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# THE AEC STUDENTS' PERSPECTIVE IN THE LEARNING PROCESS OF CAD AND BIM

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## ABSTRACT

The architecture, engineering, and construction (AEC) industry has prominently developed into a sector of interdisciplinary knowledge and collaboration over the past decade. As a collaborative tool, building information modeling (BIM) has emerged as an alternative to computer-aided design (CAD) drafting. As the BIM field matured, educators became more interested to include BIM courses in the AEC curriculum. Some universities have chosen to include BIM courses in their undergraduate core curriculum, while others have addressed the need via elective graduate courses. No matter what the type of integration was, it has become a challenge to provide appropriate techniques to teach CAD and BIM simultaneously, and yet sustain the transfer from CAD to BIM. In order to find out the appropriate teaching process and benefit students from both CAD and BIM applications, the educators should be aware of the learning pattern of the AEC students. This paper aims to reveal the learning path from students' perspective by presenting a freshman level course, taught at Milwaukee School of Engineering (MSOE). The course applies the basics of CAD and BIM philosophies to prepare students for the forthcoming design courses in the curriculum, as well as for their future careers. The study conducts a survey to learn the perception of students in CAD and BIM-based software in terms of ease of use, ease of learning, and benefits for the curriculum and construction industry. The results showed the benefits and challenges of learning both CAD and BIM-based software from students' perspectives. They will be used to improve the learning outcomes of a CAD and BIM course to better help students in their learning process.

**Keywords:** Building information modeling (BIM), computer-aided design (CAD), architecture, engineering, and construction (AEC) education

## 1. INTRODUCTION

Computer-aided design (CAD) drafting has been used for two dimensional (2D) drawings since the 1980s and three dimensional (3D) drawings for the last two decades. Being more than an alternative to CAD, building information modeling (BIM) has advanced starting from the 21st century. BIM concept has brought computed-generated models to the industry to simulate phases of a construction project from planning to operation. Besides modeling the functions, BIM is capable of modeling the behavior of building systems and components (Sacks et al., 2004). With its inevitable advantages over CAD, the industry is transforming into this new technology. In 2009, almost fifty percent of the AEC industry was using BIM and twenty percent of non-users were planning to adopt it within two years (McGrawHill, 2009). In 2012, the engagement with BIM increased to 71% among users including architects, engineers, contractors and owners (McGraw-Hill 2012).

Lack of adequately trained BIM personnel is a significant constraint hindering the use and adoption of the technology in the industry (Sacks and Barak, 2010; McGraw-Hill, 2012). In order to overcome this problem, educators has started to make BIM a part of the undergraduate and/or graduate AEC curriculum. There are many researchers supporting the usage of BIM as a design and construction education tool in

higher education institutions (Ibrahim and Rahimian, 2010; Sacks and Barak, 2010). The survey by Dean (2007) summarized two main reasons to teach BIM in construction: (1) approximately 70% of the industry participants indicated that they were either using or considering using BIM in their companies and (2) approximately 75% of survey participants considered employing candidates with BIM skills to have an advantage over candidates who lacked BIM knowledge. Recently, Becerik-Gerber et al. (2011) revealed that 80% of the architecture programs, 60% of the construction management programs, and 44% of the engineering programs of all AEC programs in the U.S. currently incorporate BIM into their curriculum. The trend in BIM, as well as the shift from CAD to BIM tools created a need to provide appropriate techniques to teach CAD and BIM simultaneously to construction students.

This paper presents a freshman level course, taught at Milwaukee School of Engineering (MSOE), to look at the perception of students in CAD and BIM-based software in terms of ease of use, ease of learning, and benefits for the curriculum and construction industry. The study will help to accelerate the BIM movement as well as its concurrent usage with CAD in the AEC education. A survey was created to collect data from students in order to reveal the benefits and challenges of learning both CAD and BIM-based software from students' perspectives. The survey also helps to learn students' studying paths to excel in CAD and BIM. The results will benefit educators in the academia and in the industry regarding the principles and application of both CAD and BIM.

## 2. CURRENT STATUS OF CAD AND BIM EDUCATION IN AEC

Many researchers are advocates of keeping up with the changing technical needs of the industry and emphasize the need to implement related information technology concepts in the curriculum (e.g. Peñamora et al. 2009). With the increasing trend in BIM, there is a variety of CAD and BIM courses related to the AEC industry. In the U.S., many departments related to AEC such as Architectural Engineering (AE), Civil Engineering (CE), and Construction Management (CM) are introducing BIM in their curricula. Some of the institutions keep the CAD courses as they are, while some decrease their content and substitute CAD information with BIM topics. The CAD/BIM courses are different not only in terms of their content, but also in terms of the year they are introduced into the curriculum. MSOE, Georgia Tech, and Purdue University are some examples that offer freshman year graphics courses, while universities like Florida International, Michigan State, and Penn State prefer to offer sophomore level drawing courses. Washington State University is an example of a junior level CAD class. Among these universities, MSOE offers both CAD and BIM content in the same class, while Penn State has created a graduate level course dedicated to BIM. The content descriptions of these courses are shown in Table 1.

Courses given in Table 1 are representative of how 2D modeling is still kept in the curriculum and 3D modeling is added to keep up with the changes in the industry. According to Buchal (2001), this process eliminated the descriptive geometry and instrument drawing content of the generic freshman year engineering graphics courses, and added instructions to cover for 3D modeling. Still, many universities are missing to teach 3D modeling with integrating the BIM content. Sacks and Barak (2010) argued, in a mandatory freshman year course that teaches both theoretical and practical aspects of BIM, that BIM could and should be taught as a course itself rather than as part of a traditional drafting course. It is still common to include BIM only in the graduate level. For example, Polytechnic Institute of NYU has 2 graduate level BIM courses as: CE 8243 Construction Modeling Techniques and CE 8303 Information Systems in Project Management. The first one covers the development of 2D and 3D design documents with the development of BIMs. The second one applying three-dimensional (3D) building information models (BIM) and four-dimensional (4D) and fully integrated and automated-project processes. Both require graduate standing to take the courses. Similarly, University of Washington offers CM 515 Innovative Project Management Concepts to reflect on emerging (BIM) technologies in the context of Project Management and Integrated Delivery, and includes visualization, 3D clash detection, fabrication automation, digital site layout, 4D modeling, as-built model generation, and digital information management.

**Table 1. Content Descriptions of Typical CAD/BIM Graphics Courses from Different Universities**

Course	University	Department	Year	Description
AE 1312: Introduction to BIM I	MSOE	AE, CE, CM	Freshman	This first course in the graphics sequence for AE and CM students teaches the basics of CAD drafting and Building Information Modeling (BIM). The CAD programs used are AutoCAD and REVIT Building. No previous CAD experience is required. 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.
CEE 1770: Introduction to Engineering Graphics and Visualization	Georgia Tech	AE, CE	Freshman	Introduction to engineering graphics and visualization including freehand sketching, 2D/3D and solid CAD models. Development and interpretation of drawings and specifications for product realization
CGT 164: Graphics For Civil Engineering And Construction	Purdue University	CE	Freshman	An introductory course in the area of computer graphics documentation for civil engineering- and construction-related professions. Experiences focus on accepted industry graphic standards and their technical visual applications. The course emphasizes creation and distribution of graphics to enable communication.
CE 107: Introduction to Civil Engineering Graphics	USC	CE	Freshman	Graphic communication and drawing; use of instruments, lettering, dimensioning, and detailing of engineering drawing; free-hand sketching, drafting, and modeling.
ENGR 2100: Intro to Engr/Computer Graphics	Clemson University	CE	Freshman	Introduction to graphics applications or engineering and related professions. 2D and 3D drawings are used to visualize, communicate, rapid prototype and analyze engineering problems.
EGEN 116: ENGINEERING GRAPHICS LABORATORY	Montana State University	CE	Freshman	Hands-on laboratory experience in two dimensional computer-aided design (CAD) for engineering design graphics.
ENGR 100: Beginning Computer Aided Drafting for Design	Drexel University	AE	Freshman	Introduces students to computer-aided graphics techniques and the use of a state-of-the-art, computer-aided design/drafting package. Students will learn 2-D and 3-D modeling techniques to support the design process. All students will be required to take a competency quiz on 4 of 6 available AutoCAD labs.
BCN 2253: Building Construction Drawing	Florida International University	CM	Sophomore	Prepare plans, elevations and sections appropriate to general construction using computer assisted modeling techniques
IDES 240: Computer-Aided Design for Designers	Michigan State University	CM	Sophomore	Designed to help students use the software to represent 2D and 3D objects.
AE 222: Working Drawings	Penn State	AE	Sophomore	Materials and methods of construction used in residences and commercial buildings; preparation of working drawings for small building.
CSTM 254: Construction Graphics	Washington State University	CE	Junior	Visual literacy and details in construction documents using drawing techniques.
AE 597G: Building Information Modeling Execution Planning	Penn State	AE	Graduate	This is a special topics course which is focused on an ongoing research project aimed at the development of a BIM Execution Planning Guide. This guide is targeted toward owners and early project team members with the goal to assist them in the selection of appropriate BIM technologies along with the development of an execution plan for implementing appropriate BIM technologies on a project.
MCM 602: Construction Information Modeling	Philadelphia University	CM	Graduate	Design to advance Revit, including architecture, structure, and mechanical, electrical, plumbing (MEP) components. Students are also introduced to estimating and collaboration skills with Revit.

Although CAD/BIM courses can be thought in different times throughout the AEC curriculum, it is essential to: (1) cover the basics of the graphics content at the beginning of the degree and (2) integrate BIM in design courses whenever possible. This paper focuses on the first part, and details a CAD/BIM course as a key element of the AEC curriculum. The next section will give an overview about the course and how CAD and BIM are handled in the same course.

### 3. THE CAD AND BIM COURSE OVERVIEW

"AE 1312 Introduction to BIM I" is the first course for AE, CE, and CM students to teach the basics of CAD and BIM. The course teaches Autodesk AutoCAD and Revit. As the students take this class on the first quarter of the freshman year, they are not required to have any previous experience. At the first class, the students are told about the content of the class, as well as the fundamental differences between CAD and BIM. The lecture material is introduced through a series of structured lectures and workshop hours. At the first class of each week, the students are introduced the related topic and the professor performs the required work in class. At the second class of each week, students use workshop hours to practice the required work on their own laptops and ask the professor one-to-one questions to clarify unclear points. As the pace of each student is different in using the related software, one-to-one workshop hours enable the professor to help students better on their own timing.

The lecture program focuses on AutoCAD for the first 5 weeks of the quarter by using the AutoCAD Manual created by the MSOE professors. The next 5 weeks cover Revit architecture topics by using "Commercial Design Using Revit Architecture" (Stine, 2014). The weekly schedule of topics is shown in Table 2. As the topics are extensive and cumulative, students' progresses are tracked by weekly assignments. For example, for the topics covered in Week 1, they have an assignment due at the beginning of the first class of Week 2. Additionally, they have 2 quizzes on AutoCAD and 1 quiz and the final exam on Revit. They are expected to deliver certain figures or building components within the given time limits of the exams.

