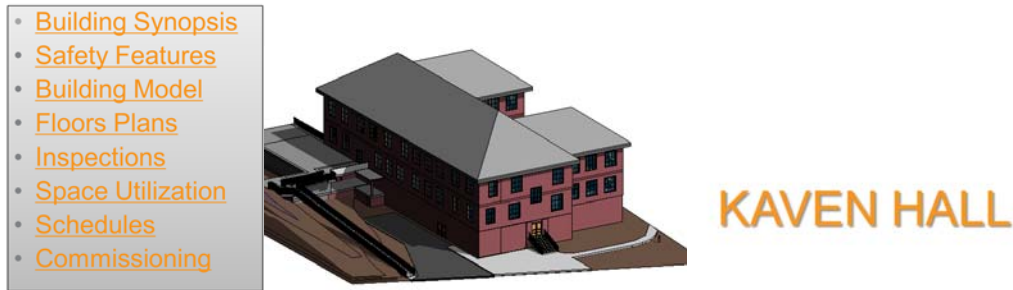


Figure 2 Graphic User Interface for each building on campus

The Bartlett Center. The Bartlett Center, is a 16,589 square-foot tow-story facility housing the WPI Admissions office. It was WPI's first "Green Building" with silver LEED certification. Construction on the Bartlett Center began on February 2005 handed over to WPI on 1st June 2006. A student Master Thesis research project (Mendez, 2006) explored the use of the Internet to create a website for storing and making available information created by the contractor during construction and submitted to the owner at the completion of the project. This information included, as-built drawings, samples of operational and maintenance manuals, warranties and guarantees and submittals (see Figure 3). At the same time, an architectural Building Information Model of the facility was created out of the 2D drawings with the intent of generating additional information about the building like total and partial floor areas according to functional uses and to having the Facilities Management department use the model as the mean to access it.

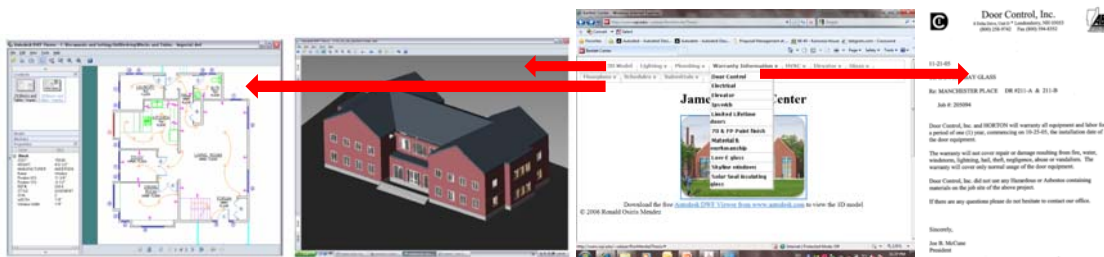


Figure 3 Bartlett Center Website (Mendez 2006)

The use of the internet facilitated the accessibility to the information as intended. This work was presented to the BIMForum leadership group and was positively considered for its practicality when in 2010 the use of BIM models for owners were starting to be explored. However, the use of the BIM model did not meet expectations mainly because of the lack of familiarity with the use of software by end-users and their reliance on the use of printed 2D Floor Plans reinforced by the many years behind this practice. The current use and adaptation of tablet computers and smart-phones as well as the increased use and access to “cloud” storage has substantially removed these barriers but there is still a high preference by facility management staff for 2D images as opposed to 3D displays as the visual reference framework to access information.

The Recreational & Sports Center. The WPI Sports & Recreation Center is a 140,000 square foot recreational, educational, and environmentally friendly facility. The building was completed in the summer of 2012 and BIM models were created by the designer and the construction manager for this project but not shared contractually. A MQP (Bertin, et al. 2011) and a PhD thesis (Alvarez, 2014) were dedicated to study what information from the BIM model was of use to the FM and how the information contained in the BIM models could be used for FM purposes. The information handover was delivered by

the main contractor in digital format through a DVD and organized by CSI trades. The package included a total of 540 files, however, only 442 files contained useful information. Table 1 below shows the nature and type of this information.

Count of Link	Column Labels					
Row Labels	DOC, DOCx (Word)	DWG, DXF (Autocad)	PDF (from digital)	PDF (from hard copy)	XLS (Excel)	Grand Total
Drawing			92	160	2	254
General Information					1	1
Guarantee	1		2	1		4
Inspection	2		1	7		10
O&M Manual	1		40	51		92
Specifications	1		10	10	1	22
Warranty			17	42		59
Grand Total	5	92	230	113	2	442

Table 1
Summary of documentation in the Rec. Center handover (Alvarez 201)

It was observed that there is redundancy in the information in terms of drawings stored as PDF and DWG format. The drawings included Bidding and As-Built documents showing some inconsistencies in room numbering and level naming. Names of the files were a cryptic and very short with no clear indication of what is included in the drawing. Operations and Maintenance (O&M) Manuals, Specifications, Warranties and Guarantees, comprised most of the remaining documents. However, these documents were of different types and not indexed making future queries for information very time consuming.

The information handed over on this project also included a BIM model provided by the designer who used the model only for the purposes of project visualization and presentation as well as for the production of coordinated 2D construction documents. The original model was updated by WPI students who modified the original room numbering assigned by the designer system to reflect the final assignment of room numbers assigned by the owner. Some of the elements not required for facilities management were filtered out. This step created a lighter version of the model for facilities management purposes. The model parameters were modified following the exchange requirement proposed in the research (Alvarez,2014), which are in compliance with the FM-Basic Handover model view definition, plus some extra parameter needed for FM according to the what was specified by FM staff. Figure 4 below shows a screenshot of the model as it was successfully structured with the added parameters in accordance with the IFC standard, combined with COBie and Owner specifications and linked to PDF scanned documentation using the proposed model view definition.

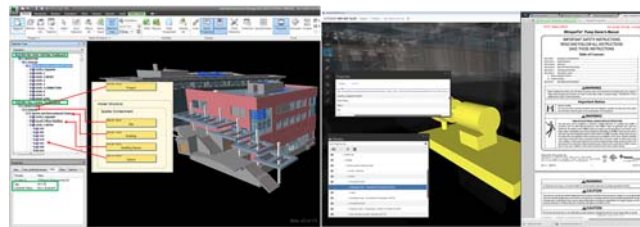


Figure 4 Rec-Center model with IFC compliant attributes and links to PDF warranty documents

The students research proposed an approach for making the documentation available for the FM users through a shared folder. However much work on classifying and sorting information was still required to make the system truly functional. In addition, recommendations were made for structuring and standardizing the file management system. Overall, these studies provided in-depth understanding of the BIM-based process and of the information needed by FM.

Project Center and Salisbury Labs. These studies concentrated in creating and using of BIM model of existing buildings. Two of the oldest buildings on campus: Project Center and Salisbury Labs were

initially chosen to explore the value of BIM in the operation, maintenance and space management of these buildings. The first building is a small and relatively low complex layout building whereas the Salisbury Labs is the opposite. The BIM models were created from existing 2D documentation that for the most part were outdated and to some extent inaccurate with regards to inner layout dimensions. Therefore, it was necessary to physically verify many of the measurements.

Space parameters such as Room Number, Gross Area, Net Usable Area, Net Assignable Area, Floor Finish, Number of Work Stations / Capacity, Use of the space (type) and Space assignment (department) were of main interest to the FM staff who were to be the primary users of these models. Therefore, graphic information about the buildings was to be presented in 2D which is the preferred mode for the FM staff. The space-related parameters were presented in colored thematic plan in multiple pre-defined views for layouts linked to specific information and accessed by the user via a tablet computer. The BIM model file format was DWFX and available through the SharePoint file system, see Figure 5.

Three sessions of training on how to access and querying the model was conducted with FM staff and instruction material was created for future reference. The facilities management staff embraced the technology, particularly when it is presented in 2D floor plans. At the same time they welcomed the new features such as the ability to retrieve information on the use of floor space.



Figure 5 Sample view of floor plans in Salisbury building and SharePoint repository

Massport Parking Garage A recent MQP project (Hunt & Torres, 2016) sponsored by Massachusetts Port Authority was conducted using the Framingham Parking Garage facility to learn how this institution uses BIM-based information for Facilities Management and to determine ways to improve the efficiency and level of integration of the process. The students created a template to help investigate better practices for data collection and to incorporate data into the existing BIM model. They also explored potential improvements for the interoperability between BIM model and the Computer Maintenance Management System (CMMS). A handover process guidelines were proposed for this project.

It was found that the issues related to Massport BIM-based practices for FM were not too different with regards to the issues faced by WPI's FM department and confirmed the validity of the approaches followed by WPI student activities. However, the specific needs for information between the two institutions are not necessarily the same and the level of engagement at institutional level with regards to BIM practices is also different. It was recommended an earlier engagement and incorporation of FM-related data in the design process to improve data integration in making the process more efficient. It was also recommended to invest in FM-user friendly software and training to make the use of the information easily accessible to the final user.

Foisie Innovation Studio Currently, a MQP project is being conducted by students to document the process by which WPI, the designer and the construction manager involved in the construction of the Foisie Innovation Center, shown in Figure 6, are coordinating FM related information from design to construction completion and handed over the owner (Doskocil & Vaitkunas, 2017). In this case, the RFP documents used to invite design and construction professionals for this facility contained an explicit statement requiring BIM-based capabilities from these professionals. However, no specific terms were included in the contract to define the scope and extent of the use of BIM in the contract language.

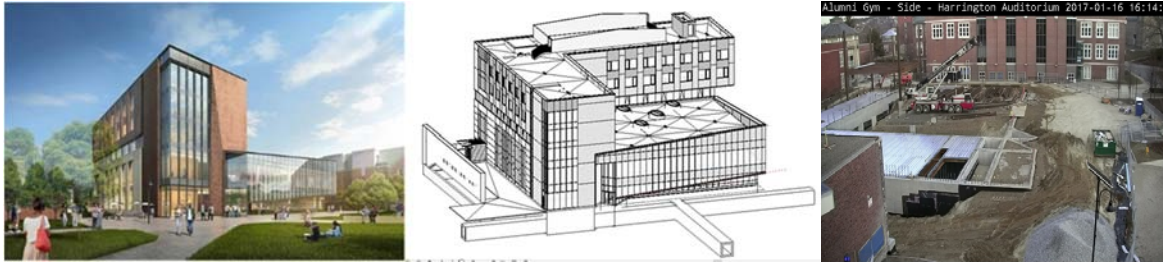


Figure 6 The Foisie Innovation Studio

As a result a very interesting and iterative collaborative process has taken place among the owner, designer and construction manager that has “forced” WPI to think critically as to what information, is really needed, what is desirable and what is not needed. Also, this has provided an opportunity to deeply examine the role of BIM in this process and what are desirable uses. Finally, specific type, structure and content of data, including BIM-models to be handed to the owner at the completion of the project has been clearly defined. The students have played a catalytic role in this process in reviewing all previous work conducted at WPI to-date and in promoting the dialog among project participants.

It has been agreed that the CM will incorporate building objects with their corresponding information into the BIM model that are of primary interest to FM staff. This information, which is primarily of the MEP type will be part of the record model and will be exported into a spreadsheet feeding directly into WPI’s CMMS system. Subcontractors are required to provide this information in their submittals.

WPI BIM Guidelines. Another important contribution coming from current student MSc research (Padhye, 2017) work is the production of the BIM Guidelines document that summarizes and organizes all BIM-related experiences acquired in generating, classifying, storing, retrieving and updating information as needed for FM purposes (See Figure 7a). It is expected that these guidelines will be formalizing all learned lessons as of today in terms of procedures and will allow WPI reap the benefits



Figure 7a: WPI BIM Guidelines;



Figure 7b Master System Architecture that

can be derived from the implementation of BIM practices on campus extended to the use of WPI’s CMMS, see Figure 7b

4. UADY EXPERIENCE

UADY is conducting research sponsored by PRODEP, a Mexican government agency, through undergraduate and graduate students projects to test two low cost technologies for semiautomatic measurement of existing buildings as an input for creating BIM model for O&M and space management.

The two technologies tested in the research are photogrammetry and the use of a low cost 3D laser scanner. Both methods produce a 3D point cloud that can be used as a reference input, to build the model using a BIM authoring tool. The main drawback using photogrammetry for interior spaces is the accuracy of the 3D point cloud based on factors such as light reflection and the camera’s field of view in crowded spaces like mechanical rooms. Exterior spaces of building action cameras mounted in low cost quadcopters, and even phone cameras produced great results (See Figure 8). Two software tools were

used with similar results: Autodesk Recap 360 and Agisoft Photoscan. Their use depend on the complexity of the captured scene.



Figure 8 3D point cloud of the exterior of a facility, produced from pictures of a cell phone

A low cost 3D scanner is a handheld scanner, that uses an infrared sensor connected to a tablet and produces an accurate 3D point cloud (See Figure 9) which in the case of interiors of mechanical rooms, is more than enough to serve as an input for creating the BIM model. This technology produced 3D point cloud with high accuracy, which cannot be matched when using photogrammetry. However the handheld scanner uses an infrared sensor that cannot be used for scanning in the exterior of the buildings because of daylight blinds the sensor. The range of the sensor is limited to objects closer than 12 ft, which make large rooms, or high rise ceilings, difficult to scan. A handheld scanner costs is about 5% of the cost of a 3D laser scan.



Figure 9 3D point cloud of a crowded mechanical room, created with the handheld scanner

The use of these technologies can be proven very beneficial in terms of accuracy and measuring time when it comes to acquiring physical data of existing buildings. However, one should consider the time involved in registering the position of one scanned space in relation to other scanned space, This time depends on the layout and the visibility of common space among the different spaces. Therefore, one should not ignore the benefits of manual registering.

5. CONCLUSIONS AND FUTURE WORK

The work above discussed spans over 12 years and has been conducted in the context of WPI's educational plan in which student projects are tightly related to real projects. This work has been extended to educational activities at UADY. The fundamental questions involved in the use of BIM to support FM activities have been gradually and systematically investigated to the point that WPI is in much better position to determine what it wants expects and what it desires when it comes to using BIM for FM.

Figure 10 below, makes an attempt to subjectively quantify the contribution that each of the projects discussed has contributed to the resolution of the issues raised by the research questions. It can be observed that there is no 100 percent resolution for a single case but collectively a significant progress and understanding has been accomplished and the later cases are very close to full resolution of the issues.

The ongoing student research conducted at UADY and at WPI as the Foisie Innovation Studio building is being built will validate the robustness of the findings derived from previous research and will point more specifically to those additional areas in which research is still needed. All the lessons learned

Key Questions	Uncertainty Resolution								
	E-Campus (2005)	Bartlett (2005)	Rec. center-2012	Project Ctr & Skeltony Labs (2014)	Massport1 (2016)	Police 2017	WPI Guidelines (2017)	UADY (2017)	UADY 2 (2017)
What information is essentially required by FM?	60	60	90	75	90	90	90		
What information that is created in the BIM model during design and construction can be effectively used by FM?		30	60		70	90	90		
What information that is needed by FM but not currently created in the BIM model can be added to the BIM model during design and construction?		90	90		70	90	90	50	50
What are the most efficient ways to organize the transfer of information to the owner at the completion of the project?			90		80	90	90		
What is the most efficient way for the end user to have access to this information	20	60	80	80	50	90	90	50	50
How should the information be maintained and updated during the project lifecycle?			90			90	90	70	70

Figure 10. Collective Degree of Research Uncertainty Resolution

from this research are immediately transferred to classroom instruction at both institutions increasing the awareness of the students about building lifecycle and its corresponding consideration for the owner long-term use of the facility as well as for the information required that is generated during design and construction information and how BIM contributes to that process.

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SUSTAINABLE OPERATION OF BUILDINGS UTILIZING BIM AND DECISION-MAKING

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Abstract

Over the last decade, a growing concern of global climate change has led industries towards sustainable practices. With depleting natural resources and rising temperatures across the globe, it has become our responsibility to better manage limited resources and consumption of fossil fuels to minimize our carbon foot print. The construction sector accounts for 23% of total energy consumption and accounts for 40% of global CO₂ emissions. As buildings account for 40% of total energy consumption in US, effective management of resources in buildings may help reduce the carbon foot print and greenhouse gas emissions. With innovative technologies like BIM and automation, effective management of resource consumption is possible during the design and construction phase of a project. However, the role of effective building management using BIM technologies during building lifespan is yet to be determined. Research institutions offer an optimal opportunity to develop the atmosphere to collaborate and foster collaborative learning through research to define BIM's role in operation and management. To evaluate BIM contributions in sustainable building maintenance, initial studies were conducted in Centennial Engineering Center (CEC), University of New Mexico. The results did not show variation in electricity consumption between operation and non-operation hours indicating unaccounted losses during non-operational hours at CEC. A framework is proposed to identify and study the losses during non-operational hours that incorporates user preference based multi-scenario approach to minimize the energy consumption without the need for retrofit.

Keywords: building information modeling - BIM, BIM research, energy consumption, energy optimization, sustainable operation, decision-making, agent-based modeling.

1. Introduction

The shift in global climate, resource depletion and increased energy consumption led the industries to opt for sustainable practices in resource management without compromising the comfort and needs of users. (Volk et al. 2014; Mantha et al. 2015). The construction sector accounts for 23% of total energy consumption and 40% of global CO₂ emissions (Choi et al. 2016), where buildings account for 40% of total energy consumption in US (Mantha et al. 2015). As we step into the age of automation (Mantha et al. 2015), initiating innovative technologies currently available to our benefit may give rise to a new era in construction industry. Of late, Building Information Modeling (BIM) initiated a data sharing among the major disciplines to minimize

losses and optimize resource consumption(Volk et al. 2014). Given the lethargic evolution of construction industry in United States, BIM managed to find its ground in the construction industry as design and modeling tool, as a database that stores attributes of building materials, and for asset management (Mcarthur, 2015). The augmented employment of BIM in construction industry led the researchers to focus on supplementary capabilities of BIM. Recent studies presented frameworks that focus on BIM in operation and maintenance of buildings (Kivits and Furneaux 2013; Brooks and Lucas 2014) which is the major portion of resource consumption in any construction project. The objective of this paper is to propose a framework that employs BIM and incorporates user preferences in decision-making to achieve sustainability in operation and maintenance of commercial buildings. The study is expected to create opportunities at research institutes and cultivate collaboration with industries in the region.

2. Background

BIM has already been active in design and pre-construction phases of a project (Brooks and Lucas 2014) to assist in planning, design, visualization of the building before completion, quantity management among others (Volk et al. 2014). With increased computer capabilities and automated studies (Zhang et al. 2013; Irizarry et al. 2013; Menassa et al. 2013; Mantha et al. 2015) in construction and building energy management issues, BIM's role in automating operation and maintenance has potential to achieve sustainability. Recent studies (Mcarthur 2015; Brooks and Lucas 2014) focused on BIM enabled facilities management suggesting retrofit, identified the challenges in operation and management (Mcarthur 2015; Brooks and Lucas 2014; McGlenn et al. 2016) such as critical information needed to minimize energy consumption, interoperability between tools and software programs, and availability of digitized data among others. However, this study intends to effectively use the existing facilities to optimize energy consumption without retrofitting. Some of the challenges identified to facilitate BIM's implementation in operation and maintenance for the pilot study here at University of New Mexico (UNM) are: 1) developing a complete digitized model for the CEC at UNM, 2) identifying the level of detail required for the BIM model, and 3) lack of sophisticated automation system for building maintenance at CEC. A multi-scenario framework is proposed for the pilot project that addresses some of the challenges listed here, with BIM and decision-making to minimize the energy consumption in a single floor of a university facility without retrofitting. Contingent on the results obtained in the pilot project, the multi-scenario framework will be reframed and employed to the entire facility.

3. Case Study: Centennial Engineering Center, University of New Mexico

The following steps were implemented to address the challenges identified in this study: 1) A BIM architectural model is created for the 3rd floor of CEC, 2) for the pilot project the level of detail is kept minimum as the initial phase of the project is only to identify the potential of BIM in facility management and, 4) based on the framework and results from multiple case studies an automation system that incorporates decision-making, agent-based model and BIM is to be developed for operation and maintenance of university and commercial facilities. The Centennial

Engineering Center (CEC) was constructed in 2008 where Department of Civil Engineering is located. The third floor in this building is considered for the pilot project. The third floor of the CEC mainly consists of faculty offices, administrative office of Civil Engineering, student offices and other administrative offices.

3.1. Data Collection

The data collection process was initiated with two sets of questionnaires sent to the contractor and the owner separately. From the responses to the questionnaires it is understood that CEC receives electricity from three different services, one for general building requirements such as lighting and receptacles, the second service for lab spaces and equipment and the third service is for safety illumination and to provide emergency power. The energy consumption of the entire third floor is to be measured for a span of four weeks to understand the pattern and the natural behavior of the building users. Similar measurements are to be recorded in different months in a year to account for weather impacts on energy consumption. However, the CEC do not have an individual energy measuring sensors to monitor each floor separately. As new installations are an administrative task, the time required is understandable. Therefore, for initial understanding the energy consumption of the entire building from lighting and receptacles service, steam and chilled water usage data were obtained with the courtesy of Physical Plant Department that handles the energy supply for the entire university campus.

4. Methodology

The methodology proposed for the pilot project is shown in **Figure 1**, which has four steps, 1) data collection, 2) identifying operating conditions, 3) building energy model 4) analyzing energy consumption results.

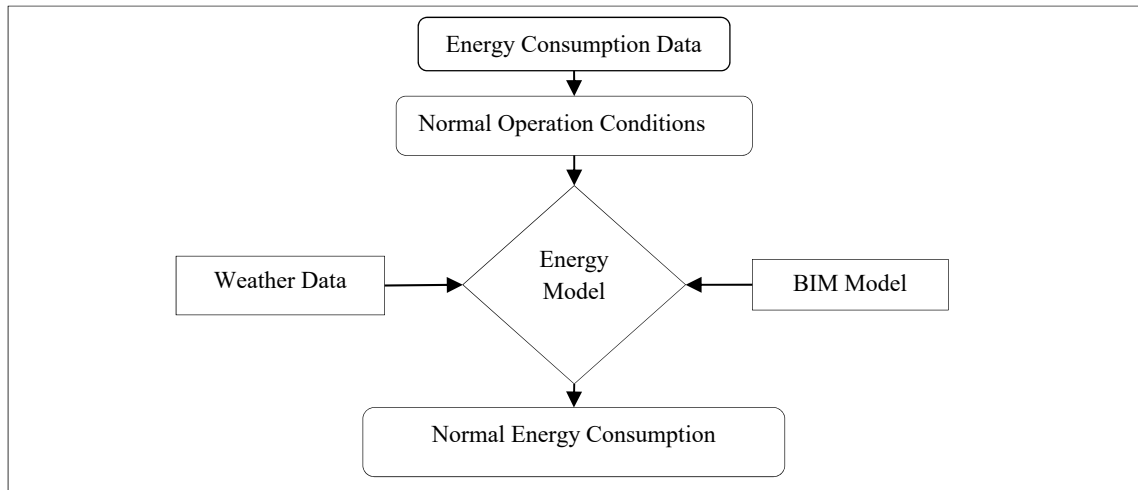


Figure 1: Methodology for Pilot Project

4.1. Multi-Scenario

Building energy consumption is based on agents i.e. building occupants behavioral aspects. Previous studies showed that occupants of buildings have varying energy consumption patterns based on seasons (Azar and Menassa, 2012). As the energy modeling tools available do not account for varying occupant energy use characteristics (Azar and Menassa, 2012), two different scenarios are to be introduced that alter the ‘*Normal operating conditions*’ depicted in **Figure 1**. These scenarios are intended to account for fluctuating energy use characteristics of the building occupants. The scenarios are created based on multiple surveys that will be conducted with the occupants of the CEC. A statistical analysis will be performed on the responses received from the surveys.

Based on the analysis of responses a set of modified operating conditions will be introduced into the methodology to minimize the energy consumption. Methodology that includes the two scenarios is shown in **Figure 2**. With the introduction of each scenario the energy consumption is expected to reduce from ‘*Normal energy consumption*’ of **Figure 1**. Based on the total reduction achieved from each scenario, a decision-making framework is established that initiates energy usage protocols to conserve energy for the entire building. The results from the energy usage protocols will be further analyzed to understand the changes in consumption patterns. The response and level of comfort of building occupants will be obtained via multiple surveys conducted after the initiation of the energy usage protocols.

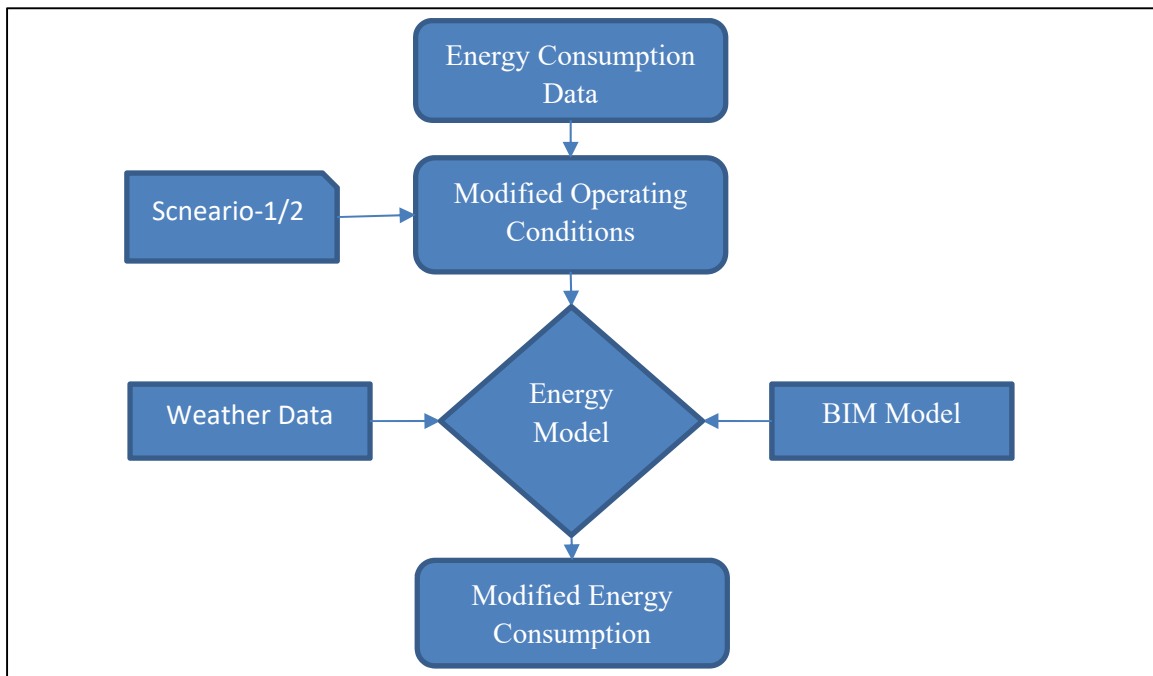


Figure 2: Methodology that Includes Scenario 1 and Scenario 2

5. Initial Analysis and Discussion

The data obtained from the Physical Plant Department of UNM is a 5-minute interval energy consumption reading from three services feeding to CEC, pounds of steam, and tons of chilled water. In Azar and Menassa, (2012) stated that a study of commercial buildings and their energy consumption pattern revealed that the turn-off rates for office equipment were 59% for desktop computer, 45% for copiers, and 41% for scanners. This indicates that there is significant amount of energy consumption during non-operating hours. The obtained energy consumption data is studied to observe the electricity consumption during non-operating hours. Three random dates were selected and the number of units of electricity consumed per hour from the service that provides for lighting and receptacles were noted. The three dates selected are 1st July 2015, 29th August 2015, 16th September 2015. Since service 2 provide electricity to laboratories that have fluctuating schedules and service 3 is only an emergency situation, the electricity consumption for only service 1 is analyzed and their respective plots were given from **Figure 3** to **Figure 5**.

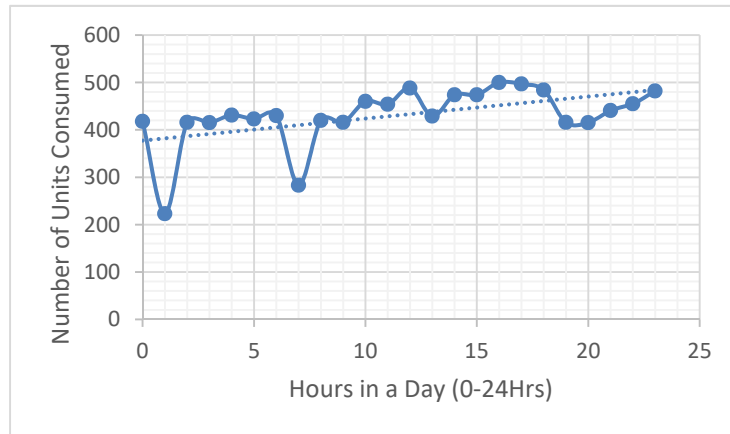


Figure 3: Electricity Consumed on 1st July 2015 from Service-1

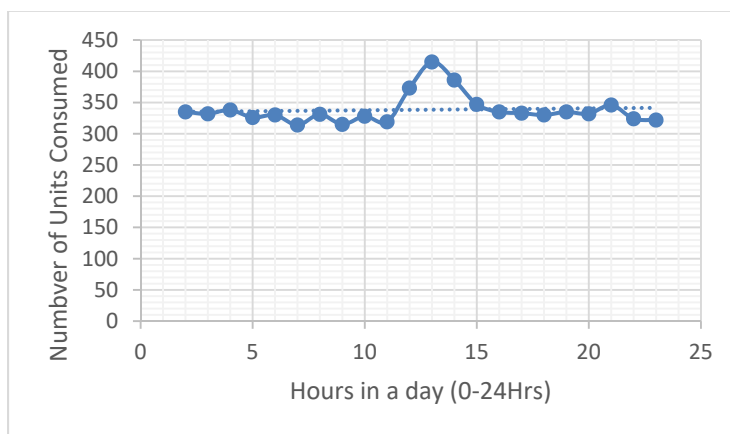


Figure 4: Electricity Consumed on 29th August 2016 from Service-1

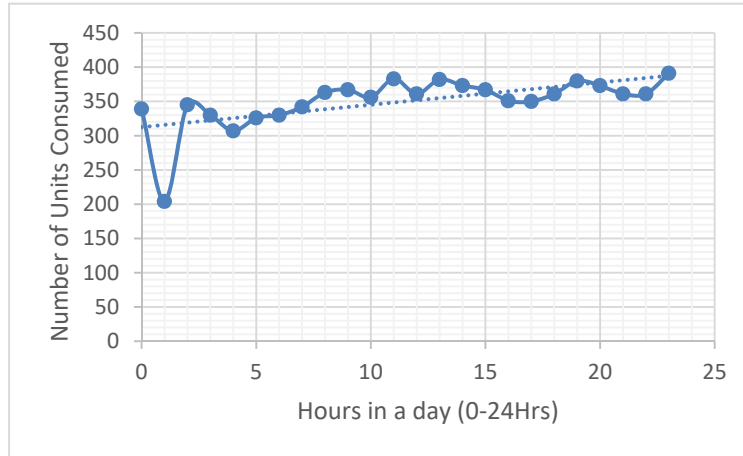


Figure 5: Electricity Consumed on 16th September 2015 from Service-1

The steep drop in **Figure 3** and **Figure 5** are due to the insufficient data generated from the energy monitoring system, hence, they do not indicate an anomaly. As classes begin at 7am and ends at 7pm at CEC, the time between 7am-7pm are considered as operating hours for the building and the rest as non-operating hours. From the plots, it is noticeable that there is no significant drop or rise of electricity readings after the two transition phases which are 6am-7am and 7pm-8pm. The plots indicate that during the non-operating hours the energy consumption is equal to operating hours. The possible reason could be the high turn off rates stated earlier in this section (Azar and Menassa, 2012). This provides an opportunity to investigate the consumption of electricity during non-operating hours at CEC. The findings from such investigation will reveal the behavioral attributes of the building occupants, unaccounted losses, and equipment malfunction that can assist to frame the energy usage protocols. These protocols are expected to minimize the losses to achieve optimum energy consumption without retrofitting the building.

5.1. Further Investigation:

The installation of energy monitors for each floor and rigorous monitoring the consumption history patterns can help in understanding the consumption rate for each floor and occupant attributes towards energy usage. Surveys conducted with the occupants of the building are to be used to frame the structure of each scenario that will be used to alter the operating conditions of CEC to minimize the energy consumption. An energy monitoring system via BIM model will be created that servers as an early warning system for energy consumption anomalies. In this process, BIM's role and limitations will be identified and studied at each level to create a robust facility management tool that incorporates user preferences in decision-making to achieve sustainable and economical building operation without the need for retrofit.

6. Conclusion

The proposed methodology will serve as a foundation for a larger and more complex framework which incorporates decision-making, agent-based modeling, and BIM to create a robust facility management tool. The initial results showed that CEC energy consumption did not vary between operational and non-operational hours suggesting undesired energy consumption. Further investigation of energy consumption during non-operating hours of CEC should provide insight of equipment turn-off rates and occupant behavior. This allows to alter the operating parameter of the building to formulate scenarios that allows to minimize the energy consumption during non-operating hours, thereby reducing total energy consumption and contributing towards sustainability. This can also provide more opportunities in academia for BIM where more students can participate in studying and researching the capabilities and limitations of BIM, and help foster relations with industry through communication, workshops, and participation in meaningful and collaborative research.

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EXPERIENCE AND LESSONS LEARNED THROUGH INTEGRATION OF BUILDING INFORMATION MODELING (BIM) IN THE ARCHITECTURAL SCIENCE CURRICULUM: AN OVERVIEW OF THE CURRENT PEDAGOGY APPROACH

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ABSTRACT

In architectural education, students should not only understand fundamental technical and theoretical knowledge; but should also be able to apply that fundamental knowledge in advanced and innovative ways. Utilizing core knowledge within the context of contemporary technology will prepare students to productively contribute over the life of their career. Building information modeling (BIM) as an intelligent parametric model-based process has increasingly become standard practice in the AEC industry. Therefore, the integration of building information modeling (BIM) into the architectural education curriculum is an inescapable educational need.

The Architectural Science program in the Department of Architectural and Manufacturing Sciences at Western Kentucky University (WKU) integrated BIM in the curriculum and changed the traditional educational curriculum to enhance student learning outcomes. The primary enhancement of this effort is to develop a comprehensive, technical and practical Architectural Science curriculum. This paper describes experiences and lessons learned through the ongoing curricular integration of building information modeling (BIM) within the Architectural Science curriculum and details an overview of a pedagogy approach through collaborative BIM education in a junior course level.

Keywords: Building information modeling (BIM), Architectural Science, curriculum integration

1. INTRODUCTION

Building information modeling (BIM) as an intelligent parametric model-based process has increasingly become standard practice in the architecture, engineering, and construction industry (Sabongi, 2009). BIM is the new generation of Virtual Models (VM) that brings building information in and supports digital data exchange mechanics within the AEC industry. With BIM utilization continuing to grow in the AEC industry (Azhar et al., 2010; Pikas et al., 2013), its integration into academic education curriculum is an inescapable educational need.

In recent years, many academic institutions have been struggling to integrate this new technology into their programs to meet industry expectation of this skill (Sacks & Pikas, 2013). The Architectural Science (AS) program in the Department of Architectural and Manufacturing Sciences (AMS) at Western Kentucky University (WKU) integrated BIM in the curriculum and changed the traditional educational curriculum to enhance student learning outcomes. The primary enhancement of this effort is to develop a comprehensive, technical and practical Architectural Science curriculum. This paper describes experiences

and lessons learned through the ongoing curricular integration of BIM within the Architectural Science curriculum and details an overview of a pedagogy approach through collaborative BIM education in a junior course level.

2. INTEGRATION OF BIM IN ARCHITECTURAL SCIENCE/ ENGINEERING CURRICULUM

The integration of BIM in architecture and architectural engineering curriculum in U.S. has been growing extensively. A survey by Becerik-Gerber et al. (2011) showed that 81% of the architecture program in the U.S. offer BIM in their curriculum (Becerik-Gerber et al., 2011). Academic programs have integrated BIM in their curriculum through different approaches. The most common approach is incorporating BIM in one to three courses, and the majority of the proposed courses are limited to one to two-week introduction of BIM (Becerik-Gerber et al., 2011; Sabongi, 2009). Barison and Santos (2010) grouped BIM integrated courses into eight categories: 1) Digital Graphic Representation; 2) Workshop; 3) Design Studio; 4) BIM Course; 5) Building Technology; 6) Construction Management; 7) Thesis Project and 8) Internship. Most Architecture programs offer BIM in a Design Studio course, however Architectural Engineering programs introduce BIM through a specific BIM course (Barison & Santos, 2010). Table 1 represents undergraduate level BIM-incorporated courses in architecture and architectural engineering programs from different universities.

Table 1: Course content descriptions for BIM- incorporated undergraduate courses from Architectural Science/Engineering curricula.

University/program	Course	Course description
Pennsylvania State University/ AE	AE 222 Working Drawings	“Materials and methods of construction used in residences and commercial buildings; preparation of working drawings for small building” (“Penn State Department of Architectural Engineering,” 2017).
Milwaukee School of Engineering/ AE	AE 1312 Introduction to Building Information Modeling I	“The basics of CAD drafting and Building Information Modeling (BIM). The CAD programs used are AutoCAD and REVIT Building. General CAD topics include basic drawing and editing of details in AutoCAD, 3D building modeling, and an introduction to the concept of utilizing REVIT Building to produce estimates.”
	AE 3311 Introduction to Building Information Modeling II	“This course prepares the student to utilize building information modeling (BIM) as a coordinated, integrated and consistent approach to a building project in design and construction decision making. Students are provided the basics to produce high-quality 3-D designs and construction documents, along with cost-estimating, and construction planning. The students will use BIM in the Senior Project sequence. The course will utilize Autodesk Revit Building Systems” (“Program: Architectural Engineering, B.S. - Milwaukee School of Engineering ”, 2017).
University of Texas at Austin/ AE	ARE 217 Computer-Aided Design & Graphics	“Introduction to procedures in computer-aided design and computer graphics used in producing plans and three-dimensional electronic models associated with building design and construction./ Introduce students to Building Information Modeling.”
	ARE 376 Building Info Modeling Capital Projects	“Focuses on the skills and information needed to effectively use an existing Building Information Model for a building construction project. In this project-based course, students gain knowledge on the implementation of BIM concepts throughout the life cycle of a building from planning and design to construction and operations” (“Department of Civil, Architectural, and Environmental Engineering,” 2017).
University of Colorado Boulder/ AE	AREN 1027 Engineering Drawing	“Introduces engineering drawing including sections and dimensioning, print readings, computer 3D, and building information modeling (BIM).”
	AREN 1037	“Learn to develop and communicate physical information using three-dimensional graphical systems including Computer-Aided Design (CAD)

	Building Information Modeling	and Building Information Models (BIM). Learn to dimension and scale physical systems and interpret scaled drawings. Get experience with industry standard software tools (REVIT) used to produce design and construction documents, and apply BIM and CAD tools in a project producing scaled 3-D drawings" ("Courses University Catalog 2013-2014," 2017).
Carnegie Mellon University/ AE (Minor)	48-749 Parametric Modeling with BIM	"This is an introductory course to BIM, both in theory and practice, via parametric modeling. Overall, the course will introduce: Fundamental concepts of building information modeling, and parametric modeling techniques and tools" ("School of Architecture Courses," 2017).
Philadelphia University / AE	AENGR 200 Architectural Engineering Design	"This foundation course is required for Architectural Engineering. It is an introduction to design principles, vocabulary, and process methodologies leading to the understanding of architectural and research process. Use of prevalent and emerging visualization tools for building information modeling (BIM) including REVIT will be covered" ("Philadelphia University Catalog Course Descriptions," 2017).

3. WKU ARCHITECTURAL SCIENCE PROGRAM

3.1 Architectural Science Curriculum

The Architectural Science program in the Architectural and Manufacturing Sciences Department at Western Kentucky University is a bridge between design theory and construction practice. The program is designed to provide graduates with a practical architectural education combining an understanding of the philosophy of building design with an applied technical knowledge of construction systems and materials ("AMS BS Architectural Science," 2017). The major in Architectural Science requires 81 technical core courses.

3.2 Current Pedagogy Approach

Program instruction includes core courses in architectural drafting, documentation, visualization, and design principles which have potential BIM-related content. Figure 1 shows AS courses sequence flowchart with BIM related content.

- 1- A series of documentation courses including AMS 263; Architectural Documentation I, AMS 273; Architectural detailing, and AMS 363; Architectural Documentation II.
- 2- A series of Design Studio courses including AMS 369; Architectural Design Studio I, and AMS 469; Architectural Design Studio II.
- 3- AMS 351; Building Information Modeling
- 4- Capstone course sequence including AMS 488; Comprehensive Design, and AMS 490; Senior Project.

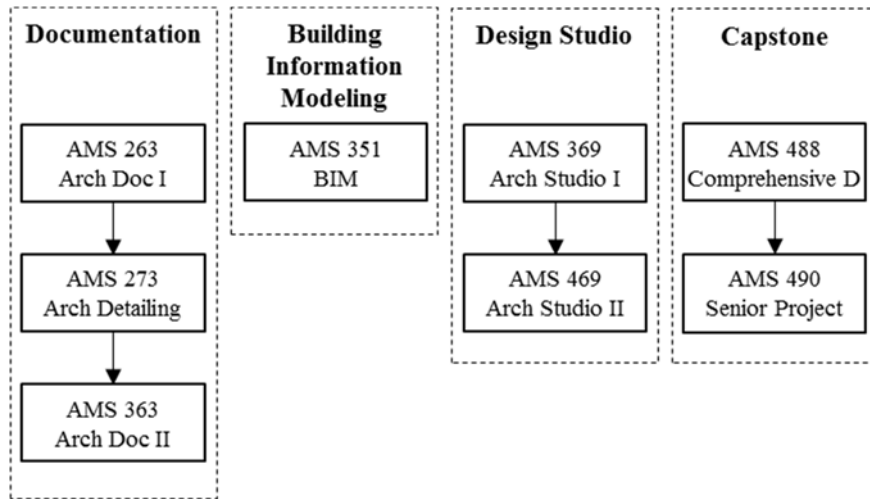


Figure 1: AS courses sequence flowchart with BIM related content

Table 2: BIM Integration into existing AS courses

Course	Course description*	BIM integration
AMS 263 Architectural Documentation I	Planning and producing residential construction drawings. Residential construction standards and codes; building materials research and specification.	Students use CAD related tools to complete projects and assignments. Students are not exposed to BIM at this level.
AMS 273 Architectural detailing	Architectural detailing in terms of function, contractibility, and aesthetics. A transition from architectural ideas to build reality. Detailing as a means of controlling: water, air heat flow, sound, aging, and load transfer. Detailing with respect to economics, ease of assembly, efficiency, and problem solving.	CAD is the primary tool in this course. Students are not exposed to BIM at this level.
AMS 363 Architectural Documentation II	Planning and producing commercial construction drawings. Commercial construction standards and codes; building materials research and specification.	There is an equal split of students using CAD and BIM.
AMS 351 Building Information Modeling	Advanced course in architectural modeling, focusing on the concepts and processes of creating object-oriented databases by embedding relevant building information into parametric modeling systems, and extracting building data using standard industry software applications.	Students are introduced to BIM in this course and work on residential and commercial projects using BIM tools.
AMS 369 Architectural Design Studio I	Design processes using architectural projects as case studies, design experience includes schematic design, program development, design methodologies, graphic and verbal communication skills, and environmental influences on building design: geographic location, daylighting, natural ventilation, size and shape.	Hand drawings and physical models are the primary tools in the studio.

AMS 469 Architectural Design Studio II	Advanced analysis, synthesis, and appraisal techniques responding to contemporary architectural issues. Theory and practice of architecture as art and science. In-depth studio experience in: schematic design and design development; selection and conceptual design of structural systems; mechanical and electrical systems, materials and connective systems, specifications and building costs with focus on sustainable design.	Students start off with hand drawings and physical models but are given the liberty to use digital tools. Students use BIM for larger projects.
AMS 488 Comprehensive Design	Identification and collaboration with a real world client, architectural proposals, project programmatic requirements, project research, site analysis, building codes and regulations, professional portfolio.	Students use BIM for schematic design which begins after data gathering.
AMS 490 Senior Project	Students work on research projects utilizing skills and knowledge from prior courses in the program.	BIM is used to complete design development and construction documents.

*Western Kentucky University| AMS BS Architectural Science

The primary digital tools in the Architectural Science curriculum used for technical courses are CAD and BIM. CAD is introduced to students at the freshman level in AMS 163; Architectural Drafting. Students use CAD in sophomore and junior courses; AMS 263, AMS 273 and AMS 363 and to a lesser degree in AMS 369. BIM using parametric modeling tools such as REVIT is currently being introduced in the curriculum as a 300 level course. In AMS 351 students are exposed to the philosophy of BIM and the REVIT platform. Two of the main objectives of the course are to create information-embedded parametric models and to extract building and construction data from parametric models. The course delves deep into modeling techniques and how information is entered into walls, doors, windows among other building elements. Students work on a residential and commercial project during the semester with a focus being on appropriate modeling techniques, solving design issues in the 3D environment, and appropriate data insertion into models. The BIM course gives students the necessary skills to use and apply in senior level courses; AMS 469, AMS 488 and AMS 490.

4. EXPERIENCE AND LESSONS LEARNED

Previous research by Aly (2015) investigated the use of digital tools in AMS 363- Architectural Documentation II. It was found that in fall 2012 all students used ACAD for creating construction drawings, but since spring 2013 students began to use BIM in the course. The data suggests that there has been an increased use of BIM since fall 2013 more students began to use REVIT for the creation of construction documents, and this number increased once again in fall 2014 (Table 3).

Table 3: Use of BIM based tools in AMS 363 in different semesters

	Fall 2012	Spring 2013	Fall 2013	Fall 2014
Revit	0	1 (25%)	10 (83%)	8 (57%)
AutoCAD	3 (100%)	3 (75%)	2 (17%)	4 (29%)
Both (Revit and AutoCAD)	0	0	0	2 (14%)

Capstone project research by Aly (2014) highlights the use of BIM tools by students for project drawings in AMS 488 and AMS 490. Conclusions drawn from this research indicate “the successful use of BIM for the three-dimensional creation of the model and two-dimensional generation of documents”.

Modeling advanced and complex forms was one of the main challenges students faced while using BIM for their capstone projects.

The number of students using BIM has been growing steadily. In the fall 2016 semester of the 31 students in the architectural documentation II course, 12 students used BIM in the course. In the current semester of the 25 students in the BIM course (AMS 351) 8 students have already been exposed to BIM and used it in previous courses to a limited extent. Figure 2 below illustrate the work done by students using BIM in AMS 363.

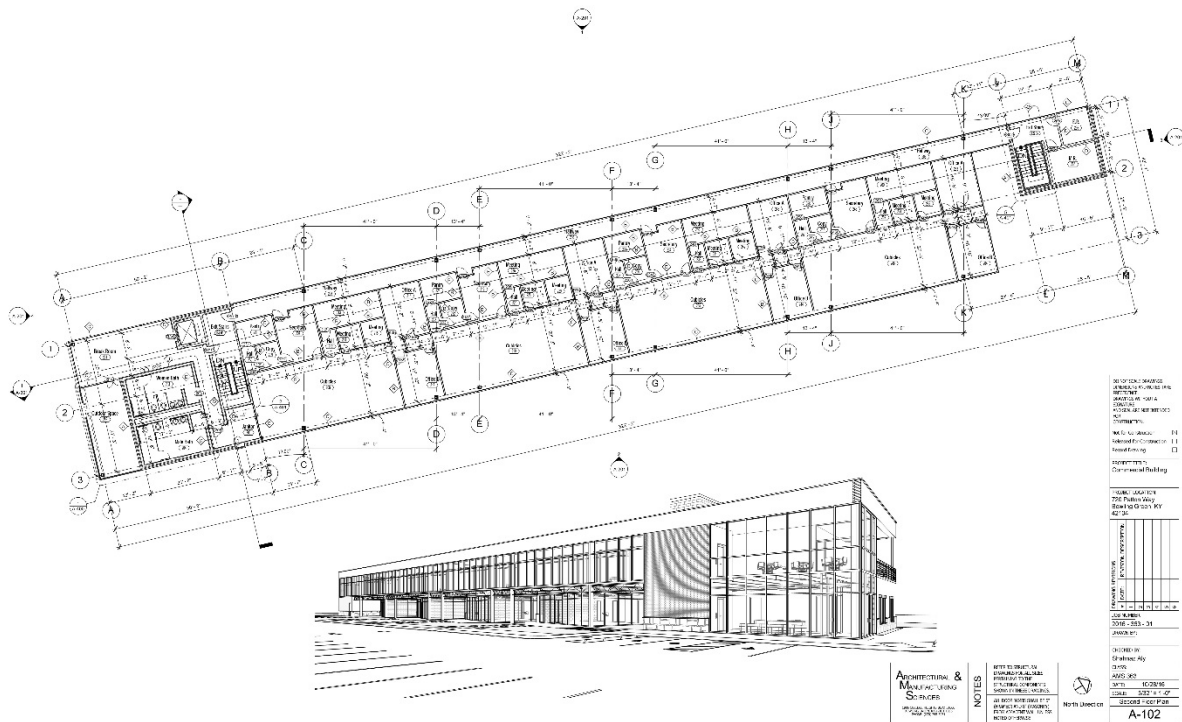


Figure 2: Student work in AMS 363 using BIM

The increased use of BIM by students in courses while a good trend brings to the fore front challenges that students and faculty are facing. In the AS program REVIT is the BIM tool used by students. As previously stated some students are trying to use BIM tools before taking the BIM course. The creation of a BIM model entails a considerable amount of front end work in terms of setup, data, and information required to create the model. At the start of projects, students do not have the required information as they are still in the early phases of design or are learning project requirements. As a result the model created typically does not contain the information that would streamline their efforts as they move deeper into the project. In some cases as the model gets more complicated, students switch from the BIM platform to a CAD platform due to complexities of the software and course deadlines. In reviewing the digital models created using BIM tools the faculty has noticed that most of the models do not contain significant data which does not enable them to take advantage of the full spectrum of BIM. Creating schedules and quantity take-offs become increasingly tedious for the students due to the lack of information in the model.

Once students are formally introduced to BIM the work that they undertake becomes increasingly streamlined. They are able to apply BIM principles into their designs and models from the start which enable them to create more robust models, and they carry through with BIM through the entirety of the

project. Students are also attempting to use BIM in design studios which come with its fair share of challenges. Creating advanced forms in BIM is a complex process and requires a thorough understanding of the rules and processes for information input. While students are introduced to the creation of complex forms in BIM their exposure is limited, and it is expected that the student will take the initiative to gain a deeper understanding of this specific topic.

In AMS 488 and AMS 490 there has been an increased use of BIM tools. Students start using BIM in AMS 488 for schematic design and continue to design development and construction documents in AMS 490. During schematic design students struggle with the creation of complex forms and ideas with the current BIM tool (REVIT). The faculty is of the opinion that for successful schematic design solutions students should not be constrained by the modeling tool. In comparing work done by students using BIM tools for schematic design and those students who use other digital tools (SketchUp, Rhino) faculty have noticed enhanced creativity with the latter tools.

5. CONCLUSIONS AND FUTURE WORK

In the Architectural Science curriculum faculties have been striving to create a balance between theoretical and technical knowledge and technology. The majority of students in the program have ambitions to join the workforce upon completion of their undergraduate degree. The percentage of students pursuing a professional Master's degree in architecture is small with about 2-3 students of 20 graduating each year applying or going on to pursue a Master's degree. The primary goal of the faculty in the AS program at WKU is to equip students with the knowledge and skills to be competitive and productive individuals on graduating from the program. AS faculty have been debating the idea of the introduction of BIM at the sophomore level for students to be exposed to BIM early on and to have opportunities to become proficient. One of the drawbacks we perceive is that students will not be fully proficient in 2D (CAD) drafting tools and this would create a knowledge gap and not adequately prepare them for professional work.

AS program faculty have been reviewing course offerings by other architectural engineering programs and are looking into the addition of a second BIM course. The first course would be an introductory BIM course- AMS 251 which would also include overviews of other digital 3D modeling tools (a schematic design perspective). The current BIM course AMS 351 would cover advanced BIM topics which would include not just the creation of the 3D and 4D but would also introduce students to the construction environment (clash detection and other advanced topics). Another scenario that faculty are considering is about schematic design and drawing; the introduction of BIM modules in studio courses to facilitate form creation. These would enable students to experiment and not limit design ideas due to modeling constraints. The objective of faculty here is to keep students up to date with industry trends and the direction that architecture is taking through the use of BIM.