**Table 2: Weekly Schedule of Topics**

<b>Weeks</b>	<b>Topics</b>
Week 1	MSOE network requirements, AutoCAD menu structure, Coordinate systems, Entity creation, Deleting and basic editing of entities, Saving drawings, Setting up a new drawing using limits
Week 2	Creating circles and arcs, using object snaps, Using layers
Week 3	Adding dimensions, Dimension options AutoCAD, Adding text, Crosshatching
Week 4	Moving and copying entities, Creating Blocks
Week 5	Block Attributes, Prototype Drawings, Title Block Creation and Use, Use of Viewports
Week 6	Getting Started with REVIT
Week 7	Wall types, Doors, Windows
Week 8	Wall types, Doors, Windows, Elevators
Week 9	Floors, Floor to Floor Height, Common Walls
Week 10	Roof Types, skylights
Week 11	Final Exam

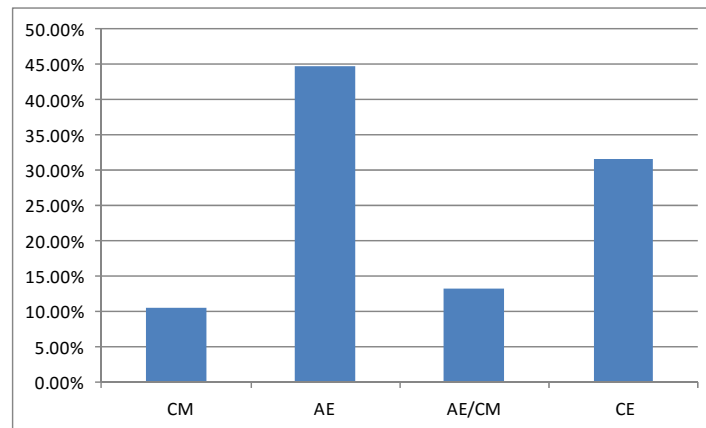
The expected outcomes of the class includes but not limited to: (1) learning the basics of AutoCAD and Revit, (2) being familiar with the user-interface, (3) being able to detect the students' own mistakes, (4) creating building plans and architectural systems, and (5) being able to use both software in the forthcoming courses and for students' future professional career. The assignments and exams test students' knowledge, as well as timing and organizational skills to determine whether they complete the course requirements successfully to pass, or not. Considering the fast speed of the quarter system, the students are expected to balance their time while learning both AutoCAD and Revit, which are two different

drawing/modeling tools. By this way, the students are challenged to improve their technical skills and study habits via the simultaneous introduction of the two software tools.

#### 4. STUDENT SURVEY AND EVALUATION OF RESULTS

To find out how the perception of students was in CAD and BIM-based software in terms of ease of use, ease of learning, and benefits for the curriculum and construction industry, the students were given a survey at the end of the quarter. The survey was filled by all students in two sections. Forty eight survey results were collected. The data collected was a mix of quantitative and qualitative information. The students were asked multiple choice questions, which resulted in quantitative data. On the last part of the survey, feedbacks from students were collected with the help of open-ended questions.

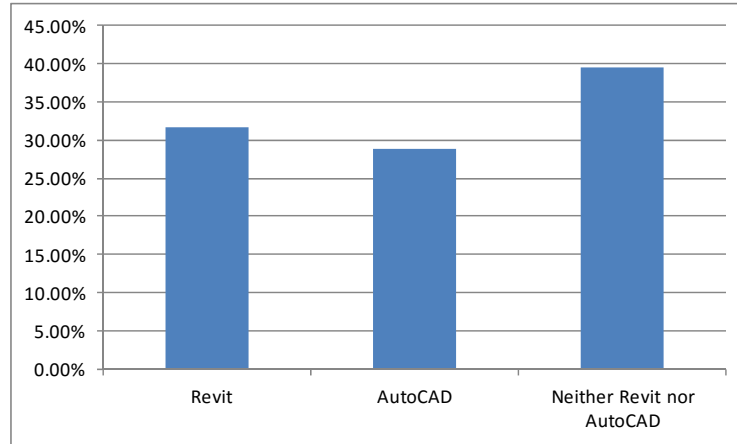
The first part of the survey included questions regarding the background of the students. As all AE, CE, and CM students were required to take this class, the students were asked about their degrees. The degree distribution of students is shown in Figure 1. As given in this figure, nearly half (45%) of the students in the class were in the AE degree program, while 11% were CM, 13% were AE/CM, and 31% were CE. The students were also asked about their previous experience in the construction industry in general. Only 21% of the students had previous experience (such as internship, part-time, or full time jobs), while most of the class (79%) did not have any experience.



**Figure 1: Degree Distribution of Students**

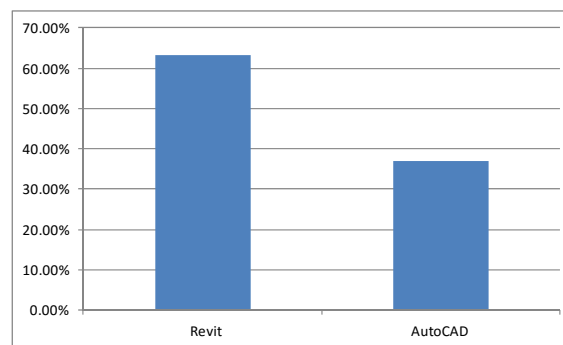
In the second part, data regarding the link between construction experience and the drawing tools, and the benefits of CAD/AutoCAD and BIM/Revit for their future career were collected. For the question of: "I think previous construction experience is needed to better use \_\_\_\_\_ to design a structure", most of the students (40%) voted for "Neither Revit nor AutoCAD" as given in Figure 2. This shows that the majority of the students did not see previous experience as a requirement to cover the basics of AutoCAD and Revit.

The following part of the survey included questions to compare AutoCAD and Revit from various perspectives such as ease of use, ease of learning, and benefits for the curriculum and construction industry. The students were given questions like: "I think there is an increasing demand for graduates with \_\_\_\_\_ knowledge in construction industry" and "I believe learning \_\_\_\_\_ is beneficial for my future career" to choose between or select both AutoCAD and Revit. Around 76% of the students thought that there was a need for graduates with both AutoCAD and Revit knowledge, while around 82% of them believed that both AutoCAD and Revit would be beneficial for their future career. Only small amount of students chose between AutoCAD and Revit, showing that the students were aware of the increasing trend in BIM tools such as Revit and also, they knew that CAD tools were still in the industry and would stay there for a while.



**Figure 2: Results for "I think previous construction experience is needed to better use \_\_\_\_\_ to design a structure"**

The CAD and BIM assignments were not similar by the difference in the nature of the tools. CAD assignments were based on ‘drawing’ building structures as CAD is a drafting tool. On the other hand, BIM assignments were based on ‘modeling’ building elements with their properties as BIM is a modeling tool. In terms of the ease of use comparison questions, 82% found it easier to create an architectural model with Revit compared to AutoCAD. In a similar fashion, 69% found it time consuming to generate the architectural model in AutoCAD compared to Revit. The results were dominant on the side of Revit in terms of the friendliness of the user-interface and help functions, as shown in Figure 3. Additionally, 68% of the students found it easier to self-detect mistakes in Revit, while 31% voted for AutoCAD. On the other hand, when students were asked about the easiness of self-teaching Revit compared to AutoCAD (i.e. without training or workshop instructions), 45% agreed Revit was easier to self-teach, while 55% disagreed and were in favor of AutoCAD.



**Figure 3: The Results for "The user-interface and help functions were friendlier in \_\_\_\_\_"**

The dominance of Revit was apparent in the following questions, which asked about easiness of understanding the structures and architectural systems. 97% of students agreed that they can create a Revit model including floor plans, elevations, and 3D view by themselves, after taking this class. More importantly, 100% of students agreed that they can study on their own to improve their Revit skills, as they got the basics in this class. This result was one of the expected outcomes of this class, and it was fulfilled successfully with 100%. Similarly, 100% of the students thought that there is a need to integrate Revit into the related design courses in the curriculum.

For the final part, students submitted written feedback on what they liked most in AutoCAD and Revit. Regarding Revit, 45% of the students wrote positive comments about the ease of creating the 3D

view and updating the design. More than 30% liked ease of use, and around 10% just put "everything" showing that Revit is their preferred software.

In terms of the evaluation from an instructor's point of view, the students had to cope with two dissimilar styles of software. At the time, when they got used to entering AutoCAD commands and using AutoCAD interface, they switched to Revit that required the creation of building elements in a different style. While in AutoCAD, only drawing elements were created, in Revit, building components were created as models including their properties. Although, the students were struggled with some problems while practicing the software programs, they appreciated workshop hours for the opportunity of getting hands on experience. The survey results showed that they know the importance and future potential of Revit and willing to improve their Revit knowledge in further courses as well as in the construction industry.

The survey results were further used to improve the learning outcome of CAD/BIM courses. With its current status, the survey results fulfills all of the expected learning outcomes of the course (as mentioned in Section 3). The students are already aware of the importance of BIM/Revit for their future endeavor. However, the importance of CAD needs to be pointed out for students. Additionally, the expected outcomes should be extended to change a BIM/CAD course from being a software-only course. The following learning outcomes are proposed to extent the limits of possible CAD/BIM courses: (6) understanding the value of CAD tools and the link between CAD and BIM, (7) recognizing the importance of CAD and BIM for AEC students, (8) working collaboratively on BIM projects, and (9) using BIM models for various purposes such as estimating or energy analysis.

## 5. CONCLUSIONS AND FUTURE WORK

This paper approached graphics education in the AEC curriculum by analyzing the student perspectives on both CAD and BIM software courses. An example freshman level course from MSOE was used to collect data from students through a structured survey. The survey revealed that most of the students did not think past industry experience was required to fulfill the requirements of such as freshman CAD and BIM class. Most of the students were aware of the importance of both AutoCAD and Revit in their future professional career. The results also indicated that the students kept track of the industry changes, as most of them said there was a need for graduates with both AutoCAD and Revit knowledge. Comparing AutoCAD and Revit functions specifically, the majority found Revit easier to use than AutoCAD, and AutoCAD more time consuming compared to Revit. The ease-of-use of Revit mostly caused by the friendliness of the user-interface, help functions, and self-detection of mistakes. In overall, all students agreed that they can study on their own to improve their Revit skills, as they got the basics in this class. This was the indication that students needed to learn the logic behind BIM and Revit in a class during their undergraduate education. They should be introduced Revit in the AEC curriculum to be able to make the software an essential part of their professional lives built upon what was thought in class. This was one of the expected outcomes of this class, and it was fulfilled successfully. The students were also advocates of integrating Revit into the related design courses in the curriculum, which showed that they were comfortable in using the software and they were willing to see its applications throughout the curriculum.

Considering the results from students' perspectives, it is suggested to have an undergraduate course to introduce BIM to AEC students earlier in their studies. The BIM content of the class can be limited to the freshman course example in this paper to offer basic modeling techniques. It is also suggested to separate AutoCAD and Revit into different courses, so that students can focus on one software and one type of user-interface at a time. When students learn the basics of BIM/Revit, BIM can be integrated into different types of courses. An example can be a senior design/capstone course, where students can design and create a real building by using BIM.

The above observations will help educators to improve the design of CAD and BIM courses to better help students in their learning process. There is, for sure, room to improve this topic by researching on higher level courses than freshman, which are dedicated to more advanced modeling concepts with BIM,



such as using structural and mechanical, electrical and plumbing (MEP) systems. Another possibility is to change the sequence of teaching CAD and Revit, i.e. teaching Revit first and CAD second to see if there is a change in the survey results. Additional studies can be performed to compare various CAD/BIM courses worldwide in the future.

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# ADVANCING BUILDING INFORMATION MODELING KNOWLEDGE THROUGH ENGAGING STAKEHOLDERS AT LOCAL AND REGIONAL LEVELS

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## ABSTRACT

Increasingly, Building Information Modeling (BIM) is being integrated into Architectural, Engineering, and Construction (AEC) coursework because of the increasing demand for a BIM educated workforce in the AEC industry. The necessity for educators who have sufficient BIM knowledge, skills, and abilities (KSAs') to teach BIM related courses is critical in most AEC fields. Research institutions offer an optimal opportunity to help meet the current and future need of educational institutions by developing the environment to collaborate and foster learning within a regional area. Leading institutions have taken a role by developing advanced programs targeting research areas specific to their strengths. BIM integration has also led the AEC industry to help foster collaboration between university programs and research opportunities.

Inspiring Science and Engineering students, especially underrepresented groups, towards innovative technology research is a goal of many engineering programs. Inspiring engineering students towards BIM research is the challenge of faculty at some institutions which do not have the knowledgeable faculty or resources to accomplish the greatly needed KSAs'. Many studies have identified the need for engaging academia, AEC industry, and government to involve in discussion and research associated with BIM interactions and challenges at every level. Establishing connections with the professionals in industry to gain additional insight of the need for advancing the body of knowledge (BoK) related to BIM and innovative technologies establishes the need for research. This paper uses a case study, a structured event to demonstrate how to help foster the atmosphere of engaging major stakeholders with vision to that end.

**Keywords:** architectural–engineering–construction AEC, building information modeling - BIM, BIM education, BIM research, Body of Knowledge - BoK, civil engineering education, collaboration, inspiring, knowledge–skills–abilities KSAs, pedagogy

## 1. INTRODUCTION

In the past and especially the last decade there has been an increased and urgent awareness that the United States is failing in preparing an appropriate number of students, teachers, and experts in the areas of science, technology, engineering, and mathematics (STEM) to meet the present-day and impending future demand in STEM careers (Kuenzi, et al, 2006). U.S. high schools have been failing to reach student aptitude goals especially in mathematics and science, while many students are being educated by teachers lacking adequate subject matter expertise (Levine, 2006). Such concerns have led the National Science Foundation (NSF), a federal funding agency, to support research and develop multipronged approaches to increase STEM awareness and participation nationally (Bonsiewicz, 2004).

The notion of American exceptionalism of past dominance in STEM fields is evolving when it comes to the global competition for highly educated and skilled workers in the STEM fields. If trends continue, America may be considered exceptional for the simple reason that it can no longer hold itself at the pinnacle of innovation and economic dominance. Fewer students are coming out of U.S. educational institutions prepared to meet the demands of current and emerging high-technology industries (Kuenzi, et al, 2006; Morgan, 2013). Expertise in STEM fields was once the domain of U.S. students and entrepreneurs, but over the past quarter-century American students have lost ground to Asian and European colleagues (Holdren, 2010). The impacts of this global competition ripple through the U.S. economy as innovators and emerging industries look beyond U.S. borders to more fertile recruitment marketplaces with larger pools of STEM-trained talent (NSF, 2010). The pipeline of U.S.-born students flowing through STEM academic fields has diminished both in terms of quality and quantity, becoming a “top priority for researchers, policymakers, educators, and youth development experts” (GSRI, 2012, p. 4).

The last three U.S. Administrations have all introduced policy to promote advancement of STEM fields, to stop the tide of loss. In early 1993 President William Jefferson Clinton introduced “Technology for America’s Economic Growth: A New Direction to Build Economic Strength,” and ascertain three main goals: (i) Long term economic growth that creates jobs and protects the environment; (ii) A government that is more productive and more responsive to the needs of its citizens; and (iii) Regain world leadership in basic science, mathematics, and engineering. President Clinton’s policy laid out objectives for Technology Policy to encourage economic growth by: Strengthening industrial competitiveness and creating jobs, inspiring innovation and investment in new ideas, providing management of technology, building partnerships among industry, government, and universities; and transforming the U.S. from the Industrial Age to the Information Age (Clinton, 1993).

Today, more than 20 years later, according to National Science Board (2014), the global demand for a knowledge-intensive (KI), workforce is increasing due to expanding knowledge-intensive economies which rely on innovations developed through research which translate into commercial and economic value. Knowledge and technology intensive industries (KTI) represented 27% of the world gross domestic product (GDP) in 2012, but in the U.S. these industries accounted for 40% of GDP, larger than any other country. Science and Engineering (S&E) trends towards KI economies which rely heavily on research, commercial exploitation, and intellectual work; which depend on investment in research and development (R&D) to produce useful innovations which significantly depend on higher education that prepare students to use S&E knowledge and research skills to develop better processes, products and perform services (<http://www.nsf.gov/statistics/seind14/>), (Yoder, 2013). These evolving knowledge-intensive economies rely on dependable infrastructure in their communities, including contemporary and reliable transportation and information technology systems used in a broadly educated and literate population to enable them to function effectively.

## **2. THE NEED**

The last few years the American Society of Civil Engineers (ASCE), quadrennial report-cards, related that the vast infrastructure is in great need of repair and or replacement (<http://www.infrastructurereportcard.org/>). Civil engineering has a wide-ranging set of sub-disciplines, which consist of transportation, structural, geotechnical, environmental, and water resources which include wastewater, and drinking water. According to ASCE, women and minorities are woefully underrepresented within its ranks. Consequential of substantial research

on paltry retention rates of undergraduate engineering students, a thorough understanding of the students' decisions not to remain in engineering programs or their ability to perform well enough to be retained is not there (Bernold, 2007).

Sustainability issues arising from population growth and expansion of urban areas demand the increase of civil engineers to accomplish the monumental tasks of infrastructure revitalization. Engineers will be needed to design, build, and expand intelligent transportation systems, increase water supply, control pollution, and construct buildings or repurpose existing building facilities. They also will be needed to repair or replace and maintain existing roads, bridges, and other underground infrastructure. The AEC industry will require increased efficiency in the design, construction, and maintenance processes to meet these challenges. Integrating BIM and other innovative processes are some ways to help realize the shortfall of engineers which will be needed.

### 3. CHALLENGES & RESEARCH

Underrepresented groups are those groups whose representation in STEM is less than their representation in the population as a whole—namely Hispanics, Blacks, and Native Americans in engineering undergraduate programs. Women and underrepresented minorities rose from slightly less than 26% of the engineering programs to 26.2%, but not near their respective demographics nationally (Hrabowski, 2011). In 2006, underrepresented minority groups comprised 28.5% of the U.S. population, but only 9.1% of college-educated Americans in S&E occupations, suggesting the proportion of underrepresented minorities lacking in S&E would need to triple conservatively to match their share of participation in the overall U.S. population (Hrabowski, 2011). A review of available data suggests that increasing the share of students from underrepresented groups who attain a bachelor's degree requires dedication to three critical stages: graduating from high school, enrolling in college, and persevering in college to bachelor's degree completion. Of the total S&E bachelor's degrees, women currently earn approximately 57% since the late 1990s mainly in biological, agricultural, social sciences, and in psychology; this same period saw women's participation in computer sciences, mathematics, physics, engineering, and economics decline respectively. NSF projections see increases in higher education and are forecasted to come mainly from minority groups particularly Hispanics and Asians (NCES, 2010). It can be argued that underrepresented groups in STEM fields including civil engineering are the most available groups to increase matriculation into freshman engineering programs. Specifically Hispanic demographics are projected to have the largest increase in the U.S. population and represent the largest pool of candidates available to increase participation in civil engineering (U.S. Census, 2010).

What are some of the possible reasons that are keeping more of the available underrepresented groups from enrolling, and graduating from civil engineering programs? Dundee Holt (2002) specifies some reasons that might be keeping underrepresented groups from enrolling, and retained through graduation in engineering programs; she states some research has indicated that the white-male domination in overall engineering programs might be at the forefront of some of the issues (also see, Hrabowski, 2011). Holt (2002) states that underrepresented minorities may suffer extreme racial isolation in engineering programs which she defines as the experience of "onlyness". Lending support to Holt's research, (NSF, 2010) Beerling suggests stereotyping attitudes of gender and minorities often leads to an unaccommodating or adverse learning environment which may diminish self-efficacy, or one's belief in capabilities to learn and successfully perform in undergraduate engineering programs. According to Holt (2002, p. 24), the challenge remains with engineering institutions. "All students suffer through the rigorous curriculum and the less-than-

welcoming environment, but the added experience of “only-ness” can break even the toughest and ablest students”. She identifies that underrepresented minorities are less likely to suffer “only-ness” at institutions that serve minorities or programs with supportive diversity infrastructures and minority engineering program administrators (MEPs) (Holt, 2002).

Women and minorities as engineering undergraduates experience high attrition rates (Marra et al, 2009; NSF, 2010). Low self-efficacy of possible underrepresented and female engineers draw a parallel with the apparent lack of participation in engineering programs, possibly due to negative attitudes of fellow students and faculty, and may be somewhat to blame for this manifestation (Ford, et al, 2000; NSF, 2010). Some indications suggest that many of the most talented college students, including women and minority students, have been moving away from STEM fields toward other professions (Blue, et al, 2005; Hill, et al, 2010; Reichert, et al, 1997). Often U.S. students determine early in their education that STEM subjects are too tedious, challenging, or inhospitable, leaving them inadequately prepared to meet the challenges that their generation will face (Hill, et al, 2010; Holdren, 2010). Examining Disparities in College Major by Gender and Race/Ethnicity, Catherine Rieggle-Crumb and Barbara King (2010) identify factors that shape students choices of college major well before they set foot on a college campus. They identify that a student’s prior academic preparation is the strongest predictor of entrance into STEM majors. The indication is that this is not really performance-based, but rather not being prepared in elementary through high school grades for STEM education seems to be the obstacle to equity in STEM majors with respect to minority and underrepresented groups in engineering programs.

#### **4. CURRENT TRENDS & CONCLUSIONS**

Engineering education in the United States has undergone a profound transformation, from a strong focus on engineering practice to the current emphasis on scientific fundamentals and mathematical analysis (Prados, 1998). Driven by major federal investment in university research has led to a structural change in engineering faculty philosophy, away from its traditional origins in professional practice, toward an academic science perspective with gains based primarily on research achievement. Rapid and innovative development of technologies have increased attention on the need for new forms of engineering instruction that will equip graduates with more competent skills in communication, collaborative teamwork, data assimilation, and fiscal understanding, as well as rigorous technical and theoretical competencies. Engineering education is now beginning to adopt this new paradigm, but academic culture changes slowly; the new paradigm will take some time to be integrated in the majority of U.S. engineering schools. Leading the force for change include efforts of the NSF, engineering professional societies, engineering college advisory boards, and the Accreditation Board for Engineering and Technology (ABET).

University and departmental engineering programs must come to the realization that there are three specific goals and objectives for the respective degrees based on the perspective of first the administration, which seeks to have engineering students go through their program as quickly and efficiently as possible; second the faculty, which seek to have the students gain knowledge and theory, and synthesize that theory within a defined period of time, and possibly go on to graduate school; and third, the student’s perspective of gaining the knowledge, skills, and entry-level abilities to find gainful employment in a possible life-long stable career. The appropriate area is the middle convergence of the three-circle vin-diagram where all three are satisfied, and where we are all dedicated to developing critically thinking engineers who have competencies in new technologies, well-established theories, and would be motivated to seek advanced degrees in their field of study. The beneficiary of these outcomes will be the universities, the students, and society

as a whole. Not being afraid to reinvent S&E programs to meet the new challenges of the 21st century and establish new pathways into engineering education must be the selfless driving motivation in the paradigm of change.

Inspiring students, especially women and underrepresented minority groups to learn how to learn based on their specific learning strengths like group research projects, team assignments, and study groups often demonstrates the faculty's dedication to mentoring and providing avenues for success in their respective coursework. These early successes can often be the catalyst to inspire these groups to continue in their engineering programs. The outcome of refining undergraduate programs in engineering with critical analysis to the quality of coursework is not measurable at this point. Only through systemic changes, adaptations, and refinements in coursework, faculty, and motivations can we prepare the next generation of engineering students to gain necessary knowledge intensive skills they will be expected to have going into the workforce, or pursuing advanced degrees and completing higher level research, which is the main goal of most research institutions (Beede, et al, 2011, Woods, et al, 2000). Integrating innovative technologies like BIM; three-dimensional scanning and printing; database creation, management, analysis, and nanotechnologies into course curriculum are excellent methods for engineering students to become inspired and more involved in their engineering programs which distinguish their academic resume from others.

Students will ultimately make their decision to stay in the S&E programs with their pocketbook, but it is up to the faculty to whether they will stay in or go away from engineering programs based on how welcoming they are and inspiring they can be; by directing them to the proper resources and support available to them to help them succeed. Many students and faculty specifically come to engineering programs with diverse populations, some only to be dismayed at the constraints imposed arbitrarily through the bureaucracy and status quo. Finding new ways to integrate women and underrepresented minority groups into engineering programs must be the goal of all educational institutions, specific to the local demographics first, and secondly as the overall demographic of the changing nation. Hispanic women in civil engineering programs offer an excellent opportunity to break the cycle of generational poverty in New Mexico; and obviously Native American, and African American populations in different geographical regions as well.