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BIM ESTIMATING IN THE CLASSROOM

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ABSTRACT

The use of Building Information Modeling (BIM) has increased in the construction industry as revealed by a recent survey in which 50% or more respondents reported BIM Use on current projects, however its adoption is lagging in its use for cost estimating. According to a recent survey, BIM use for cost estimating averages around 24% across the globe (Dodge Data & Analytics, 2015). Another survey found practitioners frustrated with inconsistent data quality and problems with interoperability between software. (McGrawHill, 2012). The most common reason for frustration reported by industry professionals was the lack of reliability in quantities exported from a model. This paper discusses the results from a study that investigated BIM use for cost estimating when utilized by undergraduate construction students. Students enrolled in construction programs at two universities were given the task of completing a quantity takeoff (QTO) using BIM for the following scopes of work: concrete, structural steel, and partition wall systems for a five story core and shell building with additional tenant improvement included. Both groups of students were given the same set of 2D documents and design models. One group of students performed the takeoff by exporting quantities from the design model using Assemble Systems to an Excel spreadsheet. The second group of students exported quantities from the design models to Sage Estimating software. The authors for this paper were also the instructors for the courses. Each author independently verified the quantities from the contractor. The students were instructed to complete their takeoff using only the model while supplementing their takeoffs with data from the 2D documents. Students also completed a survey about their level of confidence in the reliability of the quantities in their takeoff. Results from this study may be used to improve instruction about BIM use for cost estimating.

Keywords: BIM, cost estimating, 5D

1. INTRODUCTION

The use of Building Information Modeling has been increasing in the construction industry as evident in a recent survey in which 50% or more respondents reported BIM Use on current projects (Dodge Data & Analytics, 2015). One area where the adoption of BIM appears to be slow is in the use of estimating in which the average of 5D BIM use averages 24% across the globe (Dodge Data & Analytics, 2015). BIM quantity takeoff (QTO) is often used as a backup to a 2D takeoff rather than as the primary method for quantity takeoff. Practitioners report frustration with inconsistent data quality and issues with interoperability between software (McGraw Hill, 2012). One of the barriers to using BIM for quantity takeoff as reported by industry professionals is their lack of trust in the model (Aibinu, 2014).

As the number of students enrolled in construction management programs increases, expectations are that the number of professional cost estimators receiving a degree from an accredited construction program will also increase. Accredited Construction Science and Management programs at U.S. universities are required to include cost estimating in their curriculum. To what extent, or number of courses, is determined by individual programs. However, instruction about cost estimating must be such that students have the knowledge and skills to demonstrate the student learning outcomes required by the accreditation program.

The authors of this paper have experience both as cost estimators with the use of 2D documents in the construction industry, as well as the use of BIM software and its integration in the estimating workflow. As such, the authors have integrated BIM software and processes for teaching quantity takeoff and estimating in the classroom at their respective institution. Additionally, the authors have continual efforts in research about the use of 5D BIM.

Intrigued by the reported low adoption rate of BIM for estimating and curious about students' perceptions about 5D BIM, the authors agreed to investigate the topic of BIM estimating in the classroom. As cost estimators and educators of future construction professionals, the authors wanted to better understand their students' perception about learning to use BIM for QTO, their thoughts about the process, and how confident they were in their ability to complete a QTO using BIM. The goal of this study was to investigate student perceptions about using 5D BIM for QTO and cost estimating. The authors chose to use the term perception(s) for this study in place of its synonym belief(s), however one could substitute belief(s) for perceptions. To investigate their assumptions and student perceptions, the authors designed a study to answer the following research questions:

- 1) Is there a difference in students perceptions about their abilities to perform a cost estimate using BIM compared to 2D documents and the traditional estimating process?
- 2) What are students perceptions about the processes and tools used to complete a quantity takeoff (QTO) in BIM?
- 3) Do construction students trust the model quantities exported from a model for the purpose of cost estimating in BIM?

2. BIM IN THE CLASSROOM

2.1 BIM in the Construction Curriculum

As accredited undergraduate programs of Construction Science and Construction Management, students in the programs at the University of Oklahoma (OU) and Brigham Young University (BYU) are required to successfully complete courses in the topics of cost estimating, cost analysis, and cost control. Students in the OU Construction Science program must demonstrate their ability to create a cost estimate and therefore receive instruction about quantity takeoff, detailed estimating, and conceptual estimating across three required courses in the curriculum. Students in the BYU Construction Management program are required to apply their knowledge of cost analysis to meet the program's learning outcomes. BYU provides instruction about quantity takeoff and cost estimating in two required courses.

BIM was integrated in the OU Construction Science program in fall 2008 made possible by an internal university grant for innovative instruction/curriculum. BIM was added to the curriculum at BYU in 2006. Students at OU are first introduced to BIM at the freshman level, but only for visualization of graphics and model development. Instruction about BIM for estimating occurs as a module in a 3-credit hour, 16 week, BIM for Constructors course during the senior year. Seniors are also required to use BIM for their capstone project. The curriculum is sequenced so that instruction about BIM for estimating occurs only after instruction about the 2D quantity takeoff and cost estimating processes in three courses earlier in the curriculum. Students at BYU are introduced to BIM during their freshman year in the program. In the introduction course, students model a 2 story law office building. Instructions about BIM estimating occurs in the Preconstruction Services course, a 4-credit hour course during their junior year. The curriculum at BYU is sequenced similar to OU in that BIM for estimating occurs after a course that teaches 2D quantity takeoff.

2.2 Context for Interuniversity Course Project

In a recent discussion about pedagogy and learning objectives, the authors decided to develop an assignment for students to complete a QTO using BIM as their final project for a course at their respective universities.

During discussions the authors discovered that while they were using different BIM software for QTO and estimating, their experiences with students' performance and perceptions were similar. The authors agreed to collaborate on the development and release of an assignment during the same semester at approximately the same point in the semester. By doing so, students at both universities would have a similar amount of time to complete the project. The authors were interested in comparing student attitudes about using BIM after completing a complex project with specific instructions for organizing the QTO. Nineteen students were enrolled in the OU course and 33 in the BYU course.

3. RESEARCH METHODOLOGY AND DATA ANALYSIS

3.1 Participants

A total of 40 students responded to the survey in this study with 19 being from OU and 21 from BYU. Students in the study included 2 sophomores, 4 juniors, and 34 seniors. In addition to their academic classification, information was gathered about the participants' construction industry experience, such as part-time, full-time, type/role, and duration. All but one student in this study had experience working in the construction industry. The majority of students, 36, reported experience working on a project site and 21 reported experience working in preconstruction for a general contractor. Nine participants reported experience working with BIM for a general contractor. Amount of experience ranged from two months to 10+ years.

3.2 Materials

The project selected was a building that neither author had previously used in a course, thus requiring the authors collaborate to prepare the assignment objectives, instructions, and deliverables. The project was a 5 story core and shell office building with tenant improvement documentation built by a general contractor in the western United States. The owner provided the authors with the architectural shell, architectural tenant improvements (TI), electrical shell, electrical TI, mechanical and plumbing shell, mechanical TI, and structural models in Revit 2016. In addition to the models, pdfs of the core and shell plans, TI plans, and material specifications were provided to the authors.

The authors identified the scopes of work for quantity takeoff by students would include: concrete, structural steel and interior partition walls. The authors agreed to require students organize the QTO by building floor for the estimate. Each author created an assignment sheet for their specific students clearly detailing instructions about model organization, deliverables required, and file type requirements. Although two different assignment sheets were distributed, the objectives and requirements for QTO data were identical. Both the OU and BYU assignment sheets required a 5D QTO for the following scopes of work:

- Concrete with metal deck
- Structural steel
- Framed wall partitions

OU students were instructed to condition the quantity takeoff for the concrete with metal deck scope and framed wall partition systems scope by 1) level, 2) zone/area, 3) bid package, and 4) activity id. Instructions for the structural steel scope QTO was to be conditioned the same, with the exception to delete the level condition and perform the QTO using the model elements as modeled in the structural steel model. BYU students were instructed to takeoff the three scopes of work and use Level 1, Level 2, Level 3, Level 4, and Level 5 as the Bid Item Work Breakdown Structure. Both instructors also provided clarifications for each scope, such as: *“Use the structural plans to verify size and weight for each steel column”* and *“Refer to the plans for slab on metal deck thickness and configuration.”* The OU students exported the model quantities from Revit to Assemble Systems for conditioning, then exported to Excel for future price loading. BYU students used the link between Navisworks and Sage Estimating to transfer the quantities from the model to the estimating software.

In order to address the three research questions, a 17 item Likert-type questionnaire about how confident they were in their knowledge, skills, and abilities to complete a QTO using BIM and the traditional process using 2D documents. The items in this section of the instrument were adapted from Bandura’s self-efficacy measures of efficacy expectations (Bandura, 1977) which have consistently shown reliability values between .70 and .89 (Multon et al., 1991). The range of reliability values found by Multon et al. (1991) were from their meta-analyses of studies about self-efficacy beliefs and academic performance. Bandura’s (2006) methodology for measuring self-efficacy beliefs is to present individuals with surveying items portraying different levels of task demands, and they rate the strength of their efficacy beliefs on a scale of 0-100 in 10-unit intervals. Consistent with Bandura’s methodology, different tasks were presented to students in this study and they were asked to rate their belief in their ability to execute the tasks. The adapted survey for this study retained the same scale structure and descriptors, but used single unit intervals ranging from 0 to 10. The survey was administered at both OU and BYU using paper copies in an attempt to reach a 100% response rate. The OU response rate was 100% and the BYU response rate was 70% of the students completing the project.

Table 1 Research questions, constructs, total items

Research Questions	Constructs	Total Survey Questions
<p><u>Question 1:</u> Is there a difference in students perceptions about their abilities to perform a cost estimate using BIM compared to 2D documents and the traditional estimating process?</p>	<ul style="list-style-type: none"> • General QTO knowledge, skills, and ability • General ability for QTO accuracy • 2D QTO knowledge, process and tools • 2D QTO ability 	9
<p><u>Question 2:</u> What are student’s perceptions about the processes and tools used to complete a QTO using BIM?</p>	<ul style="list-style-type: none"> • BIM QTO knowledge, process, and tools • BIM QTO ability 	6
<p><u>Question 3:</u> Do construction students trust the model quantities exported from a model for the purpose of cost estimating in BIM?</p>	<ul style="list-style-type: none"> • Trust that model is accurate and reliable 	2

Participants were asked a question such as “*How confident are you in your ability to complete an accurate quantity takeoff using 2D documents?*” and “*How confident are you in your ability to complete a quantity takeoff using BIM?*” A scale of 1 to 10 was used to measure each participant’s confidence with 1 being “certain I cannot”, 5 was “moderately certain I can”, and 10 was “certain I can”.

3.2 Data Analysis

Questions from the survey were grouped and placed into one of three groups. Items were assigned to a group based on the constructs guiding this study: Group 1- General & 2D QTO Knowledge, Skills, and Abilities (KSA); Group 2 – BIM QTO KSA; and Group 3 – BIM reliability. Descriptive statistics were used to find the mean and standard deviation for each item, as well as the mean and standard deviation for each group. Correlation coefficients were also computed among the three groups and select items.

4. RESULTS

Due to space limitations for this paper, only the results from the descriptive statistics for each group are presented in Table 2. Descriptive statistics for select individual items are also discussed in this section.

Table 2 Descriptive statistics

Group	<i>M</i>	<i>S.D</i>	Skewness	Kurtosis
General & 2D QTO KSA	7.8	1.08	.12	-.10
BIM QTO KSA	7.1	1.38	.01	-.75
BIM reliability	7.1	1.5	.00	-.81

To find the relationship between items, correlation coefficients were computed among the items within each group and across the three groups. Due to space limitations for this paper, only the results for correlation coefficients across the groups are presented in Table 3, however select correlations between items are also discussed in this section.

Table 3 Correlations of groups

	1	2	3
General & 2D QTO KSA	--		
BIM QTO KSA	.377*	--	
BIM reliability	.307	.713**	--

Note: 1 = General QTO KSA; 2 = BIM QTO KSA; 3 = BIM reliability

* $p < .05$, ** $p < .01$

Analysis of the relationship between the groups of items indicates a significant strong correlation between the group BIM QTO KSA ($r = .71$, $p < .01$) and the BIM reliability group. A significant weak correlation also existed between BIM QTO KSA group and the General & 2D QTO KSA group ($r = .38$, $p < .01$).

Table 4 Correlations of BIM QTO KSA items

	1	2	3	4	5
Knowledge about BIM tools	--				
Knowledge about BIM QTO process to complete QTO	.868**	--			
Ability to complete a BIM QTO	.774**	.719**	--		
Knowledge about BIM QTO process will result in accurate QTO	.585**	.627**	.728**	--	
Ability to complete an accurate BIM QTO	.707**	.753**	.854**	.869**	--

** $p < .01$

The correlations presented between items that measured student perceptions about their knowledge, skills and abilities when using BIM for QTO are presented in Table 4. Three of the five items in the BIM QTO KSA group have a significant strong correlation. One of the items without a strong correlation with the other items measured students' confidence in their knowledge about the BIM QTO process and that their knowledge in the process will result in an accurate QTO. The analysis of this relationship resulted in a significant, but only moderate correlation with the students' confidence in their knowledge about BIM tools ($r = .59, p < .01$). The same was true with the relationship between knowledge about the BIM QTO process will result in an accurate QTO and their confidence that their knowledge about the BIM QTO process will result in their ability to complete a QTO ($r = .63, p < .01$).

Table 5 Correlations of abilities to validate and accuracy

	1	2
Ability to validate BIM using 2D documents	--	
Ability to complete accurate QTO using BIM	.728**	--

** $p < .01$

Consistent with the significant strong correlation between students' confidence in their knowledge about BIM tools and their knowledge about the BIM QTO process ($r = .87, p < .01$) from Table 4, is the significant strong correlation between students' ability to validate BIM using 2D documents and their ability to complete an accurate QTO using BIM ($r = .73, p < .01$) from Table 5. However, in contrast to the significant strong correlation between students' confidence in their knowledge about BIM tools and their knowledge about the BIM QTO process ($r = .87, p < .01$), is the significant moderate level of confidence that the model elements accurately represent the building assemblies and that the quantities from the model are reliable ($r = .52, p < .01$) as presented in Table 6.

Table 6 Correlations of BIM reliability items

	1	2
Model elements accurately represent building assemblies	--	
Quantities from BIM are reliable	.518**	--

** $p < .01$

The significant strong correlation between the BIM QTO KSA group and the BIM reliability group ($r = .71, p < .01$) is an interesting contrast to the weak, but significant, relationship between 2D QTO KSA group and the BIM QTO KSA group of items ($r = .38, p < .05$). Also of interest is the moderately significant correlation between the two items in the BIM reliability group, which measured students confidence that the model elements accurately represented the specified building assemblies and that the quantities extracted from the model were reliable ($r = .52, p < .01$).

Based on the data from this study, the authors were able to provide the answer to research question 1. The results of the correlation analysis presented in Table 3 show that the correlations between students perceptions about their BIM cost estimating KSAs compared to their 2D traditional cost estimating process KSAs were statistically significant, but low ($r = .38, p < .05$). Research question 2 was designed to investigate the students' perceptions about the processes and tools used to complete a quantity takeoff in BIM. The data presented in Table 4 indicates a significant but moderate correlation between knowledge about BIM tools and knowledge about BIM QTO process will result in an accurate QTO ($r = .59, p < .01$), but a significant strong correlation between knowledge about BIM tools and ability to complete an accurate BIM QTO ($r = .71, p < .01$). The third research question was also answered as shown by the data in Table

2 and 6. Participants mean response to the grouped questions “*How confident are you that the quantities from the BIM are reliable?*” and “*How confident are you that the model elements in the BIM accurately represent the building assemblies as specified by the architect/engineer?*” was $\mu = 7.1$. The resulting mean indicates that the students are near certain that the model is reliable.

5. DISCUSSION AND CONCLUSIONS

5.1 Observations and Challenges

During the project the authors had several observations related to the students’ organization and execution of the assignment tasks. First observation was that even after announcing discrepancies existed between the model elements and 2D documents provided with the models, the majority of students did not refer to the 2D documents. Although the adoption rate of BIM use for cost estimation lags compared to other BIM uses, it is important that construction science and management students know the process and be able to validate a model using the 2D documents provided by the design team. According to the recently released SmartMarket Brief, general contractors currently do the majority of construction model authoring (Dodge Data & Analytics, 2016). Given this fact, students need to know how to cross-reference the 2D documents for the purpose of validating a design model or creating a construction model. When asked “*How confident are you in your ability to validate a BIM model referencing 2D documents?*” the students response indicates a moderate level of confidence ($\mu = 6.5$). In fact, the mean for this question indicates their lowest level of confidence for all 17 questions.

The authors’ second observation was that the students did not automatically transfer their knowledge about the traditional 2D QTO process to the BIM QTO process when it came to organizing project information. The first step in the traditional 2D QTO process is to develop a work breakdown structure for the project. Both authors experienced this knowledge gap equally. Another observation was how unfamiliar students were with core and shell projects, and the subsequent tenant improvement projects that occur separate from construction of the building. As a result students at both universities struggled with compiling the data from the core and shell model with the data from the tenant improvement model for completing the QTO process.

Modeling discrepancies also added to the students’ confusion. One discrepancy occurred because the core and shell model was created by a different architectural firm than the TI model. This resulted in differences in the object naming and model element naming in each model. For example, in the core and shell model had one name for a certain wall type, while the tenant improvement model assigned a different name to the same wall. Additional confusion was created by model elements being modeled in both the structural and architectural core and shell models, example of this was the concrete foundation walls. The last major discrepancy was with the structural steel model. The model called out one size of column while the 2D plans called out a different sized column at the same location. Additionally, some of the steel weights assigned to the objects were incorrect.

The final observation made by the authors was that ultimately the students ‘blindly’ trusted the architectural, structural steel, and tenant improvement models provided for the project. As a result their trust that the quantities extracted from the model and the model elements accurately represented the designers’ intent led to major challenges for students.

5.2 Implications and Conclusions

The results and observations from this study has had implications on the future instructional topics for both authors in future course offerings. Based on the first observation, instruction about the BIM validation process will be incorporated. In terms of the second observation, the authors agree to require students create a project specific WBS before starting the BIM QTO process. The authors also agreed to find more core and shell with tenant improvements projects to incorporate into courses as a way to improve student understanding about this type of project. Finally, to overcome the students’ blind trust in the models

provided, the authors will emphasize the importance of completing a model check and critical analysis of the model elements and their associated data.

As the faculty observed some of the challenges the students faced in this exercise, it is easy to see why industry may be slower in adopting BIM into estimating. Because of the modeling discrepancies that are occurring, the projected time savings of BIM estimating may not be realized by industry until estimators know how to better deal with the discrepancies.

One of the benefits experienced by the professors involved with this interuniversity project process was having another faculty member to talk with and develop plans for approaching the project. Often there is only one professor on the construction faculty with the BIM skillset coupled with the estimating skillset. By reaching out to a professor with a similar teaching assignment, the professors were able to bounce ideas off each other and came up with better ideas on how to present concepts to the students in their courses. Although each professor had a unique approach to the assignment plan and its deliverables, they shared common goals and objectives for the project resulting in data both can use for instructional development in the future.

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HISTORIC BIM FOR PRESERVATION DOCUMENTATION AND MANAGEMENT APPLICATION

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ABSTRACT

In the construction management program, Building Information Modeling (BIM) may be used through other industry related applications as an appropriate platform to aid in historic and cultural building preservation applications. Like any new technology, consideration of the preferred outcome should drive decisions about the best means to use and reach the desired end product. The project presented in this paper has vested use of BIM in place of other documentation methods and it was dedicated as a visual and marketing tool for further reconstruction, rehabilitation and new space usage of a heritage building. The project was provided as a cultural preservation and community building: situated in Balkans, this project use a Category I Historical Monument, one of the few historical buildings left from the Ottoman period, as a center for arts, culture, and education. The project scope and intended purpose are the primary drivers for using BIM with very old architectural drawings and numerous pictures taken in-and-out of the building over an alternate documentation method.

The participants in the project identified also that construction managers will have to learn to alter contracts, fee proposals, and schedules to accommodate dissimilarities in the way a historic preservation project runs. Placing in more time at the beginning of the project for data collection and input into the model is creating time-savings later in the project during construction documents phase because many of the details have already been modeled. If the purpose of the documentation is to have it as a record for rehabilitation and to use it as a planning tool for renovations, BIM was proved to be an excellent choice. Also, students involved in these kind of projects may gain new skills on top of the regular modeling skills gained by way of classic building design. Another lesson learnt by using the model for historic preservation purpose is that the Historic BIM (HBIM) approach is a novel one, therefore it may play an important role in cultural and historic preservation and management.

Keywords: BIM, historic preservation, documentation, culture, technology, management

1. INTRODUCTION

Building Information Modelling (BIM) has the unique potential to turn into the major step change in the way that the construction industry operates within the built environment since the industrial revolution – encouraging major benefits in terms of cost, accuracy and time to build. Since the concept of BIM materialized, the debate has continued around the value and application but as more countries are approaching BIM a legislated requirement, the debate is no longer whether BIM should be adopted, but rather how it can be successfully implemented, and how the full worth and potential can be revealed (Hexagon, 2016). A significant way of achieving the all-inclusive benefits of BIM is by taking the principles and practice out of the office directly into the field.

Preserving historic buildings is vital component to understanding one nation's heritage (WBDG, 2016). In addition, it represents an environmentally responsible practice. Through the process of reusing existing buildings, historic preservation is essentially similar with a recycling program. Existing buildings can often be energy efficient through their use of good ventilation, durable materials, and spatial relationships. However, an immediate advantage of older buildings is that a building already exists, therefore work is not necessary to demolish a building or create new building materials and the infrastructure may already be in place. Builders can deal further with minor modifications that can be made to adapt existing buildings to compatible new uses (WBDG, 2016). Various systems and their functions can be upgraded to meet modern building requirements and codes, according to the locality or geographical area of the respective building(s) in focus.

When all stakeholders contributing to a building are working from the coordinated model (and here the historians are included too) and if that model only reflects the design elements of the asset, then its value is still limited. On older building, the knowledge and experience of historiographers can create any changes proposed to the facility that may be delivered efficiently and accurately, because they factored in variances on site within the historic time the building was constructed. In this sense, the documentation of the old architectural features is becoming essential part of this process. When all parties involved see the benefits of adopting BIM holistically - and therefore historically too - rather than viewing it as an individual action or process at their stage of the asset lifecycle, then all stakeholders can expect to see more value for the product that will be preserved.

2. A QUICK REVIEW ON BIM AND HISTORIC PRESERVATION

In the thesis work done by Worrell (2015), the applicability of the Architectural, Engineering, and Construction (AEC) industry's BIM to create a three-dimensional user interface for tracking and storing historic and management documentation is revealed. The case-study presented in this effort shows both the promise and the current challenges faced with BIM's application for the preservation field. In the same time, Van Wagenen (2012) thesis demonstrates that BIM is an appropriate, and advantageous, documentation method for historic buildings. Historic buildings face many challenges to their survival, often due to a lack of information about them, but according to this author, BIM actually leads to a more informed and more relevant historic structure report. In the same work, the author state that is possible to set up a link between the model and a database in a program like Access. In so doing, Access would house the images and text not specifically associated with discreet parts of the building, then the model would feed up-to-date information via tables into the database that would link with the associated images and text descriptions. A theoretical framework that has been constructed as a guide towards understanding the different aspects of historic preservation and management through a smart open platform is presented into another study abroad (Megahed, 2015). According to this researcher, the model known as HBIM represents a new paradigm within architectural heritage that can be used for creating, conserving, documenting, and managing complete engineering drawings and information. HBIM database can,

therefore, be used to gather information and make it available to researchers, professionals, and other parties involved in historic preservation (Megahed, 2015).

3. OTTONOMY: A CULTURAL PRESERVATION AND COMMUNITY BUILDING PROJECT

OTTOmy is a unique initiative that works in the Balkans to repair a social fabric sundered by legacies of communist oppression, post-communist conflict, and continuing social and economic instability. Based in Albania, OTTOmy will use a Category I Historical Monument, one of the few historical buildings left in the center of Tirana from the Ottoman period, as a Center for Arts, Culture, and Education. Working with Cultural Heritage Without Borders, the cultural preservation of this house combines a ground floor restaurant/bar/cafe with a cultural loft (including a library, exhibition hall, meeting room, and internet and databases access) that will provide a much needed hub through which cultural workers – public intellectuals, artists, musicians, civil society actors – can network and collaborate on projects that can facilitate regional cooperation amongst individuals, organizations, and institutions (OTTOmy proposal, 2016).

As a cultural movement, OTTOmy launches in Albania. Distinguished Professor in Department of Writing and Linguistics, College of Liberal Arts and Social Sciences at Georgia Southern University, has established a non-governmental organization in this country, a cultural preservation agency funded through the Rockefeller Brothers Fund. Previously understood as the social fabric that grounds the hope of democratization, this downward spiral of the civil sector is exacerbated by the growing economic crisis in the region, migration emergencies in the neighboring countries, and a general increase of nationalist sentiments. As a Cultural Center, OTTOmy uses a historical monument as a site for integrating these histories and identities that have been fragmented, factionalized, and that continue to divide people and generate hostilities. At this period of regional instability, OTTOmy thus proposes a unique model of cultural heritage preservation and local community development that promotes cultural and social diversity and inter/national cooperation (OTTOmy proposal, 2016).

The historical monument that OTTOmy preserves and repurposes has a long tradition of serving a cultural and communal purpose. Originally built in 1826 during the Ottoman period, it was home to the first National Library of Albania in the 1920s and, for nearly half a century (1945–1998), it served as the Directorate of Cultural Monuments. This large two-floor building includes a generous courtyard and an adjacent sequence of studios as well as a two-bedroom apartment. The bottom floor and part of the garden area will function as a high-end, slow food, locally grown restaurant, bar and café. The concept of bringing together these different functions under one roof, within one entrepreneurial ecosystem, is unique in Albania and the region, and aims to be a point of exchange and intellectual and social fermentation, channeling and directing the multitude of energies and thoughts that are invested into it. This model of socio-cultural-economic organization will be important nationally and regionally. (OTTOmy proposal, 2016). The primary partners involved in this project are: Albanian Ministry of Foreign Affairs Department of Excellence, Cultural Heritage without Borders, Ministry of Culture, Municipality of Tirana (for in-kind support) and Rockefeller Brothers Fund. As secondary partners, the authors are mentioning through others: American Embassy, Albanian Agency for Research, Technology, and Innovation, Georgia Southern University and others.

Some of the most specific activities and outcomes which are pursued through this project are to:

- Become a national and international research hub for scientific and academic inquiries in the fields of culture, humanities, and heritage and analyze/discuss their importance for contemporary and future social organization
- Establish open-access library and reading room with Internet, research database access, and secondary research resources
- Establish a socially relevant cultural center with expositions, lectures, workshops, and master-classes

- Promote care for monuments and cultural heritage in Albania, especially in urban zones
- Become a self-sustaining model of civic action by developing economic activities to support the above aims, and
- Strengthen civil society organizations working towards similar aims (OTTOmomy, 2016)

Beginning in Albania, OTTOmomy will work in the Western Balkans to restore historical monuments and recreate them as self-supporting Centers for Art, Culture, and Education and as destination sites for cultural heritage tourism (<http://www.ottonomy.org>).

As mentioned by Whole Building Design Guide (WBDG, 2016), a program of the National Institute of Building Sciences, this project can be considered as aligning with “some practical and intangible benefits of historic preservation”, including:

- Retention of history and authenticity, by
 - Commemorates the past
 - Aesthetics: texture, craftsmanship, style
 - Pedestrian/visitor appeal
 - Contextual and human scale
- Increased commercial value (economic benefits), by
 - Materials and ornaments that are not affordable or readily available
 - Durable, high quality materials (e.g., old growth wood)

There are some other intangible benefits that come with this project, like retention of building materials and reuse of local infrastructure along with energy savings (by using no energy for demolition and new construction and also reusing of embodied energy in building materials and assemblies).

4. A CASE STUDY IMPLEMENTED IN THE BIM COURSE

The undertaken HBIM case study was provided to a small construction management group of undergraduate students performed as extra credit in the BIM for Construction Management (CM) course in the CM program; the group leader of this small team is also one of the authors of this paper. The modeling process was conducted in multiple sessions over a couple of weeks timespan, and these were carried mainly outside of class environment with supervision by the instructor of the course in the CM program, when needed. The instructor had been training and advising students before in the actual course and, for this assignment, students gained relatively advanced modeling skills in Autodesk Revit 2016, including families’ modifications and management in this particular software. A laser scanning proposal of the respective building for the purpose of creating in the future of an existing-conditions model for historic records and to aid in the follow-up preservation work was discussed with the historic preservation team and a delegate member from Tirana, Albania.

4.1 Description of the project and its geographical location

The foundation OTTOmomy, created with a start-up grant from the Rockefeller Brothers Fund, is working in the Western Balkans to create a Regional Center for Cultural Heritage. With the help of many partners mentioned before, the foundation have saved a Category I Historical Monument, one of the last remaining historic structures in the city center of Albania’s capital, Tirana. The main purpose is to restore this monument and bring it back to life as a Center for Art, Culture, and Education that will become self-supporting through income from a restaurant bar-café and rental of studio apartments, event, and exhibition space. As a cultural anchor in Tirana, the Center gathers and feeds the creative intellectual energy of the city, promotes cultural heritage tourism, and provides a model of sustainable economic development. As a cultural anchor in the Western Balkans, this foundation provides a model of urban transformation that builds community leaders, in partnership with regional actors, in a holistic approach to community development and economic resiliency. A top-view geographic location (on Tirana’s map) of this monument can be seen in Figure 1.

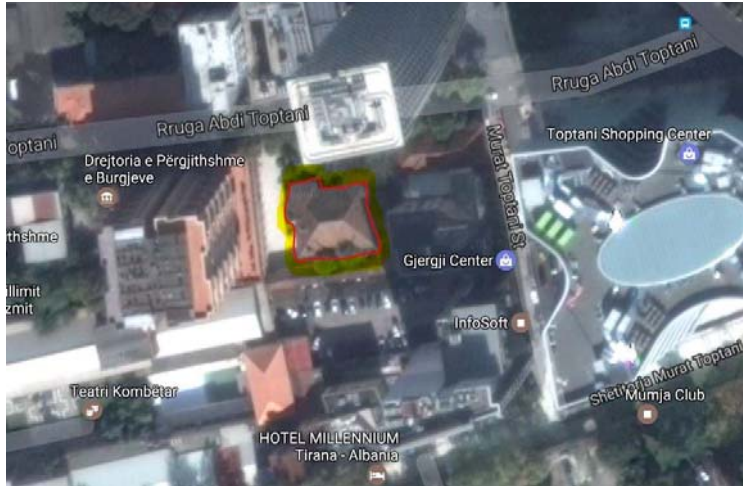


Figure 1. Top-view geographic location of the monument in Tirana, Albania

4.2 Points of departure for modeling – Historic architectural drawings and current pictures

A great number of details the modeling team had been exposed initially were provided by the Professor involved with this overseas program in the Department of Writing and Linguistics (at the same university). Some examples of old architectural drawings and sketches of various sides on this historic building are depicted in Figure 2 and 3 (preserved from 1960's or older; library records).

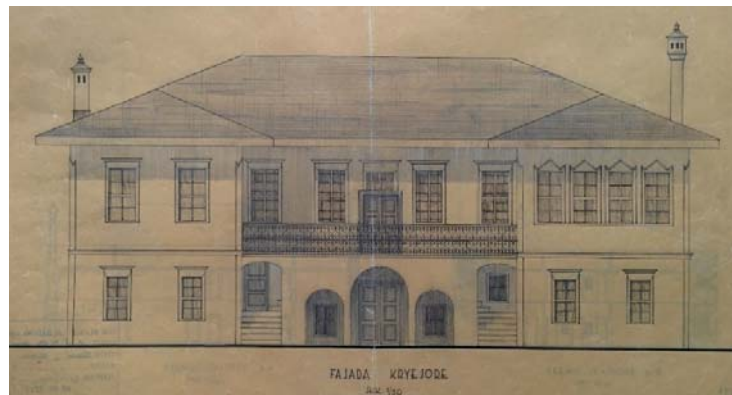


Figure 2. Front view of old architectural drawing



Figure 3. Original façade sketch of the building

Also, many pictures taken a year before or even older from a variety of angles were shared with the modeling team. For the same structure, some evidence of architectural details (considered to be included in the overall model) may be observed in Figure 4.



Figure 4. Current digital pictures and older photography of the building

4.3 The modeling effort – combining differing information from sketches, old architectural drawings and existing digital images

During initial phone conversations with historic preservation group, the modeling team had realized how complex the actual building was (this was not only a living house, as presumed) and the peculiarities of the old architectural features and details. Even though a close replica was attempted by the modeling team, there were certain building elements which have not been included in the final model due to the fact that more time was needed in the family customization process and the team had only limited time to perform this activity. The amount of work that was put into this effort to make it finally into a 3D rendered model was significant, extending over six weeks; sometimes intense sessions to debate and clarify some of the architectural and/or structural details in-and-out of the building were necessary. Considering the BIM class fully loaded with other type of work, new knowledge and various other assignments, the modeling team embarked into this new project during the spring semester of 2016 knowing that this work will receive extra credit for the course. Therefore, there was no formal assessment of this work, other than the fact that the final generated model was presented for marketing purposes to attract funding for further support on the project. As the work was underway, a few questions were addressed immediately by the modeling team and clarified with Instructor's directions:

- To what level of details this 3D model should be represented and what is the rendering needed only for presentation drive?
- How important is the presentation? How convincing should it be made for the general audience? Is this presentation required to be made along with presentation of the actual pictures on the building interior and exterior facets' and augmented by available historic architectural documents and sketches?

Although this activity was not an easy nor a cheap effort, in order to replicate the building from the available sketchy drawings and other construction details provided with less documentation than expected, the pictures taken at the face of the site in Tirana were proven to be helpful in identifying most of the 3D details needed for modeling. The obtained 3D model, first floor plan and one of the elevation view are depicted as final work examples in Figure 5 below. Also, a short movie of the model flyover was generated for marketing purposes.

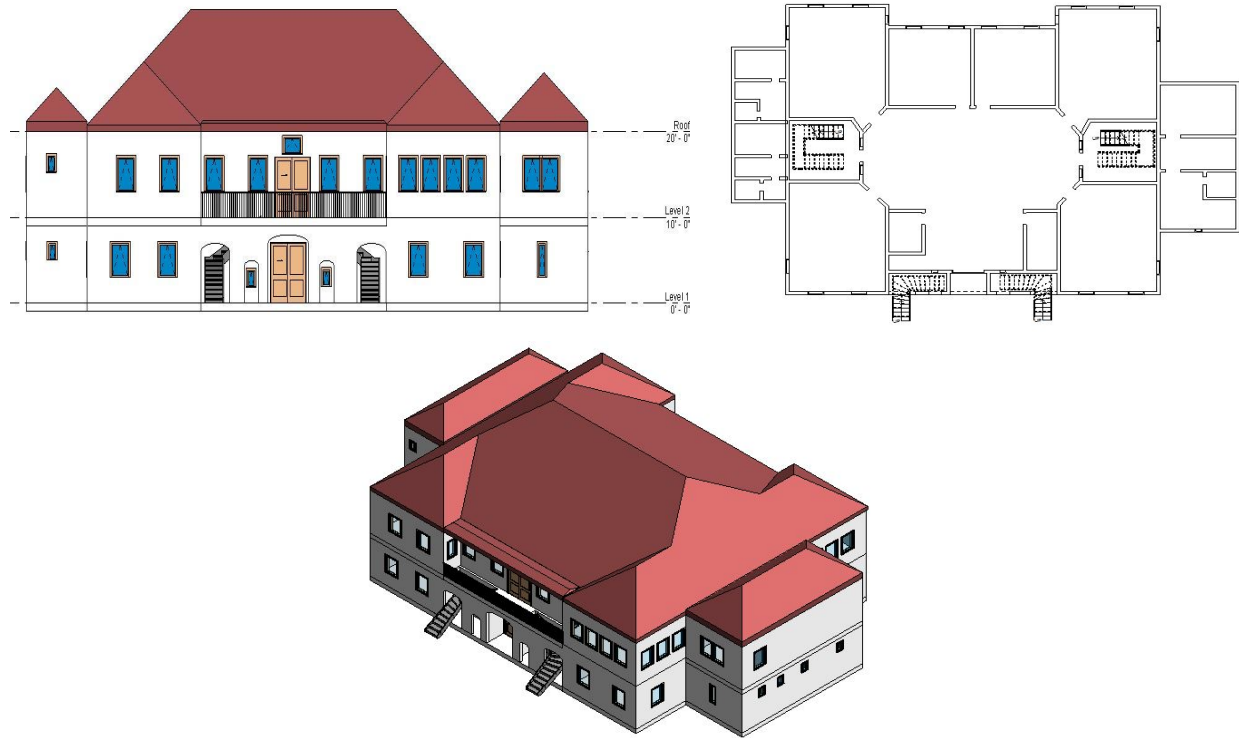


Figure 5. Front elevation, first level floor plan and 3D view generated through BIM

5. DISCUSSION, LESSONS TO BE LEARNT AND FUTURE WORK

As mentioned previously, the plan to renovate this large two-floor building includes a generous courtyard and an adjacent sequence of studios as well as a two-bedroom apartment. The first floor and part of the garden area are projected to function as a high-end, locally grown restaurant/bar and café. The concept of bringing together these functions within one entrepreneurial environment was revealed to students and the lead professor and it was conveyed by the writing professor through the Rockefeller proposal. Some of the challenges faced by the modeling team were the actual measurements and the respective conversions from existing drawings (metric centimeters to US feet); therefore the accuracy of some elements representation in the floor plans was compromised. Since some of the sketches (roof and wall details) were not drawn to scale and the assemblies were not clear on all the projection details, the team decided to let some of the details alone and not represent them or adapt them in the final model. Therefore, the creation of “as-preserved” accurate drawings from the 3D model it is yet considered a challenge and it may be studied in the near future for this project and the next ones. This is one of the main reasons why customization of the architectural and structural features in this modeling process were executed minimally, and so the aspect of interior and exterior features were predominantly focused for marketing and preservation intentions.

However, since BIM denotes a digital representation of drawings and have also the ability to illustrate old architectural features of building objects, this paper addresses a prevailing workflow of using old documentation and current/past digital pictures for the purpose of generating a model that can be further used for renovation and rehabilitation. This workflow is completed in order to preserve a building for cultural and heritage purposes. Educationally, the students exposed to this project had the opportunity to discuss and learn about the role of future construction managers who will have to be creative and cautious about altering contracts and fee proposals in order to accommodate the differences in the way a historic preservation project is conducted and scheduled. Autodesk Revit software used to connect construction components in this project that do not necessarily convert to historic building

practices was recognized as challenging by construction management students. With a need for more historic resource applications in U.S., and not only overseas, families and component specific types in this software (and some other software programs) can be further developed, highly customized and made available for this kind of project applications. The BIM modeler/drafter under a construction manager in charge with a rehabilitation/renovation project will need to have the ability to create model content of historical building components and accommodate historic assembly types, families and methods which could greatly decrease the cost and time spent to develop models of historic preservation projects. In case the purpose of the documentation is to make it as a record for rehabilitation and to use it as a planning tool for future renovations, BIM is an excellent program and process to accomplish this.

Students who put effort into this special project for the BIM course gained valuable new skills since models are three dimensional volumes and massing of any new work straightforwardly visualized next to the present structure. The architectural and structural character-defining elements and physical distinctive features that comprise the appearance of every historic building include its massing, craftsmanship, decorative details, materials, interior spaces and its features, as well as the site and environmental surroundings of the building.

Another lesson learnt by using the model for historic preservation purpose is that the HBIM approach is a fairly new one, as most BIM applications are used to design new buildings and/or expand on existing designs. HBIM role in cultural, historic preservation and maintenance management of heritage buildings is growing as importance in the eyes of preservation community as this fact is also recognized by other referenced authors and who have performed research work in this area. Two of the authors of this paper are already involved with a local preservation effort in United States promoted by a Heritage Society of a small community in the nearby region. However, the workflow planned with students for this community service project is different this time and it involves generation of 3D point-cloud model on existing building and site conditions (through laser scanning) along with the generation of a highly-customized BIM model for future rehabilitation and preservation purpose of the entire building.

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BIM IN CANADIAN RESEARCH AND EDUCATION

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ABSTRACT

Many researchers consider that changes in the industry are accelerating: the structures for the establishment of professional programs in universities do not offer the agility to adapt to the emerging needs in training of highly qualified staff to support this transformation of practices. Some consider that BIM technologies are disruptive and their adoption requires a paradigm shift in the way buildings are planned, designed, built and managed. However, unlike other countries such as France, Australia and Great Britain, in Canada there are no mechanisms that permit universities to rapidly adjust their undergraduate curricula in architecture and engineering. Professional associations are fragmented and don't have the resources nor can they count on research in the universities to update the bodies of knowledge in architecture or engineering. The industry is nonetheless moving forward in BIM and academia is lagging behind. An opportunity arises in new research approach promoting co-generation of knowledge, that is to say the industrial becomes a partner with the researcher to generate and formalize new practice knowledge. This approach is at the heart of the discipline of Construction Engineering.

The report outlines the principal outcomes of a strategic workshop that brought together key actors in BIM training, research and education as well as key players in industry from across Canada. The goals of the workshop were to identify challenges and needs regarding BIM research and education in Canada, look abroad for potential solutions and devise an action plan to establish a way forward. The report discusses the challenges and opportunities for Canada in furthering the development of its curriculum for professional, technical and academic sectors that were highlighted and discussed during the workshop. It also discusses how these efforts can align with similar efforts from around the globe. Finally, it presents a course of action to initiate and sustain the integration of BIM in current curricula.

Keywords: Curriculum development, integrated curriculum, interdisciplinary learning, BIM

1. INTRODUCTION

The current trend towards the digitalization of the Architecture, Engineering, and Construction (AEC) industry, namely through the emergence of Building Information Modeling (BIM), is seen as a paradigm shift (Shelden, 2009). This shift is primarily being brought on by the transition from a 2D, representational approach to the development of project documentation and communication of design intent and technical information to a 3D, integrated digital repository containing both geometric and non-geometric project information (Eastman, Teicholz, Sacks, & Liston, 2011). The consolidating, linking and centralizing of asset information is transforming project actors' relationships all while providing considerable opportunity to leverage data to support evidence based decision making – the industry is trending towards “perfect project information” (Crotty, 2011). While industry is embracing the practical applications of BIM due to

the many reported benefits of its use (e.g. Barlish & Sullivan, 2012), it still does not transcend nor does it pervade current practice (Forgues & Iordanova, 2010).

One of the core issues, highlighted in past research, is the disconnect between current curriculum being taught at the college and university level and the needs of industry regarding the new ways of working being driven by BIM (e.g. Cheng, 2006). There is an apparent and growing need to develop a tighter coupling between academia and industry to respond to emerging trends and new ways of delivering our built environment. The pace of technological change and the rate of innovation is growing and both academia and industry are having a hard time keeping up. The AEC industry has recognized the growing need for individuals with an expanded skillset upon graduation. For instance, a survey by the *Association des Architectes en Pratique Privée du Québec* conducted in the fall of 2016 indicated that 71% of respondents (n=210) agreed that BIM should be taught as part of the undergraduate degree in architecture. The issue however lies in the fact that “teaching BIM” is a far reaching and complex endeavour. Indeed, BIM is a multi-faceted and pervasive approach to project delivery and cannot be summarized to a single piece of software nor a single concept. Furthermore, while past work has considered the U.S. landscape (e.g. Becerik-Gerber, Gerber, & Ku, 2011), little work has been done on investigating the challenges and the needs of the Canadian industry and academic community with regard to BIM and its impact on the current curriculum. To understand the implications of introducing BIM into the Canadian landscape of BIM in Research and Education, a workshop was held at the École de Technologie Supérieure (ÉTS) in Montreal, Quebec, Canada, that brought together key actors in BIM training, research and education from across Canada. The goals of the workshop were to identify the challenges regarding BIM research and education in Canada, look abroad for potential solutions and devise an action plan to establish a way forward.

The workshop highlighted several key challenges that must be overcome to help ease the transition. Namely, the workshop highlighted the divergent perspectives between academia and industry with regard to objectives and outcomes of initiating the transition to BIM: industry have an immediate need for skilled and capable professionals with an emphasis on technical proficiency whereas academics have to contend with saturated curriculum and a lack of incentives to undertake a reform of current programs. This results in academia lagging behind industry with regard to the uptake and integration of new practices. Moreover, a technical-theoretical dichotomy emerged in so much that while the immediate need for technical skills was recognized, the absence of underlying theory was seen as a hindrance to truly transition to BIM. Lastly, the interest and appetite of industry for research was a point of discussion, mainly around the immediate need for applicable results on the part of industry versus the longer-term objectives and need for rigor on the part of academics. This incompatibility exacerbates the fragmentation between industry and academia. This fragmentation is also recognized between departments and programs within academia, which is counter to this transition to BIM-enabled collaborative project delivery. To overcome these issues, several actions were proposed:

- establish core learning outcomes that underlie the development of new educational content;
- create an on-line platform to connect industry and academic partners;
- share research results and educational materials, look outwards and learn from other countries’ curricular frameworks;
- develop collaborative, multi-disciplinary studio projects with involvement from industry stakeholders that leverage BIM;
- jointly pursue grants that benefit a wider scale of proponents; and
- develop agile educational programs by layering shifting technical concepts of BIM onto core theoretical foundations.

2. BACKGROUND

Research investigating the integration of BIM and other innovative approaches to project delivery into educational curricula is a growing trend. Abdirad & Dossick (2016) and Puolitaival & Forsythe (2016) both review prior research into BIM in education and highlight similar findings with regard to industry

expectations, key challenges, formalizing core BIM competencies, pedagogical strategies and assessment methods. Industry expectations are divided between technical and non-technical aspects of BIM. From a technical standpoint, software skills and knowledge of processes and workflows are deemed important. However, as pointed out by Abdirad & Dossick (2016), socio-technical and non-technical skills were seen as being increasingly important. This was recognized by Cheng (2006) early on who stated: “Regardless of the magnitude of BIM’s eventual of impact on the profession, its recent rise provides the ideal catalyst for rethinking architectural education. The level of expertise required to intelligently design with BIM is significant, and serious consideration must be given to how it can be taught.” (p.9)

With regard to the progression of BIM into education, Becerik-Gerber et al. (2011) conducted a survey to understand the scale, the scope and the barriers at the undergraduate and graduate levels in U.S. based universities. The authors found that 56% of AEC programs in the US offered some form of BIM content or course in 2011 and that most of them introduced BIM between 2006 and 2009. The authors also found that 57% of programs that didn’t offer any BIM content were planning to do so whereas 19% were not planning on developing any form of BIM content. This survey was replicated in Canada by Forgues & Farah (2013) who found that only 19% of AEC programs had integrated BIM content in 2012. Furthermore, the authors found that 38% of AEC programs did not intend to integrate BIM content any time soon (compared to 19% in the US).

Becerik-Gerber et al. (2011) also identified challenges to the integration of BIM into AEC curricula. Amongst the challenges identified, the lack of personnel qualified to teach BIM, inadequate resources to make curriculum changes, lack of room in current curriculum and the fact that BIM isn’t an accreditation criterion ranked highest as reasons for not incorporating BIM in curriculum. Puolitaival & Forsythe (2016) similarly identified a series of key practical challenges in developing and implementing BIM curriculum in an Australian university. These challenges were:(1) finding the balance between theory and practice; technology and process; and traditional and emerging construction project management (CPM) methods, (2) facilitating for professional development of staff; and (3) availability of appropriate teaching and learning resources for BIM. These key challenges summarize those found elsewhere around training and up-skilling educators in both the software and on theory, finding a balance in subject matters, need for a more dynamic approach to curriculum development and diffusing BIM across programs and introducing it into core curricula.

Regarding program development, Cheng (2006) identified the need to focus on the core elements that sustain professional practice, namely “design thinking” and the underlying logic that support the development of technical capabilities and skills, rather than on the skills themselves, which can quickly become obsolete. In this sense, Kocaturk & Kiviniemi (2013) identify two areas where BIM will play a role in redefining professional curricula: (1) modelling and representation, and (2) collaborative working. According to the authors, BIM’s impact will be felt “[...]to the extent to which the new technology and working methods will have an impact on the process of learning and development of both individual and distributed cognition.” (p.471) Abdirad & Dossick (2016) found that between 2007 and 2015, research focus into curriculum development shifted from adapting standalone CAD courses to recognizing the need for integration of BIM into core curriculum, requires a shift towards multi-disciplinary collaboration and the power of BIM as an educational tool.

Other work has looked into developing structured approaches to education that is adapted to BIM-enabled collaborative practice. For instance, MacDonald (2012) developed the IMAC framework, a four-staged approach mapped to Bloom’s taxonomy of learning. Forsythe et al. (2013) develop an approach to developing a programme-wide implementation strategy, with BIM supporting specific subjects according to the appropriateness of implementation. Puolitaival & Forsythe (2016) further identify a series of opportunities or measures to be taken to integrate BIM in current curricula based on their experience, including: (1) taking greater advantage of project-based learning (PjBL) to simulate real world projects; (2) creating a learning environment to support visual-spatial learning; (3) engaging students in the learning process; (4) finding a balance and a way out from a crowded curriculum; (5) developing new strategies for teaching and learning resource development; and (6) supporting staff in their professional development (p.357). The project-based learning approach is one that is supported and put forth by others

such as Leite & Wang (2014) who develop a process-oriented approach to BIM education. Finally, Sacks & Pikas (2013) develop 39 knowledge areas or topics across three broad themes (Process, Technology, Application) as a foundation for BIM education requirements for CM.

Overall, the introduction of BIM in education has received growing attention over the years due to the recognition of the importance of training future professionals and giving them the skills and knowledge to enter a rapidly changing market. The needs and challenges are consistent across the literature surveyed, however the solutions put forth varying in their approach to overcoming these challenges. That being said, there is a general consensus on the need to not only develop technical skills but to increasingly focus on collaborative and multi-disciplinary behaviour. Many researchers also put emphasis on project-based learning as a way forward. Finally, there is consensus around the need to diffuse BIM and its core concepts across existing curricula and develop new programs to suit the shifting AEC landscape.

3. METHODOLOGY

The workshop was held on October 21st and 22nd, 2016 at the École de Technologie Supérieure in Montreal, Quebec, Canada. The goals of the workshop were to identify the challenges regarding BIM research and education in Canada, look abroad for potential solutions and devise an action plan to establish a way forward. Moreover, the following questions were addressed:

- How can we make academia construction programs agile enough to train students to the reality of an industry in full transformation?
- How do we align and integrate training efforts in college, university and continuing education for the production and transfer of new knowledge on emerging practices and technologies?
- How can we encourage and support learning and transdisciplinary research?
- How do we recruit and train the next generation of researchers and teachers in these emerging areas?
- How can we make the most agile certification programs to meet current and future needs?
- What can we learn and derive from programs supporting innovation and technology transfer as ones found in Scandinavia, Great Britain or Australia?

The workshop was divided into half days where a theme was addressed through visioning sessions and group discussions. Different groups were formed per background and discipline. Groups were changed throughout the workshop. Table 1 identifies the individuals in attendance at the workshop by discipline. Table 2 identifies the different themes for visioning sessions and group discussion. At the end of each session, the group would reconvene, present the outcomes of the discussion and would rank the items in order of perceived importance. Ranking was done through the online application *Mentimeter*. This was repeated for three of the five sessions. The following section presents the findings from the workshop.