More research must be completed on underrepresented groups, namely Hispanics in undergraduate civil engineering programs to appropriately make recommendations for future investment to ensure diversity goals are met eventually. Identifying top performing undergraduate civil engineering programs nationally, and comparing results to successful national leading underrepresented civil engineering programs may provide the systemic framework for restructuring programs to help achieve goals. The overall diversity demographics, including faculty in these programs might also shed light to issues encountered in changes and recommendations for all STEM undergraduate programs.

## 5. RECOMMENDATIONS

Engineering programs which have innovative technology courses integrated into their respective degree curriculum must also provide local stakeholders the opportunity to shape the desired KSAs' and outcomes for engineers that will be entering the workforce and likely intern and be hired by them. Including industry advisory committee/ boards and Government agencies are also likely to be interested in shaping research and KSAs which will help them advance their agency's BIM goals and objectives (Marosi, Steinhurst, 2012).

Supplementing curriculum with invested stakeholder events like the joint bimSmartfoundation (bSf) and University of New Mexico (UNM) BIM Summit, BIM-Storm, and learning sites like AutoDesk's BIM Curriculum website are excellent measures that may help inspire and foster a better understanding of the need for a BIM educated professions, which bring new synergy and inspired vision to the AEC industry. The UNM department of civil engineering co-hosted the 2<sup>nd</sup> annual UNM-bimSmartfoundation Summit on Friday September 18, 2015 with a full-day of new presentations, panel discussions, and collaborative sharing of history along with the current and future vision of the use of BIM theories and practice in the AEC industry and current academic research.

The 2015 UNM-bSf event brought together local practitioners, university professors, undergraduate and graduate students from various colleges and even high school students for a day of presentations looking at the industry from the global to the local view; truly a think globally, act locally event. The intent was to identify how this community could work together to support each other's needs. Sponsors were given the opportunity to demonstrate their successes and also included local technology support for implementing the opportunities. This is an opportunity for the complete community to get an annual update on what is happening that they should be aware of from many levels and then can network monthly to help each other implement those ideas. Next year's UNM-bSf event will start to increase the size and scope of the event to eventually becoming a regional event which will seek to identify local BIM needs, research opportunities and attract underrepresented students toward BIM research.

Research and innovation centers maybe the catalyst to inspire more students toward AEC programs and inspire students to advance the overall BIM BoK and provide the anticipated needed BIM educated workforce. These types of events also help foster collaboration and advancing the BoK for BIM in the AEC industry to give owners a better understanding of potential lifecycle investments through facilities management, operations and maintenance which can have long-term impacts to society globally. BIM and Bridge Information Modeling (BrIM), 3-D Scanning and other emerging technologies are quickly gaining traction and research opportunities and intra-department collaboration will be available in the future. Research of resilient structures, communities and infrastructure through the increase utilization of drones for inspection, analysis and maintenance offer an expanded opportunity to attract new students, especially underrepresented groups to the AEC professions.

Achieving demographic and gender equity of underrepresented groups in civil engineering, and engineering as a whole can be realized in the future through additional and more in-depth research and tracking demographic breakdowns in engineering programs throughout the country. NSF and all concerned subgroups in engineering need to lead the way by adopting demographic breakdowns in their funded research projects that include minority undergraduate students. If minorities, including Hispanics and women are to matriculate in civil engineering undergraduate

programs, they must feel welcomed and see a represented demographic in their faculty. Mentoring programs that have successful underrepresented role models in PhD and Master's degree programs must be implemented to emulate the desired atmosphere and help diminish the stress in undergraduate engineering students of color.

Emphasis in grade school through high school education should integrate simple basic concepts that might help younger students identify with problem-solving skills. Dual enrollment high school-college courses may also help bridge the gap by inspiring younger students to consider engineering programs through early success in entry-level engineering classes. Societal challenges and social responsibility is another avenue to involve younger students in an attempt to help solve environmental issues such as climate change. A great way to change stereotypes and involve girls earlier in their youth is through programs like the Girl Scouts - Generation STEM program which seeks to mentor young girls with successful scientist and engineer female role-models.

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# INTEGRATING BUILDING INFORMATION MODELING ACROSS AN UNDERGRADUATE CONSTRUCTION MANAGEMENT CURRICULUM: EXPERIENTIAL LEARNING THROUGH A TINY HOUSE PROJECT

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## ABSTRACT

As building information modeling (BIM) becoming a standard component of undergraduate curricula in architecture, engineering and construction (AEC) programs, educators have been testing proper pedagogy to cultivate students' knowledge, skills and abilities (KSAs) desired for effective BIM implementation. The emphasis of BIM education, as observed from the literature, has been transforming from software skill training to project execution and management. Project-based learning as a vetted pedagogy thus has been broadly adopted. This paper highlighted a case of BIM integration across an undergraduate construction curriculum and documented the experiential BIM learning using a Tiny House project. Broad student participation, including underrepresented minority groups, and comprehensive inclusion of both lower and upper division courses exemplify high-impact BIM educational practices. The tiny house project also provides the desired pedagogical construct where essential student learning outcomes such as communication, problem-solving, critical thinking and leadership can be assessed. This paper delineates the pedagogical design in experiential BIM learning, and presented initial student learning outcomes through the tiny house project.

**Keywords:** BIM, experiential learning, pedagogical design, student learning outcomes, assessment

## 1. INTRODUCTION

Building information modeling (BIM) is gaining continued momentum as the US construction industry stays strong and major market players are reaping more BIM revenue (Barista 2015). The broad spectrum of BIM implementation across the architecture, engineering and construction (AEC) sectors necessitates an unprecedented market demand for workforce with drastically diverse set of knowledge, skills and abilities (KSAs) to deal with day-to-day job tasks and meet projects' business performance requirements. Companies are facing intense challenges in human resources and many of them have integrated employee training and continuing education programs for in-house talent development (Joseph 2011). Nevertheless, from the longer term perspective, college education holds the promise to cultivate the next-generation of workforce to sustain the development and diffusion of BIM (McGraw-Hill Construction 2009; Smith and Tardif 2009). This paper describes a unique case of BIM integration in an undergraduate construction management (CM) curriculum through a specially scaffolded learning experience, the Tiny House project. The paper focuses on the experiential learning-based pedagogy design and articulates how it is being utilized to improve target student learning outcomes (SLOs) as part of the strategic planning of curriculum redesign driven by industry expectations of student BIM competencies in the regional and local contexts.

## 2. BACKGROUND

### 2.1 BIM in college curriculum

Incorporating BIM in college curricula has gradually grown into a common practice (Barison and Santos 2010; Sabongi and Arch 2009; Wu and Issa 2014) despite considerable barriers and the lack of standard practices (Clevenger et al. 2010; Sacks and Pikas 2013; Woo 2006). Priorities were originally given to technological aspects of BIM while recently shifted to emphasize more on the implementation process and the value propositions of BIM (Sacks and Pikas 2013). Comprehensive literature review conducted by (Lee and Dossick 2012; Lee and Hollar 2013; Sacks and Pikas 2013) revealed that the trends in academia experiments with BIM teaching strategies had migrated from individual courses to more systematic and curriculum level integration (Barison and Santos 2010; Clevenger et al. 2010; Wu and Issa 2014). It is also noticed that industry perspectives have been consistently consulted by scholars in pedagogic design (Gardner et al. 2014; Lee and Hollar 2013; Miller et al. 2013) with intention and efforts to bridge the gap between drastic uptake of BIM and the lack of competent workforce that are proficient in both technological and business terms of BIM project execution. There are ongoing efforts in strategically planning for BIM education and pedagogic approaches with clearly identified student learning outcomes that match desired workforce competencies (Pikas et al. 2013; Sacks and Pikas 2013; Wu and Issa 2014).

### 2.2 Learning theory and pedagogy approaches in BIM education

By nature, any form of BIM education in college curricula represents a certain pedagogic theory and practice that is deemed as appropriate to deliver the contents to students, to engage students in the learning process, to achieve the expected student learning outcomes, and eventually to develop the BIM knowledge, skills and abilities (KSAs) that prepare students for future roles in their professional career. Put under the lens of Bloom's Taxonomy (Bloom et al. 1956), the topics addressed in generic BIM education entails knowledge of concepts, definitions, processes, practices and skills with technologies and functionalities, analyses and applications for problem-solving in project delivery, and evaluation of implementation strategies and assessment of project outcomes (Lee et al. 2013; Sacks and Pikas 2013). Apparently, the breadth and depth of BIM education necessitate careful pedagogy design to ensure progressional development of student competency, which can be facilitated with solid understanding of learning theories and utilization of established pedagogical models. Among the best practices of documented literature, exposure to real-world knowledge and implementation of BIM through case studies, guest lectures and capstone projects were frequently cited as one of the most effective approaches in curriculum design and student learning engagement (Gardner et al. 2014; Lee and Hollar 2013; Miller et al. 2013; Sacks and Pikas 2013; Wu and Issa 2014).

Practitioners appreciate BIM's business value not only as a solution to discipline-specific issues, but also a collaborative platform that improves communication among members of an intrinsically heterogeneous project team (Becerik-Gerber et al. 2012; McGraw-Hill Construction 2009). The roles and responsibilities played by project participants in domain-specific and organizational (e.g. team as a temporary organization) contexts determine that both individual and organizational BIM competencies should be expected from future workforce. Correspondingly, pedagogy design in BIM education should reflect both individualized and team-based learning needs. Experiential, project-based learning thus seems to be a promising option.

### 2.3 Experiential learning and project-based learning

Experiential learning theory (ELT) draws on the work of John Dewey, Kurt Lewin, Jean Piaget and others who gave experience a central role in their theories of human learning and development (Kolb and Kolb 2005). Experiential learning (EL) has long been a part of engineering education in the form of special projects, instruction in design and cooperative programs but most recently with greater variety and degree of innovation (Harrisberger 1976). EL focuses on the learning process of the individual and concerns the

development of student's abilities, such as memory, creativity, and sensitivity to achieve knowledge (Boud et al. 1993), which was summarized with the very popular David Kolb's cyclic, multidimensional model (Kolb 1984) as illustrated in Figure 1. EL is also deemed as an important facilitator to smoother transition of students from university preparation to professional fulfillments (Lynch and Russell 2009), and encourage the cultivation of self-directed life-long learners (Jiusto and DiBiasio 2006).



Figure 1: Kolb's experiential learning cycle (Kolb 1984).

Project-based learning (PBL) is a proven student-centered interdisciplinary pedagogical approach (Baş 2011) that focuses on real-world issues (Chinowsky et al. 2006). PBL encourages learning in both individual and collaborative settings where students will build knowledge (Liu et al. 2010), develop critical thinking, creativity (Kubiato and Vaculová 2011) and a number of essential soft skills including leadership and communication (written, oral and graphical) (Walters and Sirotiak 2011). PBL is widely used in engineering and construction management education (Zhang 2014), and has been increasingly utilized with improved infrastructure support with advanced information and communication technology (Goedert et al. 2013). PBL instills metacognition and self-monitoring skills of students in facing, analyzing and resolving problems and complexities in realistic project scenarios (Chinowsky et al. 2006), which is extremely valuable for project-oriented domains (Goedert et al. 2013).

The combination of EL and PBL can form an ideal scaffold to student learning in BIM fundamentals and its implementation in project scenarios in and out of classroom. It transfers the roles of instructors through a series of activities with sustained focus on student-directed exploration, self-reflection, and engaging in group efforts that lead to clearly defined learning goals and project outcomes of significance. On-going assessment also provides frequent opportunities for students to receive and provide feedback as the project is developing, which motivates critical and higher-order thinking and fosters development of competencies in technological, social, and business dimensions of a BIM project execution.