Table 1 : Workshop attendees by discipline

	Industry		Academia		Total	
Owner	2	8%	0	0%	2	4%
Architecture	12	48%	15	56%	27	52%
Engineering	7	28%	12	44%	19	37%
Construction	4	16%	0	0%	4	8%
Total	25	48%	27	52%	52	100%

Table 2 : Themes for visioning sessions and group discussion

Session	Theme
Session 01	Defining BIM and identifying the needs in research and education
Session 02	Identifying the challenges to fulfilling these needs
Session 03	Defining a course of action to overcome these challenges
Session 04	Identifying priorities
Session 05	Developing partnerships, defining projects and identifying funding opportunities

4. FINDINGS

The core of the workshop was focused around identifying the needs, challenges, and steps to be taken to progress the BIM agenda in the Canadian AECO industry, notably around supporting research and modifying the current curriculum to suite new ways of working adapted to the digitalization of the industry through BIM. The first session was aimed at developing a common understanding of BIM and identifying the needs in terms of research and education. Table 3 presents the outcomes from session 01 in order of perceived importance

Table 3 : Session 01 outcomes - ranked

Session 01: Identifying the needs in research and education	
Experiencing multidisciplinary collaboration & activities	17%
Teaching "theory of BIM", not one software tool	15%
Developing technical literacy: structured best practice learning BIM related tools	13%
Understand the big picture of project delivery (Technology-Organization-Process)	13%
Encouraging Industry interaction & engagement - coop programs / research / joint design studios	9%
New education stream programs: entire process, graduate attributes	9%
Understanding how BIM can support each aspect of the practice (business model)	9%
Teaching specific BIM uses: Representation, visualization, etc.	7%
Need for new spheres of specialization	6%
Distributing teaching responsibilities: who teaches what?	2%

Experiencing multidisciplinary collaboration & activities was perceived by workshop participants as the biggest need in research and education for students and practitioners alike. In fact, the concept of “learning by doing” and “learning how to learn” (or cognitive plasticity) came up often over the course of the workshop. The need to enhance the capabilities of individuals moving through the education system, mirrored by the identified need for increased interaction and engagement between academia and industry – both for research and education was high on the priority list. Another key need identified was to develop and teach a “theory of BIM”, ie. the underlying models and frameworks which are prompted through BIM-enabled project delivery at the individual and collective levels. This was also reflected in the identified need to understand the “big picture” of BIM. The “theory of BIM” should pervade technical and professional educational curriculum – not be an “add-on”. On the other hand, participants recognized the need to gain proficiency in software tools and in their use to be able to function in a BIM-enabled project delivery environment. Having a structured approach to the development of technical literacy was ranked high in this regard. Furthermore, developing capabilities, prior to entry into the workplace was seen as important by industry practitioners. This was directly related to the general sense that it is organizations in the industry that are bearing the brunt of the shift to BIM and are on the hook for the cost of training – an investment deemed risky by some given the high value of individuals with advanced BIM skills. The need to further develop spheres of specialization and delineating core responsibilities for the development of skills and

capabilities, while identified as important, ranked less than the others mentioned above. That being said, the need for new educational streams came up and is discussed below.

The second session was aimed at identifying the challenges to fulfilling these needs. Groups were divided into academic and industry stakeholders. Table 4 presents the outcomes from session 02 in order of perceived importance.

Table 4 : Session 02 outcomes - ranked

Session 02: Identifying the challenges to fulfilling these needs	
<i>Academia</i>	
Legacy mindsets and structures: traditional teaching methods vs experiential learning	20%
Lack of resources: time, money, physical space. etc.	17%
Teaching novel workflows, fitting into existing	16%
Creating partnerships with industry to validate/develop learning outcomes	16%
Breadth vs depth of BIM education	8%
BIM is not a requirement from accreditation/certifying bodies	8%
Incentives to broaden scope are lacking	7%
Non-natural workflows	5%
Overcoming the BIM hype	3%
<i>Industry</i>	
Understanding a lifecycle BIM approach - optimizing information flows	13%
Lack of client understanding: FORMULATING asks & requirements	12%
Professional culture & ideology, and tradition: people set in their ways	11%
Lack of industry understanding & capabilities: DELIVERING on expectations	9%
Lack of capable/competent staff	9%
Lack of financial resources / incentives	9%
Legal aspects: ownership of BIM	8%
Lack of theoretical bases: management theory, design theory, etc.	8%
Developing reliable BIMs: towards a single source of truth	7%
Disconnect between academia & industry (delivery, profit, etc.)	7%
Technology: too many software choices + research for 'best' solution	5%
Difficulty for academia to understand the industry's needs	2%

From the academic participant's perspective, the biggest challenge in transitioning towards educating current and future industry professionals for BIM-enabled project delivery lies in the legacy mindsets and institutional structures currently in place. In fact, the four highest ranked challenges related to the significant effort and hurdles in developing new- and modifying existing curriculum to suite these new ways of working. In this regard, validating new curricula and learning outcomes was seen as a significant challenge due to the need for industry feedback. In parallel, it was stated by many that current curriculum is already saturated and that there was little room for new content. Indeed, Moreover, it was stated that Canadian accreditation and certification bodies currently do not require BIM to be part of any curriculum across most, if not all, disciplines. These three elements: effort required to change, the saturation of current programs and lack of requirements highlight the absence of incentives to broaden scope of the curricula across different disciplines. Another key challenge was the pace of technological change and keeping content up to date.

From the industry participant's perspective, the challenges were more in line with everyday practice and reflected challenges highlighted in prior research (e.g. (Azhar, Hein, & Sketo, 2008; Chien, Wu, &

Huang, 2014; Davies & Harty, 2013; Hollermann, Melzner, & Bargstädt, 2012; Johansson, Roupé, & Bosch-Sijtsema, 2015; Korpela, Miettinen, Salmikivi, & Ihalainen, 2015; Mäkeläinen, Hyvärinen, & Peura, 2012). In this regard, challenges such as lack of market demand for BIM, change management, lack of incentives, reliability of the process and technological hurdles came up often. With regard to research and educational aspects, the first challenge identified by industry practitioners, understanding a lifecycle BIM approach - optimizing information flows, and the identified lack of theoretical bases touched on the need to develop and teach underlying theoretical notions and shift to a pervasive view of BIM across disciplines and programs. Interestingly, industry practitioners also identified a disconnect between industry and academia, however they viewed the disconnect at the level of framing research and fitting it into existing business processes without disrupting current workloads and workflows. Finally, industry practitioners also felt overwhelmed by the pace of technological change.

During the third session, participants were tasked to come up with concrete actions to fulfill the needs and overcome the challenges identified in the first two sessions. The outcomes of this session fed into the fourth session, which was aimed at identifying priorities and set courses of action. Overall, a tighter coupling between academia and industry was called for, which could take the form of research partnerships, co-op programs and internships. Moreover, more inter-disciplinary education was proposed in the form of integrated design studios. While this isn't a novel concept and has been done in other places around the globe, there was a general feeling that developing such a course in the Canadian context was challenging due to the departmental divisions found within Universities. In this light, new approaches were proposed, such as the possibility of creating a Canadian School of the Built Environment (which exists in the UK and the US) and a National Institute for the Built Environment. Identifying funding opportunities and considering all aspects of the project delivery lifecycle in the development of future curricula were also deemed a priority. Table 5 presents the outcomes from sessions 03 and 04 in order of perceived importance. The fifth and final session was aimed at developing partnerships, defining projects and identifying these funding opportunities.

Table 5 : Session 04 outcomes - ranked

Session 04: Identifying priorities	
Showcase collaborative studio projects (w/ industry partners & community stakeholders) that leverage BIM	24%
Develop an online knowledge-sharing "marketplace" to request & share curricular material	22%
Focus on studying lessons learned from other curricular frameworks developed overseas	19%
Pursue a CREATE grant (integrated design management & leveraging BIM in practice)	18%
Ensure the next step of virtual model to digital fabrication is included in the strategy	17%

5. DISCUSSION

From the findings, it becomes apparent that workshop participants identified the same needs and challenges that were highlighted in past research (Abdirad & Dossick, 2016; Puolitaival & Forsythe, 2016; Sacks & Pikas, 2013). This is encouraging to the extent that possible solutions have already been identified and that they simply require adaptation to the Canadian context. Accordingly, this was one of the questions formulated at the onset of the workshop (*What can we learn and derive from programs supporting innovation and technology transfer as ones found in Scandinavia, Great Britain or Australia?*) and highlighted as one of the courses of action to be taken: *focus on studying lessons learned from other curricular frameworks developed overseas*. In this sense, adaptation of the IMAC framework (Macdonald, 2012) or another could serve as a good foundation.

Another area of focus was around adaptation of current curricula, integration of BIM into existing programs and creation of new multi-disciplinary, collaborative programs. The question of agility came up often and was seen to pose a serious threat to future AEC training and education programs. Indeed, a

workshop question was formulated in this sense: *How can we make academia construction programs agile enough to train students to the reality of an industry in full transformation?* A partial answer can be found in the past literature around project based learning and encouraging tighter couplings between industry and academia. However, in the Canadian context, this was also seen as a challenge. One course of action developed was identifying and applying for funding and grants which cover industry-academic partnerships and encourage co-generation of knowledge. Further to this, laying out core learning outcomes relating to BIM and multi-disciplinary practice, that should be integrated into existing programs or serve as a foundation for new training and education programs was seen as crucial. This is consistent with findings by Sacks & Pikas (2013) and Forsythe et al. (2013), among others.

Regarding certification and assessment, workshop participants were asked: *How can we make the most agile certification programs to meet current and future needs?* This was a difficult question to answer and no consensus emerged around its resolution, although a tighter coupling between industry and academia could help ensure relevance and rigor of certification and assessment process. Additional questions formulated for the workshop were: (1) *How can we encourage and support learning and transdisciplinary research?* And (2) *How can we align and integrate training efforts in college, university and continuing education for the production and transfer of new knowledge on emerging practices and technologies?* It was suggested to create an online platform or “market place” to co-develop and share lessons learned and resources, instead of expecting every program to reinvent its own material. Forsythe et al. (2013) and Puolitaival & Forsythe (2016) both identified this as a challenge and proposed approaches to overcoming it. Alignment of training efforts is also a challenge that resonates with the technical-theoretical dichotomy that has been identified in the workshop and in prior research. Some approaches, such as the one developed by Kocaturk & Kiviniemi (2013) warrant further investigation in the Canadian context. There is also a need to focus on the academic “supply chain” to see what catalysts exist or which are required to initiate change to highlight responsibilities and uncover new roles which may clash with the more traditional and institutional mindsets that exist.

Lastly, questions around *How do we recruit and train the next generation of researchers and teachers in these emerging areas?* also mirrored the challenges identified by others such as Becerik-Gerber et al. (2011), Puolitaival & Forsythe (2016) and Abdirad & Dossick (2016). Again, greater integration between industry and academia was seen as a possible solution path, ie. having individuals from industry more involved in teaching BIM and involved in research projects. While this is already happening to a certain extent, there is increasing opportunity for industry practitioners to play a hybrid role in academia: expert, teacher and student.

6. CONCLUSION

Researchers have been increasingly studying how BIM and integrated, multi-disciplinary practice gets included into AEC training and education programs. The recognition by most that BIM is a disruptive and transformative innovation in the AEC industry has led many to question how students are educated and how professionals get adequate training. Some have called for a complete rethinking of the current AEC curricula, yet many barriers stand in the way of such a reform. The findings of the workshop presented in this paper set the course for action to begin rethinking the way Canadian AEC stakeholders are trained and educated. Findings reflect conclusions made in prior research that the integration of BIM into existing programs is challenging yet it can be done. The importance of tighter couplings between academia and industry were also highlighted in that there is a need to ensure the relevance of what is being taught at both a technical and theoretical level. Consistency is also seen as an important part of the transformation effort and in this regard, the creating of a learning outcomes framework, currently undertaken by buildingSMART Canada, and the networking and sharing of methods and resources is seen as an important step. Finally, agility and the promotion of “design thinking” is key to this integration effort: recognition that the tools may change, but the underlying theory remain somewhat stable is paramount in the development or transformation of AEC educational and training programs.

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BIM EDUCATION IN OPEN DIGITAL LEARNING – OPPORTUNITIES, GAPS AND FACULTY’S ROLE

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ABSTRACT

The construction industry is facing a severe shortage of skilled workforce due to the retirement of baby boomers and rapidly changing technology landscape. This urges construction companies to transform business practices and recruit for positions that demand brand new knowledge and skill sets to respond to emerging industry trends such as BIM. Global access to open online courses, competency-based training, and certification programs seem to provide promising alternative solutions outside of formal academe. Nevertheless, uncertainties and the lack of best practices in leveraging these otherwise readily available, valuable open digital learning resources are impeding the agility of higher education in attracting and retaining students and preparing them to meet industry’s demands for a competent workforce. This paper explores a new model of competency-based BIM education in this global knowledge network. Specifically, an online training program was co-developed with the active participation of the instructor, the industry advisory board (IAB), and subject matter experts (SMEs) from the Assemble Systems. The job-specific competency and metrics of evaluation were defined by IAB and passed along to the instructor, who aligned these metrics with student learning outcomes (SLOs) and worked with the SMEs to develop focused, progression online learning modules and assessment that would eventually lead to a certificate of competency. This custom-made online training program was then piloted in two institutions with construction engineering and management students. The synergies between the instructor’s pedagogy knowledge and the SMEs’ domain specific knowledge and direct engagement of employers in development were expected to demonstrate a new model of competency-based education that features clear goal setting, curated content creation, and pedagogical design and mentored and assessed student learning.

Key Words: BIM, Competency, Education, Open Digital Learning, Student Learning Outcomes.

INTRODUCTION AND BACKGROUND

The construction industry is facing a severe shortage of skilled workforce (McGraw-Hill Construction 2012). Contributing factors include the retirement of baby boomers, the rapidly changing technology landscape and the transformed business practices driven by emerging industry trends including sustainability, building information modeling (BIM) and lean construction. To keep up with these trends and stay competitive in business, companies are urged to recruit for positions that demand brand new knowledge and skill sets, which are not readily addressed in existing construction management (CM) or construction engineering management (CEM) curriculum (McGraw-Hill Construction 2012; Sacks and Pikas 2013; Wu and Issa 2014). Traditionally, higher education is slow in adapting to societal and technological changes. Incapability of higher education in meeting the changing competency expectation from industry partners has incentivized rapid development in global access to open online courses as well as competency-based digital training and certification programs, which seem to provide promising alternative education solutions outside of formal academe (McGraw-Hill Construction 2012; Wolfe and Andrews 2014). In the CM/CEM field, for example, courses from edEx, Lynda.com, the

Autodesk Building Performance Analysis Certificate (BPAC) program, and the ProCore certification series are exemplary open digital learning/training resources that may supplement conventional college curricula to help students develop relevant competency in these critical areas, and improve their preparedness for new performance expectations in workplace.

However, little research has been conducted to help understand: 1) how effective are these digital learning, training and certification in regard to engaging student learning and develop job-specific skills in the CM/CEM field; or 2) how credible and significant these online courses and certificates are as perceived by industry employers. More importantly, there are considerable uncertainties towards the relationship between higher education and emerging open digital learning solutions. The fundamental question is: will open digital learning necessarily compete or even completely replace formal higher education? If not, should there be a more inclusive and synergistic perspective to look at their co-existence? These uncertainties and the lack of best practices in leveraging these otherwise valuable open digital learning resources are impeding the agility of higher education in attracting and retaining students and preparing them to meet industry partners' demands for a competent workforce. Essentially, higher education, especially the faculty will need to step up, to investigate and evaluate such uncertainties, and provide students with clear guidance on perceiving and adopting open digital resources to foster learning and achieve academic success. Therefore, research is also needed to explore what strategies higher education and faculty may take to curate the vast volume of open digital learning resources, and mediate between them and existing college curricula to align critical student learning outcomes (SLOs) with anticipated workforce competency.

As an initial step to delve into these intertwined questions and uncertainties, this collaborative research is particularly interested in exploring the transitioning roles of higher education faculty in the digital learning era to foster student-centered and competency-based BIM education in the CM/CEM field by strategically integrating open digital learning resources with existing college curricula (Figure 1). As online learning is gaining popularity in higher education, the traditional brick-and-mortar based classroom learning environment is migrating to a more sophisticated, technology-facilitated digital learning environment. The faculty-student interaction for online student learning and engagement can be enhanced accredited to technology affordance (Robinson and Hullinger 2008). Since students' online learning behaviors may differ due to self-perceived social presence online and the drastically expanded access to subject matter resources, faculty's interaction with students online often goes beyond what was typically experienced in traditional classroom, to include learning materials curation, subject-specific mentoring, and learning community constructing and moderating (Wallace 2003). Online learning, both formal and informal, is considered an enabler and driving force toward student-centered competency-based education. As a result, competency development and career advice add up to the faculty's social presence along with their academic presence in online learning. In the global digital learning era, higher education and its faculty are in transition to become curators, evaluators, connectors and analysts for student learning and engagement (Wolfe and Andrews 2014).

RESEARCH OBJECTIVES

The project is directed under a faculty-led partnership with industry employers and third-party subject matter experts (SMEs) through remote collaboration between California State University, Fresno (hereinafter Fresno State) and the University of Colorado Denver (hereinafter CU Denver). It is originated from and expanded upon an ongoing research collaboration between the PIs on evaluating impacts of the BPAC program on sustainability education, and also a preliminary investigation of industry advisory boards' perceptions towards priorities of CM/CEM student learning outcomes in alignment with corresponding workplace competencies. Pilot findings based

on the use of BPAC as a teaching intervention demonstrated that students believed that the open digital learning resources enhanced their learning experience both in regard to specific course learning outcomes as well as sustainability competencies. Specifically, the findings suggested that the open digital learning resource enhanced student competencies in regard to skills in both systems thinking and change-agents. In this research, faculty's participation in facilitating the intervention and conveying the authentic competency expectation from industry partners to students stood out, which motivated the research endeavors proposed in this project. Specifically, this research aims to:

1. Explore the opportunities and alternative pedagogy models in BIM education leveraging an increasingly ubiquitous digital learning network;
2. Evaluate student perceptions towards BIM education in the digital learning environment and the impacts of faculty's role on student engagement, learning outcomes, and competency development.

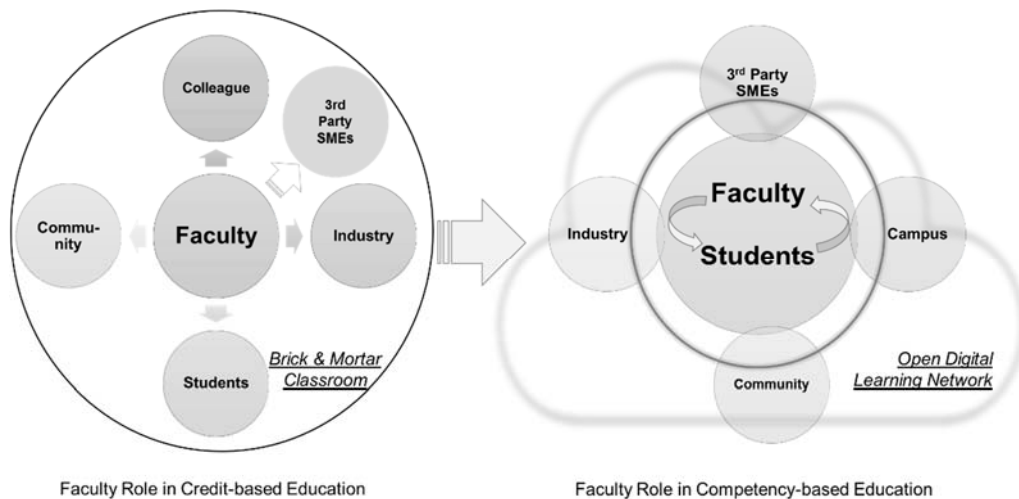


Figure 1. The conceptual transition of faculty's role from credit-based to competency-based education.

RESEARCH METHOD

The proposed research is directed under a faculty-led partnership with remote collaboration between Fresno State and CU Denver. An online certificate program was co-developed and piloted with the active participation of the instructor, the industry advisory board (IAB), and subject matter experts (SMEs) from Assemble Systems. The job-specific competency and metrics of evaluation were defined by IAB and passed along to the instructor, who aligned these metrics with student learning outcomes (SLOs) and worked with the SMEs to develop focused, progressional online learning modules and assessment that would eventually lead to a certificate of competency. In addition to the learning outcome assessment, a post-training survey was conducted to collect feedback on student learning experience and perceived effectiveness of this new model of BIM education, including the new roles played by faculty in introducing an intervention to the online training process.

ASSEMBLE SYSTEMS ONLINE TRAINING: PEDAGOGY & LEARNING MODULES

The Assemble Systems application is a web-based BIM data management solution designed to optimize BIM workflow by providing a real-time cloud collaboration platform for model-based cost estimating, model checking and change management (Assemble 2017). The decision to use

Assemble Systems as the pilot of this new BIM education model was made based on inputs from several IAB member companies that were actively using the application and capitalized on it in BIM project execution. Initial discussion took place as a brainstorming session with the instructor, a BIM manager from an IAB member company and the subject matter expert from Assemble Systems. Starting from Spring 2016, the instructor and the subject matter expert collaborated remotely using Google Apps (Figure 2) and developed a total of three (3) online learning modules that were tailored for beginners to understand the user interface, data structure, functionality and workflow of Assembly Systems:

- Learning Module 1: Getting to know Assemble
- Learning Module 2: Assemble for Quantity Takeoff
- Learning Module 3: Assemble for Change Management

Throughout the process, the subject matter expert supplied all the learning materials while the instructor curated these contents and focused on the pedagogy design that aimed to align the learning outcomes with competency expectations developed from the brainstorming sessions.

	A	B	C	D	E	F	G	H
1	Assemble Systems @ Fresno State							
2	Learning Module	1	Get to know Assemble Systems					
3	Module Description	This module introduces the basic concepts of Assemble, its navigation and the process to publish a model.						
4	Estimated Module Duration	1.5 Hrs						
5	Learning Outcomes	After completing this module, students will be able to:						
6		1	Define Assemble Systems and describe its major functionality					
7		2	Explain the concept of and challenges in model data access and sharing in BIM project execution and the ben					
8		3	Navigate the Assemble Model Viewer					
9		4	Explain the process of creating a project in Assemble					
10		5	Explain the process of model publishing from Revit to an Assemble project					
11		6	Create a sample Assemble project and demonstrate the model publishing process					
12	Learning Activity	Students will conduct the following activities to meet the anticipated SLOs:						
13		1	Read "Assemble Your BIM Team (pdf handout)"					
14		2	Watch YouTube videos:					
15			a. "What's possible with Assemble"					
16			b. "Efficiently Manage Your BIM Data with Assemble"					
17		3	Complete the Assemble Introduction tutorial					
18		4	Read and follow the Viewer Tools and Icons in your Assemble Instance					
19		5	Select Objects in the view and practice walk mode (Selection: https://assembleystems.zendesk.com/hc/en)					
20		6	Create a sample Assemble project and publish a sample model to the project created					
21	Learning Assessment	To measure the SLOs, student will be assessed with the following metrics:						
22		1	Quiz on YouTube videos					
23		2	Tutorial					
24		3	Case study: What's the project, problem, solutions, outcome of this case study?					
25		4	Invite your TA into your project					
26	Tutorials and Resources	Assemble Systems furnished tutorials and supplemental learning resources						
27								

Figure 2. Remote collaboration on learning module development using Google Apps.

As shown in Figure 2, each learning module followed a standard structure and clearly indicated the learning outcomes, the corresponding learning activities, and the assessment measures. To host the developed learning modules, a Google site (Figure 3a) was used to allow remote access by students from both campuses at Fresno State and UC Denver. Meanwhile, the hands-on part of the training was conducted through the web server of the Assemble Systems (Figure 3b) where students may publish their models, access the model data, perform quantity takeoff and compare variance between model versions for change management.

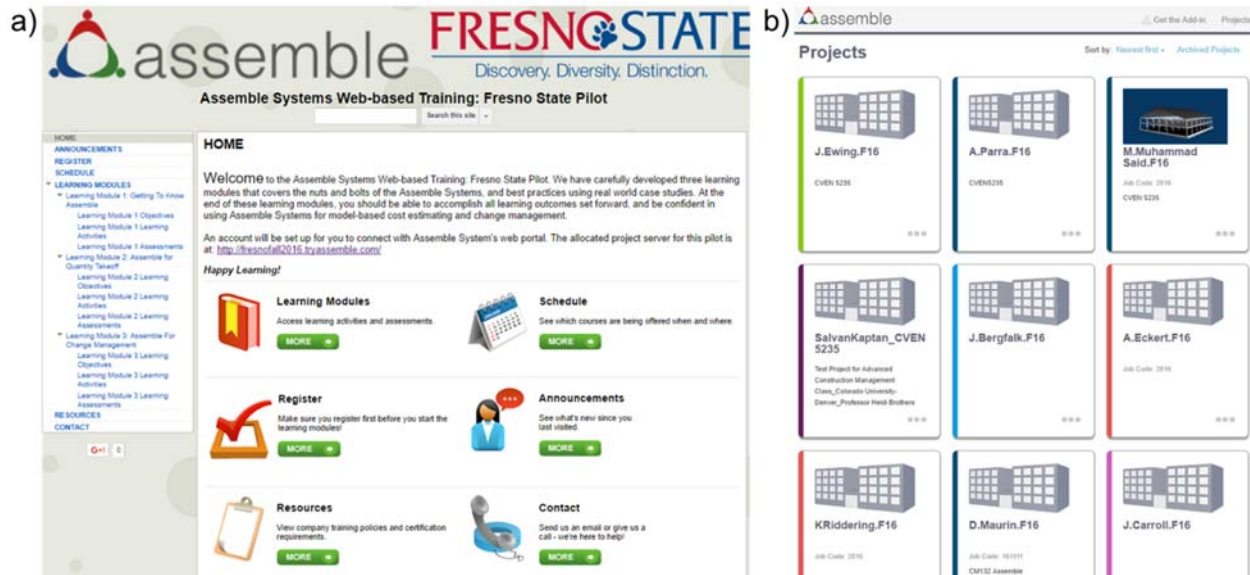


Figure 3. Assemble Systems online learning environment: a) Google site learning modules; and b) web-based project training server.

ASSEMBLE SYSTEMS ONLINE TRAINING PILOT

In Fall 2016, the Assemble Systems online training was piloted at Fresno State in the Construction Management program (CM132 – BIM for Construction Management) at the undergraduate level and followed by CU Denver in the Construction Engineering Management program (CVEN 5235 - Advanced Construction Engineering) at the graduate level between October and November. A total of 22 students (13 undergraduates at Fresno State and 9 graduates at CU Denver) participated. It is worth mentioning that most students at CU Denver were non-traditional students and held full-time positions in the industry. Both courses allocated a total of three (3) weeks to this pilot. For each learning module, the instructor hosted a synchronous online session to walk students through the module contents and expectations. Students then worked individually online to complete the learning activities and assessment.

As students were progressing with the learning modules, their understanding of BIM data structure and model data management increased accordingly, elevating from simple visualization/visibility control of data (Figure 4a) to data import/export between applications (Figure 4b), and then model versioning, variance comparison and analysis (Figure 4c). In the meantime, the business processes that relied on these model data manipulation exercises such as design review, quantity take-off and cost estimating, and change management appeared to be well received by students. Assessment measures used in this online training included quizzes, reports on hands-on activities, and a reflection paper. In summary, all 13 students at Fresno State and 5 students at CU Denver passed the three quizzes with an average grade of 85.3%, 86.2%, and 83.8% respectively. The student reflection papers also indicated a high level of interest in the contents and anticipated outcomes from this training program in relation to potential career benefits in the long term.

PILOT FINDINGS AND DISCUSSIONS

Overall, the pilot of the Assemble Systems online training program accomplished solid outcomes with 18 out of 22 participants that successfully completed all required learning activities and assessments. In addition to the direct measures for assessing student learning outcomes in model-based quantity takeoff and change management, the investigator and the subject matter

expert were also curious about students' perceptions toward this joint effort in developing a new model of BIM education utilizing open online learning resources with intervention of new faculty roles and partnership between industry and higher education. A post-training survey was used to collect feedback on several critical success factors (CSFs) of this program:

1. Learning motivation and engagement
2. Learning environment and learner experience
3. Pedagogy and learning outcomes
4. Faculty role and joint partnership

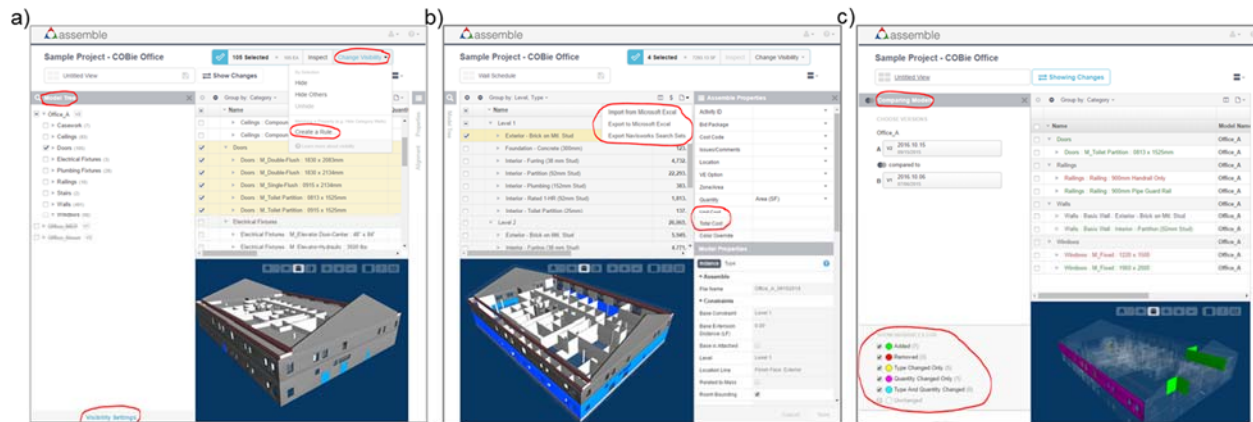


Figure 4. Progression of learning modules: a) model data visualization; b) model data extraction and exchange; c) model versioning and variance analysis.

A total of 16 completed questionnaires were collected at a 72.7% response rate with a breakdown of 11 from Fresno State and 5 from CU Denver. The majority (11 or 62.5%) of students had some industry experience through internship and 6 (37.5%) of them were either working part time or full time. Before entering this training program, students' self-evaluated knowledge, skills and abilities (KSAs) in BIM were mostly at the Novice level (50%) and half of them were not aware of model-based quantity takeoff/estimating or change management. Slightly over a half of them (56.3%) were familiar with web-based collaboration platform for BIM. Most students (81.3%) also indicated that they were aware of some online learning/training programs and platforms, including the Autodesk BPAC program, LinkedIn Learning, Lynda.com (free through university subscription, and is now part of LinkedIn), ProCore Online Training and Certification series. Besides, 12 (75%) out of them had actually taken training or courses with these programs and platforms.

When asked to evaluate the pros and cons of their own experience with online learning/training programs against traditional classroom learning, *availability*, *accessibility*, and *flexibility* stood out as the pros while *impersonal*, *lack of sustained motivation* and *lack of faculty-student interaction* were cited as the major cons of online learning. Accordingly, the major aspiration of students to take online learning/training programs was “*to attain new knowledge and develop new skill sets to stay up with cutting-edge applications*”. Meanwhile, scheduling issues, quality, and availability of subject contents were also factors that students took into account when pursuing online learning and training. To evaluate students' perceptions on the identified CSFs to the Assemble Systems online training pilot, a series of questions with Likert-type scales were utilized on the learning environment and learner experience (CSF 2), and pedagogy and learning outcomes (CSF 3). For learning motivation and engagement (CSF 1), and faculty role and joint partnership (CSF 4), some open-ended questions were asked for qualitative analysis. Since a 10-point scale was used, the responses were calculated into Net Promoter Score or NPS (Keiningham et al. 2008) as an indicator of satisfaction level and summarized in Table 1 below.

Table 1. Student Feedback Analysis on CSFs 2 and 3 of the Assemble Systems Pilot.

CSF	Criteria	% Detractors	% Passives	% Promoters	NPS	Satisfaction Index
CSF 2	Overall user interface & ease of navigation	12.5	50	37.5	25	Positive
	Overall clarity and quality of contents	18.75	37.5	43.75	25	Positive
	Overall learning activity design and delivery	31.25	25	43.75	12.5	Positive
	Overall learning guidance and assessment	12.5	37.5	50	37.5	Positive
CSF 3	SLO 1: Describe and explain functionality of Assemble and model publishing workflow	25	37.5	37.5	12.5	Positive
	SLO 2: Model data visualization and manipulation; model-based QTO	25	31.25	43.75	18.75	Positive
	SLO 3: Model versioning and data variance visualization and analysis; model-based change management	31.25	31.25	37.5	6.25	Positive

Although various metrics and tools are available for student engagement evaluation, including the National Survey on Student Engagement (NSSE) framework (Kuh 2001; Kuh 2003) and there is an abundant research literature on faculty role in promoting student engagement (Kuh et al. 2004; Umbach and Wawrzynski 2005), the sample size of this study is inadequate for rigorous quantitative and statistical analysis. However, results of the open-ended questions did suggest fairly positive feedback. Below are a couple of quotes (with some grammar corrections) by students in regard to learning motivation and engagement (CSF 1):

“Reading all of the information was a bit tedious. However, I feel like the information was explained thoroughly and broken down very well making it easier to grasp the complex concepts being taught. Overall I feel like I learned a lot through the online training. I definitely see myself using Assemble in my future internships and post-graduation.”

“As first time taking this course I believe that I have learned a lot of things from Assemble Systems that could help me with my academic education also will be really helpful and useful for my career.”

“I think it's a very effective means of teaching that material. The program was easy to follow and full of information.”

It should also be noted that 12 students (75%) expressed interest in continuing learning about Assemble Systems and were likely to use it in future internships and/or full-time jobs. Students also commented on faculty role and the partnership among faculty, subject matter experts and the industry (CSF 4) in providing better online learning/training programs. For instance, several students wrote:

“There is a big difference when compared to other online programs that I have taken. Knowledge of Revit, Navisworks, and Excel does facilitate the learning of the software. Also the way it is structured aids on the learning of it.”

“It makes sense that the software companies responsible for BIM programs would want to team up with faculty to train students to use their software. And for a CM program, I believe it gives graduating students a huge advantage if they can use and learn the programs directly from the vendors.”

“I love the collaboration between vendor and academia!”

CONCLUSIONS & FUTURE RESEARCH

The momentum in global access to open online courses, competency-based digital training, and certification programs seem to provide promising alternative education solutions outside of formal academe. The formation of a digital learning culture among the younger generation also facilitates innovations in college construction management and engineering education. As the industry is experiencing the critical transition to embrace more technology-intensive and information-driven business processes, the market demand for a workforce that meets the brand new workplace competency requirements is steadily going up. Higher education faculty can and should play a pivotal role in this context to leverage open digital learning resources, enhance partnership with employers and subject matter experts, and foster student engagement and success. This research lays some cornerstones in exploring the unique position that construction management and engineering faculty currently hold, and also motivates more in-depth, both quantitative and qualitative, investigations toward a better understanding of how should we teach and how students will learn in this global digital learning network.

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PERFORMANCE AND OPTIMIZATION LEARNING MODULES FOR BIM EDUCATION

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ABSTRACT

The energy issue plays an important role in the design and operation of buildings where careful long-term decisions can significantly improve the performance of buildings and thus reduce their consumption of energy. Building Energy Modeling (BEM) is a process in the design phase which one or more building energy simulation programs use properly adjusted Building Information Models (BIMs) to conduct energy assessments for the current building design. The core goal of BEM is to inspect building energy standard compatibility and seek opportunities to optimize proposed design to reduce structure's life-cycle costs through (1) saving time and costs by obtaining building and system information automatically from BIM model instead of inputting data manually, (2) improving building energy prediction accuracy by auto-determining building information such as geometries, volumes precisely from BIM model, (3) helping with building energy code verification, and (5) optimizing building design for better building performance efficiency and reduce building life-cycle cost. This paper presents an experiential approach adopted to BIM-enabled learning to investigate building performance with BIMs at Department of Civil, Architectural and Environmental Engineering (CAEE) in Armour College of Engineering of Illinois Institute of Technology (IIT). This methodology (1) allows the students to experience a BIM learning module namely performance and optimization module; and (2) helps them to learn how BEM tools and Building Performance Analysis (BPA) methods integrate with each other. Experiences in integrating BIM in terms of learning by doing into a graduate level course and an undergraduate immersive research program at IIT are presented and discussed through sample assignments and specific research sessions including lectures, seminars, researchers' oral and poster presentations, industry partnerships, workshops and activities. The objective of this study is to educate the future engineers/architects who will be actively using BIMs in BPA routinely.

Keywords: BIM, BEM, Experiential Learning, Performance, Optimization

1. INTRODUCTION

Rapid developments in building design and analysis software over the last decade, coupled with advances in desktop and laptop computational power, have led to the emergence of new digital models for the design and documentation of buildings: virtual buildings or building information model(s)/(ing) (BIM). Thanks to these advances, BIM - authoring software applications combine three - or four - dimensional models with imbedded, intelligent building objects related in a contextual database. As a result of BIM's data-rich 3D modeling, various design disciplines can extract and manipulate relevant tabular or graphical building views such as reports and drawings. According to Levy (2012) such an approach can improve building construction and operational performance, increase design efficiencies, and foster an integrated design workflow, among other benefits. BIM creates opportunities for the quantitative assessment of design options. That is, the data bound to the virtual building model can be defined, analyzed, and parameterized by the designer, with the ultimate goal of positively influencing building performance.

BIM is appropriate for sustainable design. Leadership in Energy and Environmental Design (LEED) for example, dictates the measures to be taken to achieve sustainability. Such prescriptive measures serve as proxies for actual building and occupant performance. The benefit of early analysis— even as early as conceptual design—is that it allows the most influence on building performance with the least effort. BIM’s adaptability is compatible with performance-driven (sustainable) design. BIM becomes a sustainable design environment, then, as it potentially integrates quantitative analysis in the design decision-making process.

The technology is advancing in a rapid fashion. Although knowledge and skills can always be acquired and learned, the real skill needed is to adapt the change and see possibilities in new situations. A BIM process needs competencies based on a technology environment consist of software platforms and tools. However, BIM is a human activity that ultimately involves broad process changes in the construction industry based on both user skills and experience. Furthermore, delivery of building projects has become more complex and technically demanding (Bozoglu, 2016).

This paper presents a modular approach adopted by the Department of Civil, Architectural, and Environmental Engineering (CAEE) at Illinois Institute of Technology (IIT) to promote BIM-enabled learning. The objective is to educate the both the engineers and architects of the future who will be actively using BIM routinely. The strategy relative to BIM Learning Modules is expected to help architecture, engineering, and construction professionals be prepared for the needs of the industry in the future (Bozoglu, 2016).

2. LITERATURE

The global building industry is one of the largest industries in the world and will grow from approximately an \$8 trillion industry in 2013 to a \$12 trillion industry by 2020. Yet, building construction is still quite often a low-tech environment that can be extremely inefficient and wasteful. Indeed, it may be the only industry that has actually declined in efficiency over the past 20 years. As building requires an enormous amount of resources, the industry has substantial effects on the environment (Schilling, 2014; and, Andersson, Farrell, Moshkovich and Cranbourne, 2016) .

The SmartMarket Report published by McGraw-Hill Construction (2012) shows a rapid increase of BIM usage in North America. The percentage of companies using BIM is 71%, increased from 49% (2009) and 17% (2007). However, the role of BIM is not fully understood neither in the construction industry nor by a large segment of educational institutions that specialize in architecture and engineering. According to the National BIM Report (2012) there is still further work to be done in regards to preparing the industry for full adoption of BIM.

The SmartMarket Report of Dodge Data & Analytics (2015) on the impact of BIM indicates a growing consensus around key BIM benefits such as constructability improvement and better design understanding. As contractors continue to implement BIM the need for BIM knowledge and skills expected of construction graduates is increasing. The findings also show that BIM analysis and simulation capabilities produce a more well-reasoned design.

The only obstacle related to technology deployment selected as having a significant impact on the success of complex projects by more than half of owners, architects, engineers and contractors is lack of team member skills at using advanced tools and methods. A high percentage of engineers in particular (63%) consider this obstacle significant. The second most significant obstacle for AEC firms is insufficient technology training for inexperienced team members. The two top obstacles for AEC firms demonstrates that knowledge of how to use the technology across the project team, rather than the technology itself, is the most important obstacle for these firms (McGraw-Hill 2014; Dodge Data & Analytics, 2015).

Professional bodies, industry and academia are the key stakeholders of BIM education. It is the role of the professional bodies to represent the BIM professionals and create attractive job positions in the construction industry for those who are skilled and talented. They need to ensure that BIM is a career choice. The professional bodies accredit degree courses provided by universities, and then inspect them to ensure that they come up to their required published standards. There should be a dynamic interaction between the professional bodies and academia, which should be informed by the requirements of industry as the end

user (Demirdoven and Ardit, 2014; Demirdoven, 2015, Bozoglu, 2016). Wu and Issa (2013) indicates that the underlying supply-demand relationship between universities and the industry has been more reliant on students' intellectual and technical readiness, especially in the case of BIM. Therefore, the effective inclusion of BIM into college curriculum has become both a pedagogic and practical imperative in preparing future employees for the AEC industry (McGraw-Hill 2009; and, Crumpton and Miller 2008).

To equip current and future industry professionals with the necessary knowledge and skills to engage in collaborative BIM workflows and integrated project delivery, it is first important to identify the competencies that need to be taught at educational institutions or trained on the job (Bozoglu, 2016). Succar and Sher (2013) describe the individual BIM competencies as the personal traits, professional knowledge and technical abilities required by an individual to perform a BIM activity or deliver a BIM-related outcome.

3. BIM LEARNING MODULES

The increased use of BIM has brought about new roles such as the BIM specialist, manager, coordinator, leader, champion, trainer, consultant, expert, technologist, etc. The BIM professional's competency could cover technology, process, commercial, and personal skills. Those skills define the professional's role depending on the entry conditions into the construction industry and the qualifications and background of the professional.

The Department of Civil, Architectural and Environmental Engineering incorporated BIM into its curriculum through the introduction of three course offerings: (1) EG 430 -Introduction to BIM, the senior level elective in the Engineering Graphics Program; (2) CAE 573 - Construction Management with BIM, a graduate level elective in the Construction Engineering and Management Program; and (3) CAE 515 – Building Energy Modeling.

The BIM Learning Modules created for Department of CAEE at IIT targets improving BIM software skills (ability to create, understand and interpret building information models), for whole life cycle processes, respectively collaborating and coordinating with models; and, performance modeling and optimizing the design and use in an integrated-communication environment, and stimulating students' interaction with BIM professionals. Gaining the momentum of three different BIM learning modules, this program helps students to understand the plurality in the construction professions.

BIM Learning modules are planned and created to cover the abilities and deliverables expected from or realized by the students (as future design and construction professionals), organizations and projects when using BIM tools and workflows. These modules are based on the experiential learning which is defined by Felicia (2011) as the process of learning through experience, and is more specifically defined as "learning through reflection on doing". Early in the 1970s, the theory was proposed by David Kolb who was influenced by the work of other theorists including John Dewey, Kurt Lewin, and Jean Piaget.

Kolb (1984) states that experiential learning focuses on the learning process for the individual. "Learning by doing" which results in "changes in judgment, feeling and/or skills" for the researchers and it is discussed how this study can provide a direction for the BIM-enabled learning methods. The students are individually encouraged to directly involve themselves in the different and diverse experiences in using BIM learning tools, and then to reflect on their experiences using analytic skills, in order that they gain a better understanding of the new knowledge of BIM in design.

3.1 Performance and Optimization Module

Performance and Optimization Module is intended for design and analysis with BIM purposes. The module targets BIM and Energy Analysis designers to (1) understand the concepts of BIM, (2) understand project process and model offerings, (3) understand project standards and deliverables, (4) understand model management standards, (5) identify technology considerations, (6) create and use energy analysis models, (7) to inspect building energy standard compatibility, (8) seek opportunities to optimize proposed design; and (9) to reduce project life-cycle costs. The objectives of using Energy Analysis Models are (1) saving time and costs by obtaining building and system information automatically instead of inputting data

manually, (2) improving building energy prediction accuracy by auto-determining building information such as geometries, volumes precisely from BIM model, (3) helping with building energy code verification, and (5) optimizing building design for better building performance efficiency and reduce building life-cycle cost.

Performance and Optimization Module covers the integrated design process by focusing on the BIM terminology and early design workflow. The module provides students with the cognitive tools they will need to work with BEM. Students are presented with complex, novel and authentic tasks. Instruction occurs in technology specific issues as well as in the more discipline specific technical issues. Autodesk (2017) and Sefaira (2017) as the selected software platform provides support for analysis, interoperability, integration, and information exchange. In addition to instruction about the desktop solutions, instruction is also focused on a web-based solution.

Performance and Optimization Module is an ongoing experimentation applied in “CAE 515 – Building Energy Modeling” course with mostly undergraduate-senior or graduate standing- and some graduate students from different majors including civil/structural engineering, MEP engineering, architectural engineering, architecture, and construction management. This course aims to demonstrate how architectural and engineering design and analysis functions are impacted by (BIM). It helps students to understand the fundamentals and practical uses of information technologies in design and analysis.

BIM is an interdisciplinary practice in which data is centralized, typically within a 3-D information model, allowing for increased efficiencies and deeper project understanding and analysis. It is a shift from mere representation of project information as in a 2-D design process to detailed simulation, from a linear design and construction process to a concurrent process with live feedback loops. Implementing a functional performance and optimization based BIM practice requires an understanding of the building process, structure and professional culture both at the project and company level. In order to ensure that the BIM workflows function well, all involved parties need to have sufficient knowledge in BIM. At the inception of a project the skill set and required training need to be assessed.

BIM tools make it possible not only to visualize specific views, but also generate performance-driven visualization and the construction of the building in sequence. Images, animations, live virtual walk-throughs, and experience simulations are gradually becoming standard project requirements. Depending on the need, it is possible to generate various types of visualization results, ranging from highly realistic experience animations that convey the final experience of the facility, to color-coded coordination studies meant to communicate concepts, discrepancies, performance criteria, issues, and interferences. Each type of visualization should be tailored to its specific audience.

3.1.1 Performance and Optimization Knowledge Set

The Performance and Optimization Module provides graduate level learning with the applicable analysis skills that are required by the construction industry and is relevant to the realities of an ever evolving technology environment. The students who are enrolled in this course gain strong analysis and teamwork skills for developing and executing a BEM strategy, a broader perspective of social, environmental and economic issues, and finally sustainability and building science knowhow that goes along with BEM practice. The primary competencies in Performance and Optimization Module Set include: (1) Sustainable Design and Building Life Cycle, (2) Energy Analysis Models/EAMs and Simulation, (3) Building Science and Equations of Modeling, (4) Software and Tool Selection, (5) Environmental Strategies and Baselines, (6) Building Components Performance, (7) Building Energy Systems Optimization: and (8) Simulation Comparisons and Interpretations. In addition to those primary knowledge areas secondary competencies such as (1) Resilient Design Strategies, (2) Facility Management, Sustainability and Enabling Technologies, (3) Sustainability Evaluation, and (4) Existing Conditions Modeling are covered.

One of the core values for students in this module is the Term Project which is both submitted as a report and presented in class. Term Project provides a framework for the fundamental design and analysis strategy that begins with identifying the performance driven design goals for using an energy analysis model and simulation software. The analysis software is used during the project simulation process to determine

building performance and sustainability goals by comparing 3D models of geometry, orientation and building systems.

A building’s performance is measured mainly by its ability to provide comfortable conditions to its inhabitants and by the amount of energy it consumes. Decisions made by the design team are reflected in the performance of the building. The design intent information model can be analyzed for energy and building performance criteria and can be used to run a range of analysis simulations. This enables the design team to measure design decisions against both qualitative and quantitative measurements.

The success of BIM depends highly on organized collaboration. For a BIM practice to flourish, the approach must be understood and agreed upon by all stakeholders on a project. The BIM team acts as a managing entity, ensuring correct integration and implementation processes. It is important for each trade to maintain strict adherence to standards provided by the BIM team while developing its model, in order to ensure uniform geometry and data formatting across all models. The hardware, software, and data-flow distribution systems must be adopted at the beginning of the project in order to facilitate a seamlessly integrated workflow. It is critical to employ well-defined standards to exchange, sort, and work collaboratively with data generated by the process and stored in the information model. Used in BIM process an energy analysis software is also very powerful, but using the tools to their full advantage requires an experienced professional to create clear protocols and workflows.

3.1.2 Performance and Optimization Skill Set

The Performance and Optimization Module Set includes practices with various software and technology as learning tools those promote learning methods for accomplishing the competencies in the knowledge set of Performance and Optimization Module as given in the Table 1. Besides the lectures, the primary skill sets are designed as hands-on sessions in detail to cover the competency targeted per each knowledge set and supported by vendor training for performance based design analysis and energy simulations for design optimization with a learning tool like Sefaira Architecture where Radiance is run for daylighting scopes and Sefaira Systems where EnergyPlus is run for HVAC and systems design scopes. Revit Green Building Studio is also practiced for whole building design and analysis goals additional to Ecotect and IES uses.

The secondary skill sets are a combination of lectures, in-lab examples supported by case studies using related videos and readings and invited guest speakers. Students see the best project examples and showcases. Thus, they understand the effect of BEM in the life cycle of a project by using other tools such as Trimble field management tools, EcoDomus and Revit Credit Manager.

Autodesk Revit for Green Building Studio and Sefaira software packages are provided both through institutional licenses and instructor’s effort to get educational support from vendors. Software related online training and support materials such as video tutorials, webinars, help files, training manuals and community networks are used to investigate the analysis process practicing BIMs for energy simulation.

An energy analysis model (EAM) simulates the geometry and data of an environment. The EAM is a virtual, geometrical, spatial relational database. It keeps track of data as it relates to specific geometry and location. Many types of data can be linked to a virtual object, and there are many possible ways to use and analyze the data contained in the model. An EAM is powerful because it allows all of the data surrounding a building project to be centralized into one ecosystem that all participants can share and analyze.

TABLE 1: Performance and Optimization Module

Knowledge Set		Skill Set			
	Competencies	Learning Methods	Practices	Learning Tools	Module Assessment
Primary Set	Sustainable Design and Building Life Cycle	<ul style="list-style-type: none"> •Lecture •Case Video •Case Reading •LEED Standards 	<ul style="list-style-type: none"> •Understanding the Design Phases and Integrated Design •Understanding the Green Building Rating Systems •Understanding Whole 	<ul style="list-style-type: none"> •Revit Green Building Studio 	<ul style="list-style-type: none"> •Participation •Assignment •Midterm Exam

Energy Analysis Models/EAMs and Simulation	<ul style="list-style-type: none"> • Lecture • Case Video • Case Reading 	Building Design <ul style="list-style-type: none"> • Model Visualization • Model Coordination • Energy Simulation • Interactive Space Use • Design Integration 	<ul style="list-style-type: none"> • Revit • Revit Green Building Studio • Case with Ecotect • IES • Sefaira Architecture (runs Radiance) • Sefaira Systems (runs EnergyPlus) • I-room (Industry) Workstations (in-lab) 	<ul style="list-style-type: none"> • Hands-on • Assignment • Midterm Exam • Presentation and/or Autodesk Building Performance Analysis Certificate • Term Project • Term Report
Building Science and Equations of Modeling	<ul style="list-style-type: none"> • Guest Speaker • Lecture • In-lab example 	<ul style="list-style-type: none"> • Understanding Design Goals • Understanding Occupant Comfort • Understanding Energy Literacy (Heat Transfer, Heat Energy Flows, Envelope) • Understanding Building Loads (thermal, Equipment, Lighting) • Measuring Building Energy Use • Analysis Methodologies (Calculation Methods) 	<ul style="list-style-type: none"> • Calculator • Converter 	<ul style="list-style-type: none"> • Participation • Midterm Exam
Software and Tool Selection	<ul style="list-style-type: none"> • Lecture • Case Video • In-lab example 	<ul style="list-style-type: none"> • Interoperability • Information Exchange 	<ul style="list-style-type: none"> • Revit • Case with Revit Green Building Studio • Case with Sefaira • Case with Ecotect • Case with IES 	<ul style="list-style-type: none"> • Participation • Midterm Exam
Environmental Strategies and Baselines	<ul style="list-style-type: none"> • Lecture • Case Video • Case Reading • Self-Learning Tutorial • Webinar • Hands-on • ASHRAE Standards • Architecture 2030 • In-lab example 	<ul style="list-style-type: none"> • Using Climate Data • Building Geometry and Massing • Building Orientation • Solar Measurements • Daylight Strategies • Wind Analysis • Daylight Analysis • Conceptual Energy Analysis • Model Visualization • Simulation • Data Interpretation • Reporting 	<ul style="list-style-type: none"> • Revit • Revit Green Building Studio • Sefaira Architecture (runs Radiance) 	<ul style="list-style-type: none"> • Hands-on • Assignment • Midterm Exam • Presentation and/or Autodesk Building Performance Analysis Certificate • Term Project • Term Report
Building Components Performance	<ul style="list-style-type: none"> • Lecture • Case Video • Case Reading • Self-Learning Tutorial • Webinar • Hands-on • ASHRAE Standards • Architecture 2030 • In-lab example 	<ul style="list-style-type: none"> • Envelope and Partitions • Building Material Properties • Building Surface Performance 	<ul style="list-style-type: none"> • Revit • Sefaira Architecture (runs Radiance) 	<ul style="list-style-type: none"> • Hands-on • Assignment • Midterm Exam • Presentation and/or Autodesk Building Performance Analysis Certificate • Term Project • Term Report
Building Energy Systems Optimization	<ul style="list-style-type: none"> • Lecture • Case Video • Case Reading • Self-Learning Tutorial • Webinar • Hands-on • ASHRAE Standards • Architecture 2030 • In-lab example 	<ul style="list-style-type: none"> • Building HVAC Systems • Building Loads • District Energy systems (Purchased and Shared Energy) • Renewable Energy Systems (Solar Thermal, Onsite Power) • Controls (HVAC, Lighting, Equipment) 	<ul style="list-style-type: none"> • Revit • Sefaira Systems (runs EnergyPlus) 	<ul style="list-style-type: none"> • Hands-on • Assignment • Midterm Exam • Presentation and/or Autodesk Building Performance Analysis Certificate • Term Project • Term Report

	Simulation Comparisons and Interpretations	<ul style="list-style-type: none"> •Lecture •Case Video •Case Reading •Self-Learning Tutorial •Webinar •Hands-on •ASHRAE Standards •Architecture 2030 •In-lab example 	<ul style="list-style-type: none"> •Comparison of alternatives •Comparison with measured data •Modeling Energy Performance •Interpretation of Results •Economic Analysis 	<ul style="list-style-type: none"> •Revit •Sefaira Architecture (runs Radiance) •Sefaira Systems (runs EnergyPlus) 	<ul style="list-style-type: none"> •Hands-on •Assignment •Midterm Exam •Presentation and/or Autodesk Building Performance Analysis Certificate •Term Project •Term Report
Secondary Set	Resilient Design Strategies	<ul style="list-style-type: none"> •Lecture •Case Video •Case Reading 	<ul style="list-style-type: none"> •Understanding Resilient Design •Understanding Strategies •Understanding the relations of Sustainability and Resiliency 	<ul style="list-style-type: none"> •Case with Paper Shelters by Shigeru Ban 	<ul style="list-style-type: none"> •Participation
	Facility Management, Sustainability and Enabling Technologies	<ul style="list-style-type: none"> •Lecture •Case Video •Case Reading 	<ul style="list-style-type: none"> •Understanding GIS •Understanding BAS •Understanding CMMS •Understanding Nanomaterials 	<ul style="list-style-type: none"> •Case with EcoDomus 	<ul style="list-style-type: none"> •Participation
	Sustainability Evaluation	<ul style="list-style-type: none"> •Lecture •Case Video •Case Reading 	<ul style="list-style-type: none"> •Understanding Sustainability •Understanding LEED Process 	<ul style="list-style-type: none"> •Case with Revit Credit Manager 	<ul style="list-style-type: none"> •Participation
	Existing Conditions Modeling	<ul style="list-style-type: none"> •Guest Speaker •Lecture •Case Video •Case Reading 	<ul style="list-style-type: none"> •Understanding Laser Scanning and Data Collection •Understand Surveying 	<ul style="list-style-type: none"> •Case with Trimble •Case with Leica Geosystems 	<ul style="list-style-type: none"> •Participation

3.1.3 Performance and Optimization Module Assessment

Performance and optimization module assessment is held through key measures such as (1) grades in online mid-term exam (40%), (2) performance in preparing and presenting assignments (%10); (3) performance in creating a term report (25%); and, (4) performance in creating a team project (25%) in terms of given criteria. All knowledge set competencies are covered as subjects in the mid-term exam. Practices in primary skill set are evaluated by the EAM submitted as the individual term report which is created by using the selected software design, analysis and documentation tools. All knowledge set competencies and skill sets are evaluated by the team project which is basically a research study on BEM.