### 3. THE TINY HOUSE PROJECT EXPERIENCE

#### 3.1 Project background

A tiny house is a small building created with the intention of making a livable and comfortable space including most of the conveniences of a typical home but realized at a much smaller living footprint (Mitchell 2014). The Tiny House competition, launched by Sacramento Municipal Utility District (SMUD) in the fall of 2014, challenges collegiate teams to design and build net-zero, tiny solar houses. The event is anticipated to be held in the fall of 2016 and is spearheaded by SMUD's Energy & Technology Center and Community Solar program. The competition is modeled after the U.S. Department of Energy's Solar

Decathlon. An educator or other school administrator will mentor each team with a size of 10 to 24 students. During the two years leading up to the event, students will design and build the energy-efficient houses with allowable sizes between 100 and 400 square feet, and a maximum budget of \$25,000. Judging criteria of the competition cover four major categories, i.e. *architecture* (juried), *energy* (juried and measured), *house life* (juried and measured) and *communications* (juried). Each category is further elaborated with a list of evaluation provisions (SMUD 2015).

### 3.2 Project approach and BIM integration

Faculty in the construction management department envisioned the Tiny House competition as a possible facilitator to the undergoing curriculum redesign that aimed to improve student learning engagement and core learning outcomes including BIM, sustainability, communication, critical thinking, interdisciplinary teamwork, leadership and entrepreneurship. Given the time frame of the competition, which lasts for two years, a cyclic rolling strategy was taken to break down the design and construction phases of the project and allocated critical design and construction tasks concurrently into several lower- and upper-division courses. The goal is to maximize learning experience to students at different academic levels so there will be enough students that have exposure to the Tiny House project at the final stage of the competition in fall 2016. Student leaders in CM and other engineering, business, marketing and mass communication majors were identified earlier at sophomore, junior and senior levels to form a truly collaborative and multidisciplinary project team.

BIM plays an essential role throughout this competition. Table 1 summarizes a list of courses that are committed to support or directly incorporate certain components of the Tiny House project at different phases, and indicates the potential learning activities and expected outcomes pertinent to BIM. As an entry level course, *CM4: Construction Graphics* replaced the traditional CAD-based graphics class and laid the foundation to essential knowledge and modeling skills for incorporating BIM in ensuing CM courses in the curriculum. Both *CM20* and *CM180AS* address the design efforts of the project while the former course emphasizes the design concepts and documentation, the latter one focuses on the pre-construction aspects, performance modeling and evaluation, as well as project execution planning. *CM180B* is for the actual construction operation and management. Students are expected to build the first prototype by the end of fall semester in 2015, and continue on performance-testing and improving the Tiny House per judging criteria till the final competition exhibit in fall 2016.

Table 1. Curriculum integration of BIM in the Tiny House project.

	Course Info	BIM Learning Activities	Expected Learning Outcomes
Lower Division	CM4: Construction Graphics	Print reading, exposure to BIM concepts; fundamental drafting and modeling with major BIM software applications	Able to: read and interpret construction plans; create building information models per plans
	CM20: Contracts & Specifications	Tiny House feasibility analysis; architectural and structural design; construction documentation and specification	Able to: conceptualize, author and evaluate design models; create conceptual cost estimates; create construction documentation & specifications
Upper Division	CM180AS: Capstone 1	Tiny House design review and detailing; building system evaluation, performance modeling; cost analysis; project scheduling	Able to: create and check construction models; conduct performance modeling and 4D simulation; create cost models
	CM180B: Capstone 2	Tiny House construction; project controls and management	Able to: utilize BIM to procure, install and manage the Tiny House project; track budget and schedule

### 3.3 Project process and experiential, project-based learning

The project kicked off in spring semester 2015, with concurrent participation of students from *CM20* and *CM180AS*. While *CM180AS* took the lead in team building, feasibility analysis and strategic planning, both courses performed design authoring and evaluation, and performance analysis. A grand task for *CM20* students was to produce the construction plans and specifications that could be passed along to *CM180B* students for construction in the fall. The overall project process and expected key events are illustrated in Figure 2.

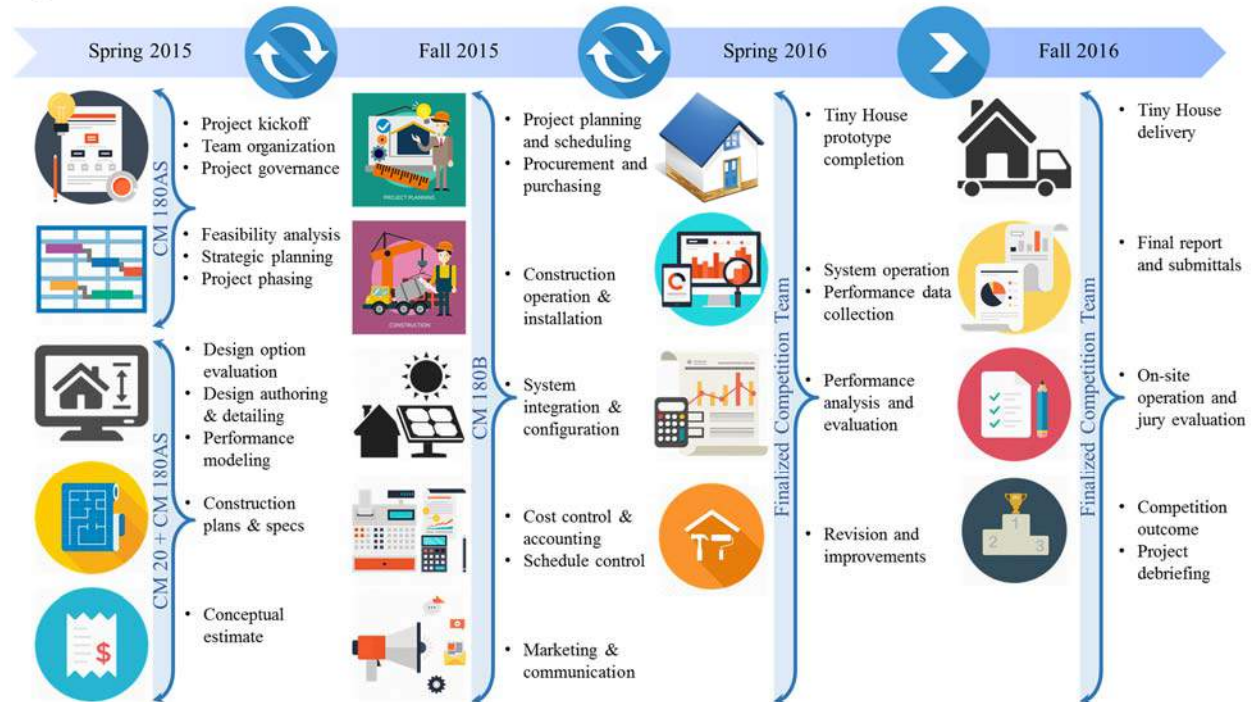


Figure 2. Overall process map of the Tiny House project.

The experiential, project-based learning started with a site visit to a local tiny house builder. Students were introduced to the history and philosophy of tiny house, its design criteria and construction process, and system/material selection and performance guidelines. This direct and comprehensive exposure to tiny houses grabbed students' attention immediately and quickly turned into the basis for their own design. During the feasibility analysis and strategic planning, such understanding was reinforced, which led into the design authoring and evaluation process. Students were required to propose at least three design options, and compare the pros and cons of each design against the competition judging criteria at a very generic level. Interviews with local contractors and visits to material and equipment vendors were strongly recommended to students so they could make decisions based upon real world scenarios. BIM provided students with insights and flexibility to visualize such variances among these design options and helped determine the optimal design. From design to construction, which signals the transition from conceptualization to experimentation, is a critical step in experiential, project-based learning process. Again, BIM provided students with valuable affordance to plan and control the project outcomes with powerful 3D representation, 4D simulation and 5D cost estimating capacities. Such affordance could sustain through the construction process when students referred to BIM for field installation, performance verification, cost and schedule tracking, to name a few. Figure 3 updates Kolb's experiential learning cycle with the experiential, project-based learning process of Tiny House project so far.

### 3.4 Student reflection on the Tiny House experience

In order to gauge the BIM learning experience in the Tiny House, a survey was administered to students from *CM20*, *CM180AS* and *CM180B* at the end of fall semester, 2015. A total of 39 students were reached with 21 responses (response rates at 53.8%). It was worthwhile mentioning that 90% of the students were minorities and for 57% of them English was not the first language.



Figure 3. The Tiny House experiential, project-based learning cycle.

The surveyed focused on BIM usages and core SLOs in the Tiny House project. Top BIM usages in the design phase include *design authoring* (schematic 85%, detail 80% and conceptual 60%), *feasibility analysis* (60%), *visualization and presentation* (60%). Top BIM usages in construction phase include *plan & specs view for scope of work* (70%), *measurements and framing details* (65%), and *construction site layout plan* (50%). For SLOs, Table 2 summarizes core SLOs in the Tiny House project experience perceived by the students. Leadership, entrepreneurship and overall student engagement in learning received highest rating.

## 4. CONCLUDING REMARKS

Appropriate pedagogic design is essential to effective college BIM education. To meet the breadth and depth of BIM competency expectations for future workforce, pedagogical models such as experiential learning and project-based learning were experimented through a Tiny House project in this study. Noticeable characteristics of this project include curriculum-level BIM integration, broad participation of minorities students at various academic levels, and a relatively flexible project time frame that allows for repetition and continuous improvement of target SLOs. Regardless of the relatively small scope of the Tiny House project, the BIM learning activities and student learning experience were well contained and scaffolded. So far, student perceptions and feedback from the informed campus units and local community

are very positive overall. Most importantly, students attained valuable BIM project execution experience at a relatively affordable cost, which rarely happened in other pedagogical approaches. Further investigation and a more comprehensive student learning assessment will be performed after the final competition in fall 2016.

Table 2. Student reflection on core SLOs in the Tiny House project.

Category	Student Learning Outcomes	Likert Scale (1: Strongly Disagree to 5: Strongly Agree)				
		Min Value	Max Value	Mean	Variance	Standard Deviation
BIM Fundamentals	Enhanced understanding of BIM concepts and definitions	2	5	3.63	1.05	1.02
	Enhanced understanding of BIM usage in different stages of project delivery	2	5	3.75	0.6	0.77
	Enhanced understanding of business benefits of BIM to different stakeholders	2	5	3.73	0.64	0.8
BIM for Design Communication	Enhanced skills in BIM modeling for architectural design and space planning	2	5	3.75	0.73	0.86
	Enhanced skills in BIM modeling for structural framing and detailing	2	5	3.75	0.6	0.77
	Enhanced skills in BIM modeling for building systems	2	5	3.88	0.78	0.89
	Enhanced skills in design visualization and presentation	2	5	3.93	0.78	0.88
	Enhanced skills in design specifications and documentation	2	5	3.67	0.95	0.98
BIM for Problem-solving	Enhanced skills in building performance and sustainability analysis	3	5	3.93	0.64	0.8
	Enhanced skills in model-based quantity takeoff and cost estimating	3	5	3.8	0.6	0.77
	Enhanced skills in preparing construction site layout	3	5	3.87	0.55	0.74
	Enhanced skills in extracting construction information (e.g. measurements, details, finishes and workmanship) from BIM	3	5	3.8	0.46	0.68
	Enhanced skills in managing project key performance indicators (schedule, budget, safety) with BIM	3	5	3.73	0.5	0.7
	Enhanced skills in project quality control with BIM	3	5	3.73	0.5	0.7
BIM for Other Essential SLOs	Enhanced teamwork and collaboration	2	5	3.88	0.78	0.89
	Enhanced leadership skills	3	5	4.31	0.5	0.7
	Enhanced entrepreneurial spirit	3	5	4.06	0.73	0.85
Overall enhanced engagement in learning		3	5	4.2	0.46	0.68



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# DEVELOPMENT OF A PEER REVIEW-BASED ACTIVITY TO IMPROVE STUDENTS BIM PROCESS MAPPING UNDERSTANDING

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## ABSTRACT:

Building Information Modeling (BIM) adoption has been steadily increasing in the Architecture, Engineering, Construction, and Operation (AECO) fields. Universities have evolved in the way they teach BIM, preparing students for this new AECO paradigm. Part of the educational challenge is in teaching students the technical skills of how to use a constantly growing list of BIM software applications. Another more abstract, yet equally important, component is in teaching students how to plan for the execution of BIM on a project, requiring students be able to: define BIM phases; identify responsible parties; and determine associated information exchanges between those parties. Prior educational research identified challenges in getting students to develop process maps as a method to conceptualize and illustrate a BIM execution plan. This current iteration of the research explores the value of a peer review-based, in-class activity providing students with a simplified version of a real-world BIM planning scenario. The activity challenged students to: conceptualize a basic level 1 and level 2 BIM process map for an example project; trade process maps with one of their peers to analyze and assess their peer's process maps, and; collect their peer edited process maps and reflect on the feedback they received to include modifying their original concepts. Pre- and post-activity questionnaires completed by the students illustrate observable shifts in perception as a result of the activity. The results confirmed initial observations that students currently lack understanding and comfort with developing BIM process maps to illustrate an execution plan. While the findings of this initial implementation primarily illustrate challenges with this mode of education, they also provided some insight into ways to further simplify the peer-review activity for future semesters. Future work will modify the learning activity, simplifying the concepts, with the objective of enabling students to achieve a comfort of and ability to develop process maps for BIM execution.