4. CONCLUSIONS

There is a need to establish and improve BIM knowledge, skills and experience of current engineering professionals. Besides, developments in building design and analysis software in recent years, coupled with advances in desktop and portable computational power, have engendered effective virtual buildings, or building information models. Gradually, use of BIM is replacing traditional two-dimensional drawing as an architectural design, analysis and documentation methodology. Such an approach can increase design efficiencies, foster an integrated design workflow, speed construction documentation and reduce errors, improve building construction and scheduling, and optimize operational performance.

Advanced training of current workforce through competency and skill based programs leads to mastery and performance improvement. Furthermore, a safer industry attracts more workforce. In addition to technology selection process and criteria for learning modules, the value that both undergraduate and graduate degree educational modules add to the BIM professions needs to be determined and discussed in a latter study. The IIT strategy relative to BIM by using the learning modules approach is successful and expected to help architecture, engineering, and construction professionals to be prepared for the needs of the industry in the future. Efforts should continue and expand to provide exposure, skills and opportunity to students.

In the coming years, advancements in a wide range of technologies will have a large impact on the phases of building: conception, design, construction, and maintenance. In the future, performance-based design will enable myriad scenarios to be simulated, tested, and validated in advance of construction. Consequently, designs will be better informed, and fewer errors will present themselves in the field. Real-time systems that track the state and location of materials, possess the ability to dynamically control automated construction robots, and interface with various sensors will substantially optimize construction. With advanced visualization tools and data, such as augmented reality, virtual mockups, and complete building simulations, designs can be virtually realized and optimized for multiple factors such as usability, energy consumption, environmental, aesthetics, constructability, material availability, operational, and lifecycle considerations. Developments in automation and fabrication will allow for faster and more precise production. Some technologies might eliminate the need for humans to perform tasks that are repetitive or monotonous, while others, such as exoskeletons, will serve to extend a site worker's capabilities.

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INTEGRATED PROJECT DELIVERY AND TEAM BASED LEARNING IN BIM EDUCATION

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ABSTRACT

Since the introduction of Integrated Project Delivery (IPD) concepts in construction engineering and management (CEM) education, few studies have explored its impact on students' learning outcomes, particularly as a means of performance measurement in course projects and examinations. Educators envisioning the importance of IPD in CEM education need effective pedagogical design to implement the method. Team-based learning (TBL) has similarities with IPD especially in the form of structured small-group activities. This study was conducted to determine whether student performance on group projects is affected by participation in TBL. The author analyzed the performance of 167 students on 80 comprehensive course projects over three consecutive academic years (2013–2014, 2014–2015 and 2015-2016). This research used the paired samples t-test to determine whether the mean of the TBL grades was greater than the mean of the non-TBL grades. The students achieved the mean of difference scores of 4.30 (T-value of 4.66) higher on course projects in Building Information Modeling (BIM) courses that assessed their knowledge of BIM&IPD-based contents learned using the TBL strategy compared with grades achieved via other methods ($P < .01$, t-test). Students' higher performance on course projects learned through TBL suggests that TBL enhances mastery of course content.

Keywords: Team Based Learning, Integrated Project Delivery, BIM, Pedagogical Design, Construction Project Management

1. INTRODUCTION

Compared to the Design-Bid-Build (DBB) or Construction Management at Risk (CM at Risk or CMR) delivery methods, the Integrated Project Delivery (IPD) method is relatively new for project management in the construction industry (Bilbo, et al. 2015). The increasing need for the IPD method overcame the difficulties in managing the lifecycles of increasingly complex buildings, particularly in design and construction stages, and to satisfy the demand for efficient project delivery (Kent & Becerik-Gerber, 2010). IPD was considered to be a superior delivery method to DBB (Kulkarni, Rybkowski & Smith, 2012; DeBernard, 2007). The benefits of implementing IPD include: (1) fewer change orders; (2) cost savings; (3) shorter schedules; (4) fewer requests for information; (5) easy to incorporate Building Information Modeling (BIM) technology into integrated operations; (6) less construction administration; (7) more prefabricated materials; (8) fewer injuries; (9) better quality; (10) less stress and friction; (11) more productivity; and (12) more enjoyable projects (Bilbo, et al., 2015; Kent & Becerik-Gerber, 2010).

The implementation of IPD in project management and the adoption of BIM technology could most effectively facilitate each other in the construction industry (Kent & Becerik-Gerber, 2010; Eastman, et al, 2011). The use of BIM technology is for the improvement of work efficiency in construction processes, which is still a major concern in today's construction industry. For example, design documents from designers or engineers may not arrive at construction companies with adequate and accurate information. This would cause a lot of arguments and disturbance in the construction and commissioning phases of projects. With the implementation of BIM technology, the interaction, communication and reliability of information will be greatly improved in project process. BIM technology brings unprecedented value to the whole construction industry, and this value is reflected in many aspects such as feasibility study, schematic design and design development, fabrication and construction, constructability and clash detection, etc. (Eastman, et al, 2011) It is necessary for individuals and organizations to strengthen cooperation with

the use of advanced technology and project management methods. Many construction education programs in the Associated Schools of Construction (ASC) have at least one BIM related course in their departments. To successfully prepare students, professors have the responsibility to take actions and promote the developments of IPD and BIM applications. There were pedagogical designs of using IPD or BIM in various courses. For example, the senior-level, engineering capstone design course at Penn State University required students to conduct multidisciplinary team collaborations using IPD/BIM in the architectural engineering major (Solnosky, Parfitt, & Holland, 2015). There was an integrated curriculum at Cal Poly San Luis Obispo based on both horizontal and vertical integrations of its courses. The jobsite construction management course was one of seven core courses of the integrated curriculum. It was developed with IPD emphasis (Barlow, 2011). Although, professors implemented the practice-based teaching environments around construction management topics to develop specialized knowledge and skill sets in students, many courses were designed as segregated and isolated sets of concepts and disconnected problem-solving strategies (Albano & Salazar, 1998; Barlow, 2011). The purpose of the development and implementation of IPD in BIM courses is to educate students to understand and accept IPD/BIM to create the collaborative environment, which is required for comprehensive uses of BIM, and produce sustainable processes in IPD projects. Literatures showed that team-based learning (TBL) has similarities with IPD especially in the form of structured small-group activities. TBL is selected as the pedagogy to teach the IPD/BIM contents.

The research question in this case is whether TBL improves students' learning of IPD skills in BIM courses? The following discussion shows the solution developed and implemented by the author for the TBL arrangements in the IPD/BIM projects in BIM classes. Per Bloom's Taxonomy of learning, the pedagogical designs of the classes had the following objectives: (1) Students should be able to apply the knowledge of IPD and BIM in course projects. For example, students sketched the relationship diagrams of IPD contracts and communications based on the course lectures and textbook readings in BIM classes. In the case-study projects of the BIM classes, students needed to use the IPD information in new situations. Students assigned team responsibilities to each member of their groups following the guidelines of IPD. In the case-study projects, each student team would have a different case and need to use modeling skills to build the BIM model for their project. (2) Students should be able to analyze different IPD/BIM situations. For example, student drew connections among different IPD/BIM ideas and compared the advantages and disadvantages when implementing the ideas in their projects. Students discussed different team organizations with each other and with the instructor of the course. At the end of the case studies, students performed presentations and peer evaluations. The instructor also asked students to analyze their own scopes of work and writing reports of project review, lessons learned and possible improvement areas. In addition, the instructor asked students to examine and compare their group members' work. The case studies prepared students for the following IPD/BIM projects which had higher levels of requirements on detailing.

For the academic years 2013–2016, the educator implemented TBL as a pedagogical tool every semester in the small-group component of the BIM courses. The BIM courses had the students from interior and environmental design (IED), construction engineering and management (CEM), and engineering technology education backgrounds. Most of the students in the BIM courses had not previously experienced TBL as a graded learning component in a construction science course. But some of the students had TBL experiences in other academic fields. The hypothesis was that students would be better prepared and find the TBL more effective than self-organizing small groups. The expectation was that because the TBL strategy urged students to keep up with the flow of course contents, academic performance (e.g. project grades) of all students would improve, in comparison to learning through other methods.

The organization of this paper includes the following sections. The Introduction section describes the purpose of this study and the research problem of implementing TBL into the BIM courses. The Background section discusses the concepts and features of IPD, BIM, and TBL in CEM education. It also provides keys in implementing TBL in BIM education. The Methodology section analyzes the framework of materials and methods when establishing teams using TBL method. The Data Collection and Analysis section presents and analyzes the student experiences with TBL in the BIM classes, data on student performances on individual learning activities and TBL activities, and project grades. The last section summarizes the conduct of the TBL teaching, learning experiences, and suggestions regarding TBL approach in BIM education.

2. BACKGROUND

Since IPD method is relatively new in the construction industry, there are only a few implementations of the IPD concept in course designs in CM education. In the integrated Jobsite Construction Management course designed by Barlow (2011), the instructor challenged the students to achieve in the areas of presentation and communication skills, collaborative and inter-personal skills, creativity and forward-thinking abilities, teamwork and problem solving skills, active-learning and creative problem solving, and self-learning and time management. The delivery methods of the

course included instructor lectures, lab assignments, jobsite field trips, and a final project. Barlow (2011) emphasized on the following items learned from offering the class: (1) the need for a variety of delivery methods which were both appropriate and well prepared; (2) the creation and implementation of lab assignments for a direct reflection of TBL; and (3) the integration of construction curriculum subjects, such as scheduling, estimating, controls, and contracts. In the course design of the advance education in Sustainable Design and Construction using integrated student teams, Brncich, et al. (2011) developed new educational systems and structures to facilitate student learning, using the Action Research Model instead of TBL or IPD. Compared to the communication in a regular team-building method, IPD had communications throughout the entire project lifecycles. Particularly, the communication in design process was clear, concise, open, transparent, and trusting among facilities managers, end users, contractors and suppliers, who were all involved at the start of the design (Miettinen & Paavola, 2014). In the following discussion of teamwork design for the BIM class, these features were considered and measured in the teaching/learning methods.

BIM was both an important technological topic for CM major students and a useful teaching instrument or platform that provided cooperative design, efficient project management and improvement of design efficiency (Gu & London, 2010). Studying BIM technology in multidisciplinary and collaborative courses had the important practical significance on design, construction and operation of building projects. Particularly, collaboration in BIM projects had significant influences on student learning outcomes (Plume & Mitchell, 2007).

When teaching BIM classes, instructors were aware of the importance of TBL for the detailed pedagogical design. TBL used a structured form of small-group learning strategy with emphasis on student self-preparation and the application of learned knowledge in different cases (Michaelsen & Richards, 2005; Gunderson & Moore, 2008). TBL was used in construction education for varieties of topics. For example, sustainability design and construction (Brncich, et al, 2011), structural engineering (Quinn & Albano, 2008), construction capstone (McIntyre, 2002), etc. The constructive features of TBL made it applicable to undergraduate education of CEM courses. In this research, the educator considered several strategies for increasing the sense of ownership of students in small group sessions and decided to implement TBL. The features of TBL method included the following items (Michaelsen & Richards, 2005): (1) an active-learning pedagogical strategy based on procedures for developing high performance learning teams or small groups; (2) group compositions of 4-7 students with diverse skill sets and education backgrounds, approximately equivalently distributed among groups; and (3) emphasis on individual accountability for out-of-class work such as site visit and reading project documents being done prior to the class meeting of each course when the student groups had discussions. Educators gave incentives for working effectively together as a team, such as credits or course points, for team activities. For example, team meeting notes or minutes and design notes of group projects are used to gain course points. The subsequent in-class activities (group projects) were the hallmark of TBL, in which educators were more involved with the students than in traditional lectures. With the involvement of educators in student activities, both educators and students knew quickly what they are achieving. TBL gave students an opportunity to learn how to work with different members of teams and how to evaluate themselves and their peers. In TBL, in-class project applications promote both learning outcomes and team development and needed to have prompts and accurate feedback.

3. METHODOLOGY

3.1 Course Design and Learning Outcomes

The focus of the three credit BIM course is on modeling, annotating, and on document creation. It also uses BIM systems to design and document architectural and construction ideas. The course is required by the education program and is offered in both fall and spring semesters. Each session of the course lasts 1 hour and 50 minutes for lecture discussions, demonstrations, and hands-on exercises. The prerequisite of the course is Construction Graphics which includes understanding drawings, AutoCAD for architecture and construction drawings, and SketchUp modeling. This course introduces students to the management philosophy and integrated approach to creating a built environment. Included in the course is a study of techniques used by architectural and construction professionals when creating BIM models. Students learn that BIM is for designing, building and maintaining a project using high-level software systems that manage the project through computer models, schedules, drawings, and renderings. This course includes a study of the modeling processes in BIM systems, but also examines the system management techniques for project components, families of components, schedules and details, and other information management functions. Students develop understandings of how to use powerful BIM tools such as Autodesk Revit™ to create models and drawings that are not only common in the field, but integrated throughout construction enterprises.

For the knowledge of IPD in BIM projects, students would be able to achieve the following learning outcomes: (1) Remember the facts and basic concepts of IPD in BIM projects; (2) Explain ideas or concepts related to IPD; (3)

Apply knowledge to sketch the figures of IPD, assign team responsibilities, perform case studies, and use information learned from class discussions in new situations (for example, their own final projects); and (4) Analyze the connections among ideas. The educator would discuss different team organizations with students. Students would perform peer evaluation and analyze their own scopes of work. Students would examine and compare their group members' work. The above 4 steps are aligned with Bloom's Taxonomy. The pieces of reflections and students' work would be integrated into BIM models.

3.2 Contents, Rationale, and Teaching Strategies/Methods

The learning contents of IPD in the BIM course give students an opportunity to examine the complex concept of team organization and assessment. Students would understand that team members have different work styles. For some it may mean simply divide a group assignment into individual scopes of work; for others it may include communication, confliction detection and integration. The rationale of the design was that construction projects are done by collaboration and communication no matter how they are designed and teamwork brings people a sense of fulfillment. Knowing how to select and organize a team, use strategies for project modeling and simulation, and coordinate and report team effort helps students to deepen their understanding of what they are studying.

In addition to TBL, the BIM course implemented multiple teaching methods to prepare students, including traditional classroom lectures and demonstrations, discussion groups, on-line lectures (such as web-based slide shows with audio streams), guest lectures, hands-on labs, site visits, and computer-aided instructions on software use, including Autodesk Revit®, Autodesk Navisworks®, Tekla®, Microsoft Project®, and Adobe Photoshop®. One faculty member in the Department of Technology delivered the lectures (classroom and on-line) and instructions, covered the hands-on labs and taught in the TBL sessions, all of which were instructional scaffolding aspects of the course (Reiser & Tabak, 2014). A graduate teaching assistant provided grading assistance for the class. Students were scheduled for 64 hours of instruction (classroom lectures, labs and TBL) during the 16-week course. The independent learning aspects of the course included reading, on-line lectures with software instructions, and lab reviews. The instructional scaffolding and independent learning aspects of the course were reinforced with self-preparatory assignments, including individual homework, lab exercises and projects.

Specifically, the individual learning activities related to IPD was 2 session hours and 1% of the course grade. The TBL activities which were related to IPD comprised 18 session hours and 25% of the course grade. The remaining activities were not related to IPD nor TBL, but for student preparatory. They contributed the remaining 74% of the course grade. Students should score a 70% average on the overall course grade to pass the course. At the first day of the class, every student completed an opinion survey regarding group consensus process, which initiated the student awareness of TBL activities. In the opinion survey, students were asked to about their TBL experience and whom they wanted to work together in a group. The information was considered when the educator assigned student groups. There were 2 TBL-type IPD&BIM project assignments. One was a case study; the other was a BIM project.

3.3 Design of the TBL

In a 16-week semester, the BIM course included 1 individual session and 9 TBL sessions that were specifically related to IPD. Each session had 1 hour 50 minutes class time and included multiple formats of teaching-learning elements, such as individual preparatory assignments, checklists of both individual and group readiness assurances, and schedules of group application items (SGAI). The BIM course also included peer evaluations, which contributed to the course grade of each student. At the beginning of each TBL project assignment, students were asked to define a weighting system for individual performance, which was reflected by the individual and group performance (CIRA and CGRA, respectively). Students were also trained to perform peer evaluations. The CIRA, CGRA, and SGAI portion each contributed 10% of the total TBL grade and together contributed 30% of the grade. The student peer evaluation was calculated 10% using this distribution. There were four to five students per team. The students were sophomores, juniors and seniors with a variety of educational backgrounds. When assigning groups, the educator used matched group design (Sekaran & Bougie, 2016) to control for individual differences (gender, seniority, experience and background) by matching similar subjects or groups with each other. In every semester, there were individual and TBL assignments. The design of the TBL included three Sessions Assignments associated with IPD learning in BIM class. During the first session individual student learning outcomes were tested in homework questions such as "Use Word, Excel, or any other computer software to draw your idea of BIM related Integrated Project Delivery process". One week before the first TBL assignment, the assignment instructions were posted on the course website.

The first project was comprised of 3 TBL sessions for a case study. The instructions were discussed in classroom lectures. The class activities designed for the project included classroom lectures and on-line videos, readings on the case studies, library and online search for information related to the particular projects, and group meetings. The

second project comprised 6 TBL sessions for a group BIM project. The sessions were designed similar to the first TBL project, except that labs were scheduled in the classroom. For each project, students received a list of objectives. The educator attended the TBL sessions as a facilitator and scheduled adequate time for students to ask questions.

Checklists of individual readiness assurance (CIRA) and group readiness assurance (CGRA) were administered. First, at the beginning of a session, each student was asked to present a CIRA to the person's group. A sample CIRA was posted on class website. The items in the CIRA were focused on the plan of work the student needed to complete, questions or problems for the project assignment, and possible solutions to the problems. The questions or problems were handled in a Request For Information (RFI) format. Examples of the CIRA used in this class included "My role in this project is ___"; "My scope of work is ___"; "The members of my group and their contact information are ___"; "The time and location for the group meetings are ___". Then, the group leader of a team summarized the group's checklist based on the CIRA of each team member. The teams verified the completeness of their scopes of work first within the team and then with the educator. The educator created and maintained a master schedule of all the teams, or schedules of group application items (SGAI), which was visible to all teams. The teams were asked to post their questions, problems, answers, and solutions on the class webpage within 24 hours of the conclusion of a TBL session. These posts were reviewed by the teams and the educator. If team answers did not agree, the educator addressed the discrepancies and asked the team members to defend their answers. The educator helped the teams to resolve misunderstandings or errors in class. If team answers agreed with one other, the educator asked if there were any issues related to the ones answered. New discussion topics may arise from those elaborations. SGAI works as the agreement between the educator and each student group.

Prior to participating in a Team based project, students performed individual projects to understand BIM related skills as individual preparatory assignments. There was 1 TBL case-study project and 1 TBL IPD&BIM modeling project in each semester studied. In the case-study project, each student group sent the team leader to randomly draw from 10 provided cases, which were of similar complexity. These 10 cases were from the textbook of the class (e.g. Eastman, et al. 2011). Each group needed to analyze and address the following contents in the case study: (1) Context: Background information, concerns, issues; (2) Strategies Described: approaches taken, agencies and actors involved; (3) Challenges: concerns that emerged, various perspectives; (4) Outcomes: accomplishments, changes, lessons learned; and (5) Conceptual Design of the Project Model and Cost Estimate.

Fault protection procedures included a point system for "team maintenance". Points were given to recognize contributions made to the team and withheld from team members that were inactive or did not complete assigned tasks or lacked cooperation. In addition, peer evaluations were conducted at the end of each TBL project. Students evaluated their own teams, but also the presentations of other teams. The within-group peer evaluation form required from students to allocate a maximum of 10 points to their teammates with the requirement that not all teammates could receive 10 points. Justifications for the lowest and highest scores were required. The average score of the peer evaluation constituted a part of the project grade for the student. The within-group peer evaluation form also included qualitative questions. Students used the formative evaluation scales to rate their teammates in the aspects of cooperative-learning skills, communication skills, conflict-solving skills, etc. The ratings were anonymous and sent to specific students. These comments were not included in the project grades. The peer evaluations on presentations were used to evaluate communication skills of other team members.

4. DATA COLLECTION AND ANALYSIS

TBL assignments contributed 25% and non-TBL assignments contributed 75% to the final grades. The TBL and non-TBL student grades were analyzed by the paired samples t-test to determine whether the mean of the TBL grades was greater than the mean of the non-TBL grades. Statistical analyses were carried out using SPSS, with significance level of .01 and one-tailed hypothesis. The T-value was 4.664074. The mean of difference scores was 4.30, with $\mu = 0$, $S^2 = SS/df = 94.24$; $S^2M = S^2/N = 0.85$; $SM = 0.92$. The p-value was <0.00001 . The result is significant at $p \leq 0.01$. The analysis showed that student performance on group projects was improved by participation in TBL activities. Table 1 shows the student's rating of learning venues and resources. In the study period of fall 2013 to spring 2016, 92% ($36\% + 56\% = 92\%$) of the students agreed or strongly agreed that TBL was helpful to their learning. The computer programs (4.45), TBL sessions (4.44) and individual hands-on BIM labs (4.23) were rated much higher than online resources (3.81), lectures (3.59) and textbooks (3.11). TBL sessions were believed more helpful than traditional lectures by a substantial margin. When answering the focused questions on TBL, students agreed that TBL helped them to understand course contents and procedures, made them schedule their time more reliably and encouraged interaction, discussion, and problem solving. The class was diverse on whether more frequent TBL sessions should be used. Students commented on the effectiveness of the current pedagogical design and TBL ratio. Lastly, most students agreed that it was appropriate to have TBL grades accounting for 25% of course achievement. Student

comments were equally positive on using TBL for IPD&BIM contents. From the observations on peer evaluations, the instructor noticed that students were very unenthusiastic to give negative comments on other members. Several students admitted that they would rather give all their team members 10-point average scores. With the promise from the instructor that the formative portion of the peer evaluation would not be included in the project grade, nor would the instructor read the portion, students valued the anonymous feedbacks from their teammates. The other concern was in the scope of work each teammate assumed. Junior or senior students felt that the amount of time needed to explain the assignments to other members of their groups was sometimes inadequate.

Fig. 1 shows the overall scores compared across years. There was no significant difference between average exam scores over the 3 years. Through observations, there seemed to be a positive correlation between individual readiness (for example, accurate description about individual scope of work) and major rubric-grading items. Teams whose members performed well on the individual readiness and team preparation also tended to do better on the major rubric-grading items. The results showed a significant correlation between individual readiness scores or team preparedness scores with the promptness in schedules of group work.