**Keywords:** *BIM, BIM Process Mapping, BIM education, Peer Review*

## 1. INTRODUCTION

The built environment has become increasingly complex. Building Information Modeling (BIM) has responded accordingly, becoming an indispensable component of the construction process. When effectively implemented BIM enables project participants from various disciplines to collaborate, identifying and resolving potential conflicts prior to construction. The ability of BIM to serve as a collaborative tool is essentially a result of the data embedded in a three dimensional model and the utility of that data to add value to the overall project (Eastman et al. 2011). The data embedded in BIM allows for communication between those engaged in the construction of the model, execution of the project, and facilities management.

A traditional collaboration of responsible parties, tasked with authoring the embedded data, is essential to the successful implementation of BIM in support of an Architecture Engineering and Construction (AEC) project (Eastman et al. 2011). In contrast, the pedagogical structure of BIM education has indirectly favored the technical implementation of BIM over the interdisciplinary dialog BIM is capable of fostering (Barison et al. 2010).

Prior research focused on project execution planning (PxP) educational strategies from the perspectives of previous educators who lead and assisted with course instruction. The aim of this initial phase of research was to better understand the students' comprehension of PxP techniques and the teaching methods used to foster this understanding (Ayer 2014). In this work, two different teaching and assessment strategies were analyzed for presenting PxP concepts. While certain benefits were suggested by the different teaching strategies, several common challenges were also observed related to student understanding of PxP concepts. The research presented in this paper further explores the topic of PxP education from the perspective of both educators and students. Specifically, it addresses the following research questions:

- Can students demonstrate an understanding of the various project participants' roles and responsibilities for a BIM project, effectively planning for a BIM implementation? And
- Are students able to document plausible project information flows in their process maps?

To address these questions, a new learning module was developed and implemented with students enrolled in a fourth-year Construction Management course at Arizona State University (ASU), called CON 453. The developed learning module involved a simplified process mapping activity where students were challenged to organize five, common BIM uses into a level-one process map, and subsequently develop a detailed workflow for one particular BIM use (Phase Planning (4D Modeling)) in a level-two process map. After creating these process maps, students reviewed a set of maps developed by one of their peers. Finally, students re-reviewed their own process maps based on the feedback they received from their peer. This paper summarizes the findings of this research from the students' and instructors' perspectives.

## 2. BACKGROUND

BIM implementation allows for more collaboration in terms of project delivery methods, providing a paradigm shift in the current construction processes (Mihindu et al. 2008; Roorda et al. 2008). In order to fully implement and realize BIM potential, a project manager must clearly identify the flow of information from ground breaking through every subsequent phase of construction (National Institute of Building Sciences 2007). The act of mapping the BIM process addresses the challenges in BIM adoption and implementation at an early stage and throughout the project (Saluja 2009; Coates et al. 2010). Additionally, process mapping helps to better represent the tasks a project team must perform to effectively implement BIM at different project milestones (Saluja 2009). The construction industry has also used BIM process mapping to identify interdisciplinary constraints and communicate the project execution plan (Kreider et al. 2013). Moreover, sustainability efforts and green building principles are now integrating Lean standards within BIM process maps (Lapinski et al. 2005; Klotz et al. 2007), and system engineering (Bersson et al. 2012).

It is critical for a project team to author a detailed and comprehensive process, enabling a successful implementation of activities associated with a BIM project (Wu et al. 2014). Specifically, a process map is defined as a visual or graphical depiction of a process flow (Cooper et al. 2013). A typical BIM process map provides details for the execution of BIM activities, business goals, process inputs/outputs, responsible parties, and tasks or sub-processes. However, there are two different BIM process maps that may be involved within a project execution plan: 1) a high level map that shows the identified BIM use cases (Level 1), and; 2) a detailed map describing each BIM use case individually (Level 2) (CIC 2010). Process maps are not intended to have a fixed structure. Rather, the structure of a process map is largely subjective, differing by author, yet may reach a similar overall purpose. It is expected that concurrent or sometimes

reiterated activities may occur within a process map for the same BIM activity (CIC 2010). However, the design of a BIM process map can be examined to aid in the understanding of the overall BIM execution plan, additionally, the design of the map clarifies where BIM can typically be used throughout project life cycle (Wu et al. 2014; Cooper et al. 2013).

Overall, BIM process maps contain three primary elements (Eastman et al 2010). The first element includes the activities that have specified purpose throughout a projects life cycle. This also serves to define the specific tasks that BIM use-cases address. The second element represents how these activities are linked and interrelated. This can be shown as solid or dashed lines, and arrows between the activities indicating the direction of the information flow and precedence relationship. The third element represents the information exchanges needed at a particular process or activity.

In general, the level of knowledge obtained is influenced by educational strategies and methods to include process mapping and peer review (Balogh et al. 2013). Differing pedagogical strategies are suggested by researchers to enhance BIM education specific to construction engineering and management. For example, (Wu et al. 2013) conducted a comprehensive review of BIM teaching strategies, concluding that a considerable number of AEC programs (16.5%) developed BIM within specific courses. Additionally, a brief review of how BIM teaching techniques are being introduced by different universities around the world were also investigated (Barison et al. 2010).

Universities have responded to the demand for BIM offering an ever increasing academic offering(Sacks et al. 2013). The pedagogical models and methods used by these institutions to present BIM education vary. In fact, there is no accepted pedagogical strategy for teaching BIM in AEC-related curriculum(Woo 2006). Although BIM is commonly understood to be interdisciplinary, 90% of the educational platforms are developed on a single Architecture or Engineering platform(Barison et al. 2010). This uncertainty in how to best prepare students with the BIM skills necessary for future, career success in the AECO fields supports the need for improved pedagogical strategies. This work takes a first step toward addressing this goal by creating a learning module intended to improve student understanding of PxP process mapping.

### 3. METHODOLOGY

To understand how best to present BIM process mapping learning concepts, a new learning module was developed and implemented in a fourth-year course (CON 453) at ASU. CON 453 meets twice weekly for a seventy-five-minute lecture and one hour per week in a laboratory setting. The course lecture focuses on the theoretical application and potential industry impact of BIM. The lab sessions target the hands-on execution of BIM, including model manipulation using commercial modeling software. The course involves a semester-long project where students are challenged to develop a theoretical BIM PxP and also apply software skills to demonstrate their BIM abilities. The learning module developed and implemented in this research aims to better prepare students with fundamental BIM process mapping skills that can be used on the semester project and after graduation.

#### **Pre-activity Lecture Content:**

The activity of process mapping was introduced in lecture the week prior to the study, with an objective of creating a familiarity with the documentation, process, and purpose of BIM process mapping. Principle aspects of a process map were covered at length to include the dialog box, inbound and outbound flow, decision hubs etc. The lecture concluded with an overview of a completed Level 1 and Level 2 process map, capturing informational exchanges and creating a visual connection between the completed map, BIM, and PxP.

After the introductory lecture on BIM process mapping, students were tasked with applying these concepts through the peer-review-based process mapping activity. This activity consisted of several components, which served to illustrate students' perception and abilities regarding BIM process mapping. The components involved in the activity are described in the following sections.

### **Pre-activity Assessments:**

Prior to beginning the developed process mapping activity, a pre-activity questionnaire was given to students along with an informed consent sheet, in accordance with the Institutional Review Board (IRB) requirements. This pre-activity questionnaire targeted baseline information related to the students' background experience. The initial grouping of questions targeted professional experience as well as the students' industry experience working with BIM. Secondary questions used a seven-point Likert-scale to understand the students' knowledge of and experience with: BIM, BIM process mapping, and; the role of PxP in BIM implementation. The pre-activity assessment concluded with subjective questions to understand the students' experience working with BIM and PxP, as well as their overall comfort with process mapping.

In addition to the pre-activity questionnaire, the pre-activity documentation included an informed consent form, in accordance with IRB requirements. Students were required to complete the in-class process mapping activity for course credit, but could elect to not allow their responses to be used for research purposes. Because the instructor for the course was also involved in this research, a graduate research assistant, who was not involved with course grading, administered all pre-activity documentation while the instructor was not present in the classroom. Furthermore, this graduate research assistant maintained possession of all research activity documents until the end of semester after grades were posted. Use of an impartial third party, the graduate student, encouraged candid, anonymous responses from the students.

### **Process Mapping Activity:**

Once the students had completed all pre-activity assessments, they were given the actual learning activity documentation consisting of one Level 1 and one Level 2 process map template. The learning activity included several different phases. To better understand what and when students considered when completing these different components, a color-coding approach was developed. Colored pens were distributed and collected at three transition points during the activity. A black pen was provided when students developed their initial level 1 and 2 maps. A blue pen was used by students when reviewing their peer's work. Finally, red pens were used by students after the peer review, when students were allowed to reflect on the feedback received by their peer on their original process map.

Students were given five minutes to complete a Level 1 process map specific to the 4D phase of BIM execution. Upon completion of this activity an additional ten minutes were provided to complete a Level 2 process map for Phase Planning (4D Modeling). This level 2 map challenged students to consider the detailed roles and responsibilities necessary for 4D BIM implementation. While this first phase of the activity encouraged students to spend approximately 5 minutes on the simplified Level 1 process map and 10 minutes on the detailed Level 2 process map, students maintained possession of both process maps. The retention of both process maps enabled the student to make modifications to either map as they worked through what they believed to be the necessary workflow for implementation. The objective of this activity was to better assess the student's knowledge of PxP as it relates to the exchange of information.

Once the initial process maps were complete, black pens were collected and blue pens were distributed. Students were then instructed to exchange their developed maps with a peer and review their peer's work using the blue pen provided. Although peer feedback was at the discretion of the reviewer, students were instructed to focus on the flow of information, content of the dialog box, and the exchange of information as documented by the map author. The peer review was intended to provide students with an opportunity to analyze a different process map after having created one on their own. The responses generated during this phase helped to identify disparities in the comprehension of the subject matter.

After students completed the peer-review activity, blue pens were collected and red pens were distributed. Students were instructed to review the feedback they received on their original process maps, incorporating changes as they deemed appropriate, and provide additional commentary as necessary.

At the conclusion of the mapping exercise, the Instructor and TA were again excused from the room and a post-activity questionnaire was administered by the proctor. The post-activity assessments included several similar questions as the pre-activity assessments related to process mapping understanding. Additionally, the post-activity questionnaires elicited responses from the students related to their perceptions of the peer-review process mapping activity. These subjective, open-ended responses helped to support or question the findings from subsequent data analysis. Students submitted their completed post-activity questionnaire at the conclusion of lecture.

### **Data Analysis:**

After the activity was completed, the collected data was organized and refined to include only responses from students who consented to the research and completed all activity components. Of the twenty Likert questions asked in the post-activity survey, a total of twelve pre- and post-activity questions were matched for a paired analysis of the findings. Evaluation of the data was completed using a paired, two sample statistical analysis with an alpha greater than .05 supporting the null hypothesis. Of the twelve paired questions, three resulted in a refuted null hypothesis indicating a measurable change occurred as a result of the process mapping activity.

## **4. RESULTS**

A total of thirty-six students consented to allowing their responses to be used and also completed all questionnaires and process maps. The class was comprised primarily of Seniors, along with seven Juniors and two Graduate students. Industry experience averaged 26.2 months with a median of 12 months' experience. Of those students having experience, no student claimed to have any experience process mapping a BIM implementation.

Four of the paired questions addressed the educational aspect of PxP to include purpose, structure, and goals. These questions related to the students understanding of activities to include the ownership of and planning for activities. Results of the pre- and post-questionnaire showed a measurable shift with regard to the students' ability to organize parallel and overlapping activities. The pre-questionnaire assessment specific to this educational ability resulted in a mean score of 4.7 with a variation of 1.4. The post-activity mean score of 3.8 and variance of 3.8 generated a paired two tail value of 0.0057 suggesting a measurable change as a result of the activity. The three remaining questions related to education had a mean paired two tail value of 0.172 which did not indicate measurable change in the students understanding of BIM/PxP as a result of the activity.

Two of the pre- and post-questions were designed to address the concept of identification and application of specific BIM uses most suitable for construction implementation. This assessment showed no measurable change resulting from the activity with a mean paired two tail value of 0.383. Results of the study did however reveal a variance increase of approximately 0.8, an average change of 36%, indicating the students' confidence level with respect to their understanding of the subject matter varied widely as a result of the activity.

Managing is the third contributing factor affecting the students overall understanding of cross disciplinary collaboration, and the survey's addressed this topic in three paired questions. Although two of those questions returned no measureable change, the third question yielded results suggesting a measureable decline in confidence as a result of the activity. Researchers asked the students if the process mapping activity improved their understanding of the communication requirements necessary to execute a BIM project. This question resulted in a paired two tail score of 0.009 which would indicate a measurable change in understanding.

The final contributing factor as measured by the pre- and post-activity questionnaire, captured the introduction to and application of BIM authoring tools. Unlike the first three contributing factors assessed by the survey, the students' understanding of process map authoring seems to have changed positively after the learning activity. The average mean score increased from 2.37 in the pre-activity questionnaire to 3.16 in the post-activity questionnaire. The measurement of variance however, aligned with the trend having an increase averaging 0.828 or approximately 25%. This may indicate confusion on the part of the student, or indicate the students' inability to assess their comprehension of the subject matter. One authoring question asked the students to rate their ability to draft a process map dialog box. The collected data showed a measurable change in their responses to this (P-Value = 0.0002). In contrast to the positive change as measured from the questionnaires, of the eighty-two Level 1 and 2 process maps submitted only twenty-two or 27% correctly depicted a process map dialog box in accordance with the template.

In total, three of the twelve paired questions were shown to have a measurable change as a result of the peer-review activity. The research was successful in capturing the students' realization of the limitations of their knowledge regarding the complexity of PxP. Overall, eight of the twelve assessments resulted in a perceived increase in understanding of the subject matter, although seven of the eight questions were not measured as a statistically significant change. A secondary measure viewed as successful was the impact of the peer review in enabling critical thought with regard to the process maps. Of the process maps submitted 63% were edited by the author as a direct result of peer review feedback.

## 5. DISCUSSION

In reviewing the students' process maps, it appears that processes for defining 4D Modeling and project-level informational exchanges may still be abstract concepts to many students. Completed process maps were reviewed for the placement of 4D Modeling in relation to the phases of the project. A secondary review focused on the flow of information between 4D Modeling and supportive informational exchanges. Based on the placement of 4D Modeling within the template map, 29% of the students demonstrated a lack of understanding. It is unclear if this perceived educational gap is representative of the students' understanding of 4D Modeling as a deliverable or if the deficiency is associated with an understanding of 4D Modeling in the context of a project. An observation of student feedback collected from the peer review included comments as such:

*“It [Level 1 Process Map] should end with 4D Modeling as the last task”, and*

*“[I] Thought all the activities were leading to 4D Modeling”*

The process maps and subsequent peer review comments indicated the students did not have a clear understanding of the purpose of 4D Modeling and the information exchanges required to develop that deliverable. A future iteration of this research may address this challenge by choosing a BIM use for students to plan other than 4D Modeling. Additionally, the observed results suggest potential benefits to truncating the hypothetical project timeline, thus simplifying the placement of the BIM activities.

A secondary limiting factor appears to be the students' familiarity with process mapping. The class was introduced to process mapping as a business tool during a class lecture prior to the research activity. In this lecture students were asked to create a dialog box documenting Author, Phase, BIM Use, and Deliverable Name. Students were then introduced to the concept of information flow as defined by “inputs” and “outputs” to the dialog box. A final topic of lecture was the placement of swim lanes indicating Reference Information, Process and Information Exchange thus completing the map.

The students' retention of the process mapping lecture material may have hindered their ability to meet the expectations of the learning activity. The mean student response rate of 2.7 specific to the pre-activity question “I am fully prepared to create a Level 1 Process Map” indicates a low level of confidence in the ability of the class. After completing and reviewing peer review feedback, the post-activity mean rose to 3.2, but this did not illustrate a statistically significant change (p-value = 0.108). This further suggests that



there is an opportunity to refine this activity to better address the students' lack of confidence in their process mapping abilities.

Approximately 34% of the process maps created in the study failed to use dialog boxes as a method for documentation. Of those maps where dialog boxes were used, an additional 30% failed to clearly indicate a flow of information. These two measurements serve as additional justification of a perceived educational gap specific to process mapping. The written comment provided by one student, "I can't critique because I'm not sure I understand it", appear to have been a common thread among students based on the peer review commentary.

Lessons learned as a result of observation and student feedback which may impact the results of future iterations of the study include changes to the process mapping template and a change to the targeted BIM phase. Student comprehension of 4D modeling may have impacted the ability to effectively map the activity and capture PxP in support of the BIM phase. Replacing the BIM phase from 4D Modeling to a more easily understood BIM phase, such as 3D Modeling, would not compromise the intent or integrity of the research. Future iterations of the process map template should limit the phases of construction, as called out by vertical lines of demarcation, to align with the BIM phase. Having called out "operate", essentially facility management, may have added an unwarranted degree of complexity as 4D Modeling would have completed well before entering a sustaining state.

## 6. CONCLUSION

The study, to include process mapping, peer review, pre and post surveys, provided valuable insight into the pedagogical approach of CON 453. Of the four areas of cross disciplinary collaboration assessed, a measurable change was identified in the students' ability to organize parallel and overlapping activities, their ability to create a process map dialog box, and their understanding of the communication requirements necessary to execute PxP supporting BIM implantation.

An intended outcome of the research was evaluating the students' comprehension of the complexity associated with organizing parallel and overlapping activities associated with a PxP. The declining change in self assessment indicates that students may have had a false sense of understanding with respect to these concepts prior to beginning the activities. Further research is needed to understand if these concepts were not fully understood as a result of the curriculum or the data simply reflects a knowledge gap specific to process mapping.

The ability to create a dialog box as part of a process map is a result of an in class lecture addressing the subject. While the measure of change in assessment of this skill was positive, the students' assessment of their ability to create Level 1 and 2 process maps failed to show an equally positive measurable change. Furthermore, student narratives would indicate process mapping as a business tool documenting workflow is not fully understood. However, the positive attributes of transitioning conceptual information into a written document is a valid assessment of skills warranting an increased role of process mapping in further sessions of CON 453.

A third finding of interest was a perceived inability to effectively identify and communicate the informational exchanges necessary for BIM implementation. This educational gap may be a result of the homogeneity in the student population, as 76% of the students are enrolled through the Construction Management program. A secondary contributing factor may be a lack of industry experience. Results of the pre-activity survey indicate the average industry experience to be 26.2 months, but the students in this study were not exposed to cross collaboration as part of that professional experience.

Future iterations of the study must address the educational deficiencies which may have contributed to a lack of understanding. The concept of embedding scheduling information within a BIM entity and the value add the 4D model brings to a project appear to be abstract concepts, as indicated by the process maps. Furthermore, the skill of creating a process map and using that map as a method of clearly communicating PxP is out of reach for many of the students enrolled in CON 453. Although the path of least resistance may involve a change in the targeted BIM deliverable, shifting away from 4D to more easily understood concepts, class curriculum specific to the understanding of 4D modeling warrants additional review and

modification. Process mapping may be introduced as a tool to better understand informational exchanges, rather than an instrument of study.

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# BUILDING INFORMATION MODELING SKILLS FOR CAREER SUCCESS

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## ABSTRACT

Building Information Modeling (BIM) efforts have been increasing in the Architecture, Engineering, Construction, and Operations (AECO) fields. Many research efforts focus on BIM education to develop educational modules that can provide students the necessary skill sets for both career and project success. However, limited understanding about a few questions related to BIM education and implementation in real projects might impede the construction industry from effective BIM workforce development. These questions are: 1) What skills are correlated with BIM skills? 2) Do people who possess more BIM skills have a higher likelihood, or decrease in years of becoming a project manager? 3) Do people who possess more BIM skills also possess other typical skills that are not BIM skills and do these increase the likelihood, or reduce the time to becoming a project manager? This research identifies the BIM skills, and their relationship to project manager titles through an analysis of AECO professionals' social media pages on LinkedIn. The authors collected their endorsed skills and number of endorsements, current and past positions and years of work experience. The data was analyzed to identify BIM skills and the trends between BIM skills and project manager titles. The results illustrate an indirect relationship between BIM skills and project manager titles. This does not necessarily mean that BIM skills do not have value to individuals' career success. Instead, it may suggest that the newness of BIM technology might influence the lack of correlation between BIM skills and project manager titles. To better understand this relationship, future research will perform follow-up studies to understand whether BIM skills might lead to faster promotion in the long run or potentially to a different path of career advancement. This understanding can enable the education community to tailor BIM educational design to desired professional outcomes.

**Keywords:** AECO, BIM, education, social media

## 1. INTRODUCTION

A Building Information Model (BIM) is a digital representation of physical and functional characteristics of a facility (buildingSMART alliance, 2007). Implementing BIM in construction projects could result in diverse potential benefits (Bryde et al. 2013). Adequate BIM skills in project managers can be critical to implement BIM successfully (Fox and Hietanen, 2007; Gu and London, 2010; Singh et al. 2011). In addition to BIM implementation, project managers are one of the contributors to successful construction projects (Sanvido et al, 1992; Chan et al. 2004; Pheng and Chuan, 2006).

BIM education is one of the solutions to hasten the learning curve in implementing BIM by providing companies graduating students with adequate BIM skills (Young et. al., 2008). The education community has started to integrate BIM into the Architecture, Engineering, Construction, and Operations (AECO) curricula to assist the industry demand for engineers with BIM skills (Barison and Santos, 2010; Becerik-

Gerber et al. 2011). This integration includes creating BIM courses and experimenting BIM pedagogic strategies to incorporate BIM into the curricula (Wu and Issa, 2013).

However, limited understanding about a few questions related to BIM education and implementation in real projects might impede the construction industry from effective BIM workforce development. These questions include: *1) What skills are correlated with BIM skills? 2) Do people who possess more BIM skills have a higher likelihood, or decrease in years of becoming a project manager? 3) Do people who possess more BIM skills also possess other typical skills that are not BIM skills and do these increase the likelihood, or reduce the time to becoming a project manager?* Answering these questions can help: Students to find out the skills they should learn; Industry to identify suitable candidates for certain positions needed in their BIM projects; And universities to customize their design of BIM courses according to specific industry needs.