Table 1. Student's rating of learning venues and resources

Student Evaluation Questions	Percent Responding (N = 167)					Mean Rating		
	Strongly Agree = 5 Points	Agree = 4 Points	Neutral = 3 Points	Disagree = 2 Points	Strongly Disagree = 1 Point			
The following were helpful to my learning:								
Lectures	19	42	21	15	3	3.59		
Individual BIM Hands-on Labs	51	38	2	1	8	4.23		
TBL Sessions	55	37	6	1	1	4.44		
Textbooks	15	28	25	17	15	3.11		
Online Resources	32	25	37	4	2	3.81		
Computer Programs	72	15	3	6	4	4.45		
Focused Questions								
TBL sessions helped me understand BIM concepts and procedures.	56	36	4	1	3	4.41		
TBL encouraged problem solving in our group.	83	5	6	4	2	4.63		
TBL encouraged me to ask questions, join discussion and interact with others.	61	23	5	5	6	4.28		
TBL helped me understand how to work in an IPD project.	78	22	0	0	0	4.78		
TBL helped me to apply BIM technology in projects.	35	25	29	1	10	3.74		
TBL forced me to study more consistently.	65	28	3	2	2	4.52		
There should be more TBL sessions.	15	24	21	17	23	2.91		
The size of the TBL projects are appropriate. If you disagree, please explain if you want the project size to be bigger or smaller.	27	25	16	13	19	3.28		
Having TBL contribute 25% to the final grade was appropriate.	49	37	5	5	4	4.22		
Semester	Fall 2013	Spring 2014	Fall 2014	Spring 2015	Fall 2015	Spring 2016	Total Students	No. of Teams
Students and Teams	28	25	30	26	28	30	N=167	40

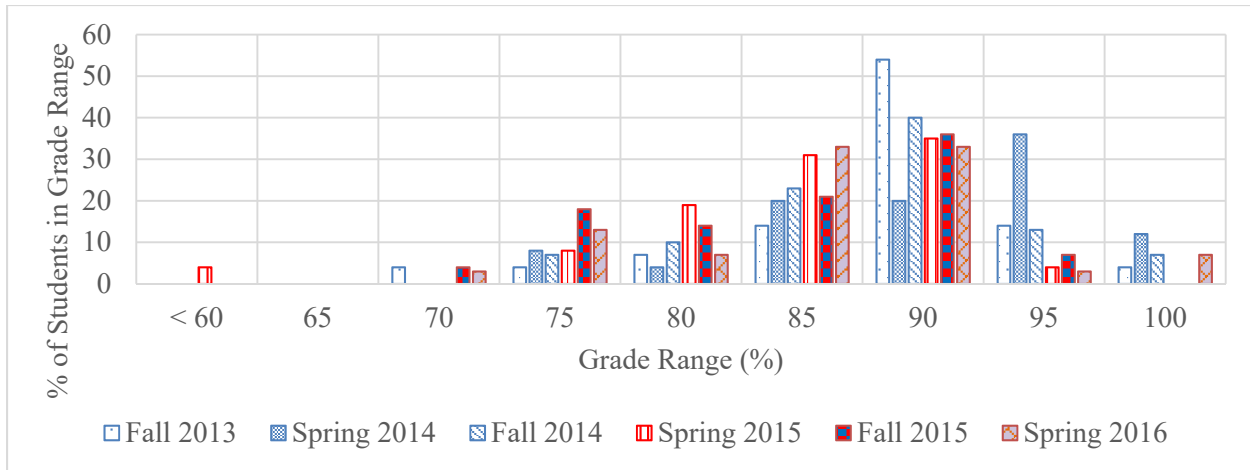


Figure 1: Comparison of grading-rubric scores

5. CONCLUSION

IPD approach integrates people, systems, business structures and practices into a collaborative process that harnesses the capacities and visions of all project participants to optimize project results. This research distinctively applied TBL as a structured and cooperative learning method for BIM course. Different from small group learning, the TBL pedagogy used in the BIM classes had the emphases on application and analysis. Students went through assignments, checklists, schedules, projects, and evaluations to reinforce the understanding of BIM technology and IPD teamwork skills. Besides BIM, the subject discussed would fit into the curriculums of construction contracts, project administration, and construction management capstone. The vast majority of the students reported that TBL helped them to understand IPD&BIM concepts, encouraged problem solving and team communication, and improved their time management abilities. The attendance and student involvement of TBL session were remarkable. Students came to TBL sessions with preparation and knew their own scopes of work. The faculty and students were encouraged to participate in discussions, ask questions, and explore new topics.

In conclusion, this research provided possible ways to implement structured TBL in BIM classes. Using the structured TBL helped students to improve academic performances and develop teamwork skills. The results would provide inspiration to educators in the construction management area to consider using TBL in teaching. The author observed that students in the lowest quartile of academic performance in the classes benefited more from TBL than did those in the highest quartile. In the future research, the author will analyze the mean scores of the lowest-quartile students on course projects using TBL method than course projects not using TBL method, compared to the mean scores of the highest-quartile students using TBL method than course projects not using TBL method. Overall, TBL engaged students in unique and positive ways.

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Incorporating BIM Technologies in the CM Program at Wentworth Institute of Technology – Successes and Challenges (Case Study)

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Abstract:

Building Information Modeling (BIM) has introduced great efficiencies to the delivery of building construction projects. This evolution in technology has provided tools to foresee and to fix issues that might otherwise result in costly change orders and claims. Investments in major projects are closely scrutinized today by Project Owners from the initiation phase up to the start of construction and beyond. BIM has proven to be a powerful tool in minimizing wasted time, materials, and money. If today's construction managers are to survive and prosper in the new collaborative workplace that BIM provides, they must be highly proficient in its use and eager to embrace new and useful technologies that will lead to higher efficiency. At Wentworth Institute of Technology, we have incorporated these new tools into construction management program courses, wherever appropriate.

This paper introduces the Wentworth educational model, as well as the teaching models of the Construction Project Management course and of the CM Senior Project Capstone course. These courses educational models have been developed by the author and have been implemented for over two decades. These models require students to demonstrate competency in innovative problem-solving situations and proficiency in analytical writing and presentation skills. Senior students have the opportunity, in the Capstone course, to collaborate in a construction project with students in other disciplines such as Architecture, Mechanical and Civil Engineering.

BIM was first introduced into the Capstone course in 2001 when Revit Technologies launched the first version of Revit Architecture. This provided an opportunity to the Construction Management Program to implement new technology into the Capstone course and equip the students with additional skills when embarking into the workplace. The Construction Graphics Course was the second step in implementing BIM followed by the Construction Project Management course. BIM is now in the process of being integrated into the Building Services course. Industry Professionals who participate and the Industry Advisory Board of the Construction Management Program (a forty members group) have embraced the implementation of the models and have continuously been involved in its support and advancement.

Key words: Construction Management (CM); Building Information Model (BIM); Project-Based learning; Safety; Risk; Quality; Construction Manager In Training (CMIT); Virtual Design and Construction (VDC); Integrated Project Delivery (IPD); Revit-Autodesk™; Lean Construction; Guaranteed Maximum Price (GMP); Mechanical, Electrical & Plumbing (MEP);

Introduction:

Building Information Modeling (BIM) was introduced in early 2000, this is when Revit Technologies launched the first version of Revit Architecture. At that time, the design industry was more prone to utilize BIM tools in the architectural design of buildings unlike the construction industry. The construction industry, however, considered this new technology as an unnecessary added cost to the project. The BIM tools available in the early phases of development were not advanced enough to provide the elements of the building project. In addition to that, the construction industry is known to be slow in embracing change. Additional software training or adding more staff was not in the plans of Construction Management (CM) firms; especially when the technology bubble burst took place about the same time (April 2001). In spite of the technology bubble burst, the construction industry was still in the expansion phase nationally in 2001. In 2008, the steep recession was a wakeup call to the construction industry. At that time, CM companies fought fiercely to survive the recession. Project owners took this opportunity to affect change in the construction industry. They began to press for the adoption of more efficient practices, including Integrated Project Delivery (IPD) Method, Lean Construction Principles and BIM. This is evidenced in the adoption of IPD in New England. More than two billion dollars was spent in the past seven years on projects using IPD and innovative practices such as lean construction principles and BIM.

Wentworth educational Model, encourages the utilization of state-of-the-art industry practices in all programs and especially capstone courses. There is special emphasis and focus on teamwork and interdisciplinary collaboration.

Wentworth educational model, as well as the teaching models of the Construction Project Management course and the CM Senior Project Capstone course are introduced in this paper. The two courses educational models have been developed by the author and have been implemented for over two decades. Industry Professionals participate in the support, grading and evaluation of the Capstone course. In addition, the Industry Advisory Board of the Construction Management Program (a forty-member group) have embraced the implementation of the models and have continuously been involved in its support and advancement. The CM capstone course, for a number of years, has utilized teamwork and interdisciplinary collaboration with the Architectural, Civil Engineering, and Mechanical Engineering Programs.

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Several guest speakers from Revit technologies introduced the software to the senior graduating class since its launching. In time industry leading CM firm in BIM provided training sessions to the students and allowed the students to have hands-on experience using the software. There was no formal course provided in Revit software. The use of the software was an added task to the other tasks the students have to accomplish in the Capstone course. Four years ago Revit software became part of the construction graphics course.

There were challenges in implementing the software as a requirement, however it ended in successes in implementing BIM in the past two years as added requirements.

Project-Based Learning Models:

The Wentworth Model is used as the guide in developing the teaching models of individual courses. The Wentworth Model is described first and is followed by the teaching models of the Construction Project Management and the CM Senior Project (Capstone) courses.

a. Wentworth Educational Model¹:

In order to fulfill its mission, and to prepare students for workplace, Wentworth has established the following *General Education Learning Outcomes* as the institution's definition of an educated person.

After completing their General Education curriculum, students will be able to demonstrate competence in:

1. Written, oral, and visual communication
2. Problem solving
3. Information literacy skills
4. Applications of ethics to decision-making
5. Logical thinking and scientific and quantitative reasoning
6. Critical analysis of scientific, historical, and social phenomena and aesthetic dimensions of humankind

At the end of their sophomore year, day baccalaureate students have the opportunity to participate in Wentworth's optional cooperative work prior to entering their junior year. The cooperative education model, in which students complete two semesters along with their academic degree requirements, is both a Wentworth tradition and a graduation requirement. To ensure that the student learning goals are being achieved, the Institute's undergraduate curricula incorporate a core of general studies. Baccalaureate students in day programs are required to take, at minimum, one course in basic mathematics, one laboratory science, three communication courses, five courses in the areas of humanities and social sciences, and a capstone course requirement. The capstone requirement provides opportunities to senior students to demonstrate competency in innovative problem-solving situations and proficiency in analytical writing and presentation skills. Team and/or interdisciplinary projects, with clearly defined individual responsibilities, are encouraged.

b. CM Senior Project (Capstone) Course Model:

This is a four semester credit course (14 weeks), consisting of lectures (2 credits) and laboratory (2 credits/4 hours). Students work in groups and are provided with an instructional guide to assist them in

developing the project deliverables. Over more than two decades the author has developed this model and has introduced different additions over time. Industry Professionals participate in the support and evaluation (grading) of the Capstone course. In addition, the Industry Advisory Board of the Construction Management Program (a forty-member group) have embraced the implementation of the models and have continuously been involved in its support and advancement. The CM capstone course, for a number of years, has utilized teamwork and interdisciplinary collaboration with the Architectural, Civil Engineering, and Mechanical Engineering Programs.

The requirements of the course are to simulate a construction project development in an academic setting. This course integrates courses studied in the CM program into a real project which is generally under construction. The documents of the project are made available on a website that is accessible to the students on- and off-campus.

The course covers lectures, guest speakers, site visits and simulation of the project delivery. Industry Advisory Board members participate as guest speakers and make their project sites available to the students which reinforces the importance of the participation of industry in the academic settings.

The delivery method used in the Capstone projects is CM at Risk with Guaranteed Maximum Price (GMP). Fast-tracking the project is a second requirement. Students are required to produce the following project deliverables listed below and as shown on Figure (1):

1. Statement of Needs + Proposal to deliver CM Services at Risk with (GMP). Engagement of the CM services starts at the Schematic Phase. A request for Proposal (RFP) is provided by the faculty to the students which outlines the requirements to be delivered in the project.
2. Status Report at 30% Design Development
3. Status Report at 80% Design Development and Submittal of the GMP
4. The elements covered in these deliverables are:

Project Management, Contract Administration, Time Management, Cost Management, Risk Management, Safety Management, Quality Management, LEED applications, Lean Construction, and BIM.

Students' assessment covers, Industry Professionals' assessment (grading), Peers assessment, written presentation (graded as team grade), oral presentations (individually graded), laboratory performance (individually graded), final exam and quizzes as shown in Figure (2).

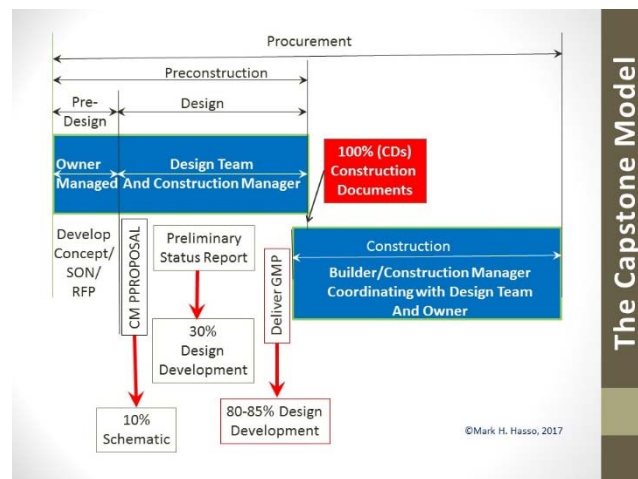


Figure (1): Capstone Course Project Simulation Process

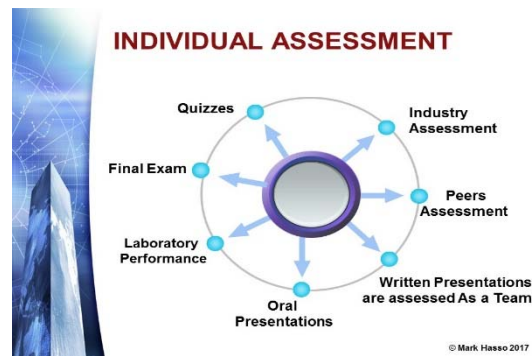


Figure (2): Individual Student’s Assessment

The Construction Management Association of America (CMAA)² publications are used as guidance in submitting the deliverables, along with the Capstone Course guide developed by the instructor.

The course learning outcomes are to:

- Develop written and oral presentations appropriate to the construction discipline.
- Analyze professional decisions based upon ethical principles.
- Develop construction project cost estimates, schedules, safety, risk and quality at the different phases of project development.
- Analyze construction documents for planning and management of construction processes.
- Analyze methods, materials, and equipment used in construction projects.
- Apply construction management skills as an effective member of a multi-disciplinary team.
- Apply electronic-based technology to manage the construction process.
- Analyze different methods of project delivery and the roles and responsibilities of all constituencies involved in the design and construction process.
- Explain the basic principles of sustainable construction.

c. *Construction Project Management Course Model:*

The use of BIM starts in the freshman Graphics course in which students are taught the basics of developing BIM Models. The Construction Project management course is offered in the junior year and requires junior standing. It is a four credit semester (14 weeks). Three credits are lectures and one credit is laboratory (two-hours). BIM development is a requirement for use in the laboratory project.

The lectures lay the foundation of the Construction Management process. As part of this course, students are required to take the Construction Manager In Training (CMIT)³ test at the end of the semester in addition to their final exam. This test provides the students with the CMIT designation which demonstrates competence in the practice of construction management early in an individual’s career. Individuals who have earned their CMIT designation are showing employers and clients that they are invested in the industry as well as in their own professional development. The CMIT program helps them develop both as construction managers and as leaders. After an individual successfully becomes a CMIT, he/she will be given access to the Certified Construction Manager (CCM) mentor directory, enabling CMITs to expand their networks and to connect with leading industry professionals as mentors who will assist them in mapping their career path.

The laboratory part of the course, focuses on a construction project in the range of \$15 million. The students will have the opportunity to visit the site and have access to the construction documents, including the schematic and Preliminary phases drawings, and the project manual. Students are organized in groups of four. Each week the group has to adhere to a predetermined deliverable, and each student in the group is assessed individually based on his/her collaboration and delivery of tasks. The students receive a course project guide to enable them to make the necessary progress in submitting the project deliverables. The requirements for the full semester cover:

1. The development of the Statement of Needs from the schematic drawings and the project manual. This reverse approach is a simulation process to enable the students to capture the project

requirements as stated by the project Owner. The development of the Statement of Needs is an adaptation of the requirements set by NASA⁴ for their projects.

2. Developing the BIM model for constructability purposes and for visualization from the Schematic Phase documents.
3. Developing Conceptual Estimates and Schedule (from concept to completion), and the roles and responsibilities of the project team.
4. Developing CM Proposals for three delivery methods:
 - a. CM as Agent
 - b. CM at Risk with GMP (Guaranteed Maximum Price)
 - c. Design-Build
5. Deliver written and oral presentations to construction management professionals.

The course learning outcomes are to:

- Develop written and oral presentations appropriate to the construction discipline.
- Analyze professional decisions based on ethical principles.
- Develop an understanding of the foundation of management of construction projects cost, time, quality, risk, safety, and materials and equipment.
- Develop an in-depth understanding of the different methods of project delivery, as well as the roles and responsibilities of each of the stakeholders in the construction process.
- Understand the legal implications of contract, common, and regulatory law in managing a construction project.

Utilization of BIM in the Capstone Course

As mentioned earlier, the introduction of BIM modeling in the CM Program started in 2001 when the first generation of Revit was launched by Revit Technologies. Initially, the introduction of BIM (Revit Architecture) to the students took different phases, starting with guest speakers. In 2002, CM firms started providing training sessions to the students on BIM and its developments. In addition, guest speakers are invited to demonstrate the different applications of BIM in different types of projects. In 2006, the MEP module was introduced, in like fashion, students were introduced to the MEP module by one of the Beta testing firms. Training in the capstone course by industry continued for about ten years. The formal training in Revit in the Graphics course started in 2012 which led to requiring students to develop the BIM model in the Construction Project Management and the Capstone courses.

The use of BIM in the Construction Management Course was limited to building the model for presentation and constructability purposes. The capstone course requirement is more extensive where focus is to provide the following:

1. Visualization of the project to the owner in presenting the proposal.
2. Clarifications and solutions to issues of concern to the project owner.
3. A site planning and logistics model at different phases of project development.
4. Safety planning model.
5. Constructability analysis through the utilization of the model.

The utilization of the model in the CM Senior Project is developed in three phases:

1. *Proposal Phase*: Develop the BIM model for constructability purposes and for visualization and constructability analysis drawn from the Schematic Phase documents.
2. *Preliminary Phase*: The model shows more details as the project evolves, including logistics and constructability issues.

3. Guaranteed Maximum Price (GMP) Phase: The BIM Model at this phase provides detailed safety and logistics planning at each phase of the construction project, in addition to covering constructability issues.

The images below demonstrate the work necessary in the development of the Revit model. The model below is of a school gymnasium building in Newton, Massachusetts. Students are required to create a building model for construction purposes from the pdf files available to them through a web site as mentioned earlier. Students must then analyze the project's constructability, and provide complete safety and site logistics planning as the project progresses through construction. The discussion of the model is based on the detailed construction schedule developed for the construction phase. The model evolves with the development of the project's design documents. Figures (3 – 7) demonstrate the level of detail in using the Revit model.

There is still work to be done in expanding the student's work into developing the MEP models, however, due to time limitations and extensive requirements in this course (as outlined above), MEP is not yet a requirement. It is optional at this point.



Figure 3: Revit Model of School Gymnasium

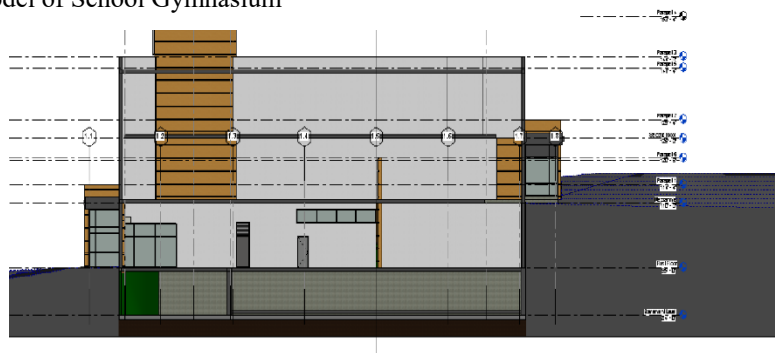


Figure 4: Revit Model of School Gymnasium – Sample Section for Constructability

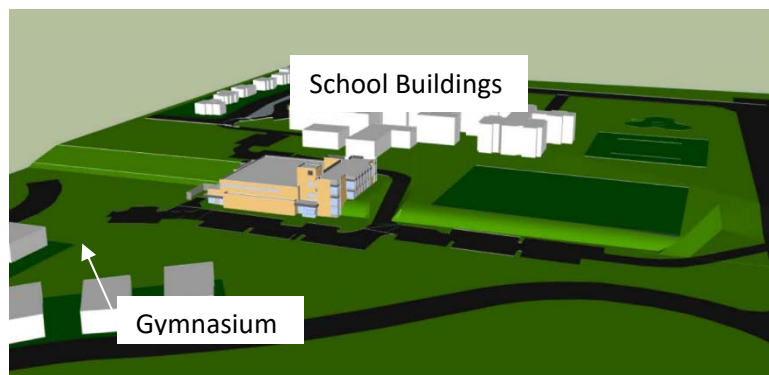


Figure 5: Revit Model of School Gymnasium – Sample Site Planning

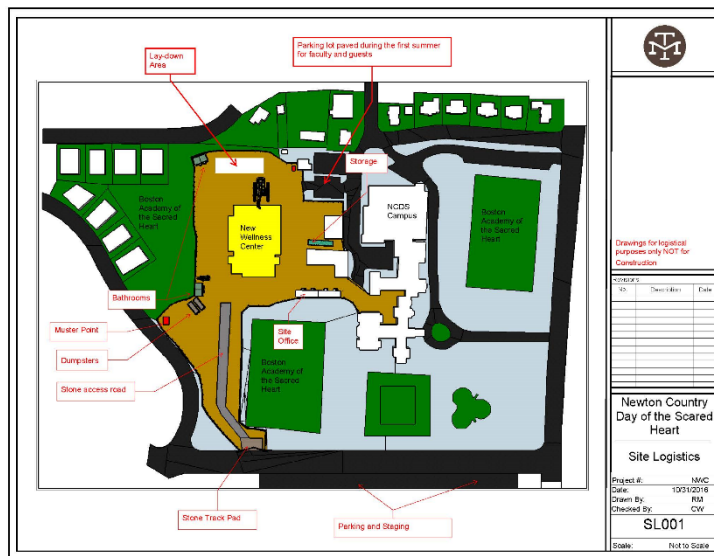


Figure 6: Revit Model of School Gymnasium –Site Planning

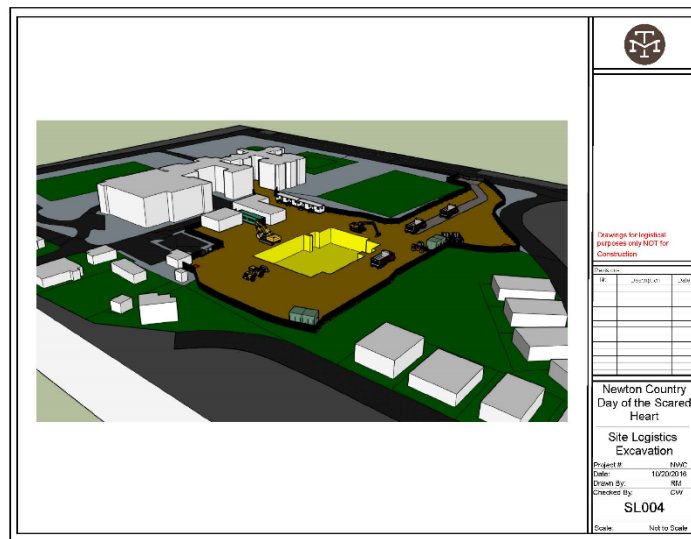


Figure 7: Revit Model of School Gymnasium – Sample Construction Progress and Site Logistics

The past decade has demonstrated continued development in the use of technology in construction projects. The main purpose of these new tools is to enhance efficiencies in the delivery of construction projects. Adaptation of these technologies in the academic settings is very crucial in preparing future leaders in construction management. However, it is also important that one should not lose sight of the fact that there are limitations in adding more courses to the program. These limitations are set by accrediting agencies. Incorporating appropriate technologies in a CM curriculum is also very important. Creating a balance between course content and incorporating technology is essential.

Initial implementation of BIM faced resistance from the construction industry as the industry did not see high value in its utilization. Students during their cooperative training, did not encounter the use of BIM in industry when Revit was launched. Thus, students did not see any immediate value in using BIM, since the industry has not embraced it. As a result, there was initial resistance to requiring BIM in the capstone course. However, in time, the utilization of BIM in the CM Program has been welcomed by the students who started to see the importance and value of BIM in the Construction Industry. Among the successes of BIM in the program:

1. Students are very keen to learn the new tools as they see the importance and value of these tools being used in the field during their cooperative training.
2. The availability of internal resources to teach BIM as part of a course, i.e. the Construction Graphics course, has been preparing students to apply the basic principles into other courses.
3. CM students take three structural courses and Revit use is now a requirement in the course.
4. The Construction Project Management course has a requirement that students develop a construction model for visualization and constructability analysis, as part of the Proposal for CM services.
5. The Capstone Course requires students to develop a model with more depth, covering visualization, constructability analysis and site planning, safety and logistics.
6. A number of graduates of the CM Program are taking roles in Virtual Design and Construction (VDC) departments in major CM firms and also taking leadership roles as directors of VDC departments.

BIM implementation faced some challenges among which:

1. Availability of outside resources to provide training.
2. The construction industry was not receptive to the idea of using BIM as a professional practice who did not see the benefit and value of using BIM in construction before 2008. Construction was at an expansion mode before 2008. CM firms were not willing to invest in new technology.
3. Lack of availability of internal resources in the CM Program to provide training for 100 students.
4. Accreditation has required reduction in the total number of credits in the CM program which restricts additions of more credits to teach Modeling as a separate course.

In the short term, future plans in integrating BIM in the CM Program includes:

1. Implementation of clash detection in the Mechanical, Electrical and Plumbing in the building model as part of the Building Services course.
2. Development of model estimating in the Advanced Estimating Course.

In the long term, the CM program will be considering the use of other BIM tools such as laser scanning and Introduction to Virtual Reality and Augmented Virtual Reality.

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⁴NASA. “Statement of Work”: <http://www.hq.nasa.gov/office/procurement/newreq1.htm>

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Hasso, Mark. *Capstone Project Guide* ©Mark Hasso 2016.