This research analyzes AECO professionals' social networking profiles from LinkedIn to identify BIM skills, and the relationship between BIM skills and project manager titles. The authors collected their endorsed skills and number of endorsements, current and past positions and years of work experiences. Then, analyzes the collected data to identify BIM skills. Finally, identifies the trends between BIM skills and project manager titles.

## 2. METHODOLOGY

### 2.1 Overall approach

To answer the research questions, the authors explored and analyzed professionals' social media profiles from LinkedIn. This data source was selected because it is the most preferential social networking platform for business professionals (Forbes, 2012). The authors chose this type of data as an alternative to reporting methods such as interviews and questionnaire surveys. A structured system was developed using Python to collect the data on 14 November 2015 and 17 November 2015.

From the information collected, the authors categorized the endorsed skills into two categories: (1) BIM skills; and (2) other skills. Skills that had at least a positive low correlation with a "BIM" endorsement were considered for this research to be "BIM skills". Skills that had less than a positive low correlation with "BIM" were considered to be "other skills". The following sections describe the method of collecting and analyzing the data in this research.

### 2.2 Data collection

This research identifies individuals by using the search feature in LinkedIn. Figure 1 shows the steps taken in filtering the profiles. The search feature only allows one thousand profiles per search query. Therefore, the authors used the industry filter to further refine the results. This divides each search result to less than one thousand profiles per search during data collection. This research considers only profiles from Phoenix, Arizona to explore the local trend, which may facilitate Arizona State University's learning objective of adopting personalized learning practices.

The data collection focused on the following parameters in each individual's profile: (1) Name; (2) Current location; (3) Current industry; (4) Endorsed skills and number of endorsements; (5) First year of employment; (6) Earliest year having **only** the title "project manager"; and (7) Earliest position and year having **any title** containing "project manager" term. The authors collected the first three parameters to validate and remove duplicate profiles, profiles outside Phoenix and profiles not within the architecture & planning, construction, design or civil engineering industry. While, the other four parameters were used for data analyses.

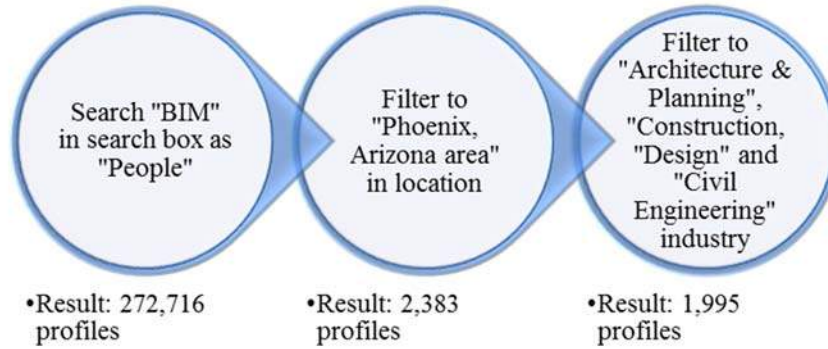


Figure 1: The steps performed to filter profiles in LinkedIn

After collecting the data, the data was screened for duplicate profiles and skills. The skills feature in LinkedIn allows members to list skills in a free manner. Thus, the authors grouped together skills that differed based on their text case or additional special characters. For example, “3D Modeling”, “3D modeling”, “3D-Modeling” and “3D-modeling” were grouped into one group of “3D modeling”. Then, the authors removed skills that were endorsed for less than 2.5%, and for more than 97.5% from the total number of profiles. This truncates the skills to be possessed by 95% of the population.

### 2.3 Data analysis

During data analyses, this research defines all titles with the title “project manager” excluding assistant project manager and intern project manager as project manager titles. This includes project manager titles with multiple titles such as “estimator/project manager” and project manager titles with sub-specializations such as “architectural project manager.”

Assistant project manager titles were analyzed separately due to the different responsibilities of the position, which is to assist one or multiple responsibilities of project managers; while project manager is the ultimate person that is responsible for the whole project (PM4DEV, 2007). Although assistant project managers do not necessarily have the same roles as project managers, they may become a project manager in the future as their careers develop. Thus, this research also analyzes the relationship between BIM skills and assistant project manager titles.

This research analyzed the relationship between BIM skills and both project manager and assistant project manager titles by performing two approaches. The first approach uses bivariate correlations to calculate the correlation coefficient between the number of endorsements of each endorsed skill and all other skills. The same approach was used to calculate the correlation coefficient between the number of endorsements of each endorsed skill and the number of years taken to attain the titles. The correlation coefficient value represents the intensity of the relationship between two variables. From the intensity of correlation as defined by Weber and Lamb (1970), this research considers correlation coefficients with at least low correlation ( $\geq 0.20$ ) as correlated. Here, the authors identifies BIM skills, which are endorsed skills that have at least a positive low correlation with a “BIM” endorsement. Then, the relationship between BIM skills and the decrease in years of having the titles were analyzed. This research also analyzed the correlation coefficients between BIM skills and other skills. The analysis was attempted to further understand the relationship between BIM skills and other skills that are linked with the titles.

The second approach uses binary logistic regression to analyze the relationship between the number of endorsements for each endorsed skill towards the title project manager and assistant project manager. There were two groups during this analysis: number “1” represents the satisfaction of the definition, while “0” for the opposite. Here, we analyzed the relationship between BIM skills and the likelihood of having the titles.

### 3. RESULTS AND DISCUSSION

Table 1 summarizes the characteristics of the collected data. During data collection, 1,784 profiles from 1,995 profiles (90%) were accessible. After data reduction, 1,543 profiles remained for data analysis. A total of 2,787 skills were possessed by these individuals. None of these skills were possessed by 97.5% or more of the individuals. After removing the skills that were possessed by 2.5% or less of the individuals, 133 skills remained. These 133 skills were analyzed to determine their relationship to career success.

Table 1: Summary of the data collected

Characteristics	Number of observations	Characteristics	Number of Observations	Min	Max	Average
Profiles	1,543	All skills	2,787			
Industry		Endorsed to less than 2.5%	2,654			
Architecture & planning	683	Endorsed between 2.5% and 97.5%	133			
Construction	655	Endorsed to more than 97.5%	0			
Design	127					
Civil Engineering	78	Skills within 95% confidence interval	133			
Title		Endorsements	205,219	0	362	1.20
Project manager (PM)	431					
PM	257	Years				
PM with multiple titles	108	Of experience	1,530	0	56	15.96
PM with sub-specializations	66	In having PM title	431	0	40	5.01
Assistant PM	45	In having assistant PM title	45	0	18	5.80

#### 3.1 Skills coexist with the skill “BIM”

Table 2 shows the correlation coefficients between skills that have at least a positive low correlation with “BIM” and other skills listed. Correlation coefficients with “\*” represents correlation coefficients that are statistically significant at  $\alpha = 0.05$ . Bolded correlation coefficients represents correlation coefficients having at least a positive low correlation ( $\geq 0.20$ ) and statistically significant at  $\alpha = 0.05$ . “Revit”, “CAD” and “3D” have a positive moderate correlation (0.40 to 0.69) with “BIM.” “Steel detailing”, “Navisworks”, “submittals”, “modeling”, “construction drawings”, “AutoCAD”, “sustainable design”, “metal fabrication”, “renovation” and “steel” have a positive low correlation (0.20 to 0.39) with “BIM.” These skills and “BIM” are the skills that the authors consider as BIM skills.

Table 2: Correlation coefficients between BIM skills and other skills that increases the likelihood or decreases the years of having the title project manager or assistant project manager

Analysis	BIM	Project manager	Assistant project manager										
			Architectural drawings	Architectures	Comprehensive planning	Design management	MEP	Microsoft Office	Microsoft Word	MicroStation	PowerPoint	Site plans	Tenant improvement
Skills correlated with “BIM”/ Other skills	BIM	Zoning											
3D	<b>0.430*</b>	-0.011	0.017	-0.007	-0.030	0.139*	0.033	0.096*	0.063*	0.168*	0.040	0.016	-0.022
AutoCAD	<b>0.299*</b>	-0.036	<b>0.226*</b>	-0.012	-0.044	0.011	0.170*	<b>0.405*</b>	<b>0.253*</b>	<b>0.307*</b>	<b>0.270*</b>	0.085*	-0.088*
BIM	<b>1</b>	-0.002	0.112*	0.077*	0.082*	0.122*	0.127*	0.019	0.012	0.122*	-0.004	0.028	-0.001
CAD	<b>0.484*</b>	-0.030	0.172*	0.014	-0.049	0.111*	0.165*	<b>0.292*</b>	<b>0.207*</b>	<b>0.258*</b>	<b>0.207*</b>	0.090*	-0.066*
Construction drawings	<b>0.343*</b>	0.143*	<b>0.368*</b>	0.186	<b>0.214*</b>	<b>0.222*</b>	0.127*	0.059*	0.009	0.091*	0.005	0.181*	0.123*
Metal fabrication	<b>0.228*</b>	-0.010	-0.040	-0.022	-0.029	-0.013	-0.001	-0.011	0.003	-0.011	0.001	-0.017	-0.016
Modeling	<b>0.346*</b>	-0.006	0.023	-0.002	-0.021	0.000	-0.008	0.097*	0.067*	0.133*	0.061*	0.020	-0.022
Navisworks	<b>0.382*</b>	-0.023	0.022	-0.044	-0.062*	<b>0.204*</b>	<b>0.245*</b>	0.020	-0.009	0.100*	-0.007	0.029	-0.041
Renovation	<b>0.215*</b>	0.067*	0.146*	0.068	0.137*	0.056*	0.001	-0.001	-0.038	-0.024	-0.037	0.050*	<b>0.335*</b>
Revit	<b>0.534*</b>	-0.026	<b>0.210*</b>	0.090	0.088*	0.055*	0.127*	0.145*	0.080*	0.159*	0.092*	0.002	-0.058*
Steel	<b>0.206*</b>	-0.012	-0.048	-0.020	-0.019	-0.014	-0.023	-0.018	-0.012	-0.010	-0.014	0.012	-0.011
Steel detailing	<b>0.388*</b>	0.006	0.035	0.019	0.002	0.032	0.015	0.005	-0.012	0.007	-0.014	0.006	-0.019
Submittals	<b>0.367*</b>	<b>0.203*</b>	<b>0.291*</b>	0.194	<b>0.332*</b>	0.109*	0.056*	0.001	-0.015	0.015	-0.013	<b>0.200*</b>	0.157*
Sustainable design	<b>0.255*</b>	0.070*	<b>0.316*</b>	<b>0.324*</b>	<b>0.421*</b>	<b>0.036</b>	-0.065*	-0.048	-0.046	-0.034	-0.023	0.083*	0.152*

\* Represents statistically significant at  $\alpha = 0.05$ .

**Bolded** represents having at least a positive low correlation ( $\geq 0.20$ ) and statistically significant at  $\alpha = 0.05$ .

### 3.2 Relationship between BIM skills and “project manager” titles

Table 3 shows the likelihood of having the title project manager or assistant project manager for each additional endorsement of BIM skills. Each additional endorsement for “steel detailing”, “construction drawings” and “modeling” results in a 9.1%, 5.6% and 4.3% increase in the likelihood of having the title project manager, respectively. These increases were higher than other BIM skills. Each additional endorsement for “3D”, “renovation” and “Revit” increase the likelihood of having the title assistant project manager by 24.2%, 15.7% and 8.8%, respectively. Also, these increases were higher than other BIM skills. From these results, BIM skills increases the likelihood of having the title project manager and assistant project manager, the highest at 9.1% and 24.2%, respectively.

Table 3 also shows the correlation coefficients between BIM skills and the decrease in years of having the title project manager or assistant project manager. BIM skills have either positive slight correlation (0 to 0.19) or negative slight correlation (-0.19 to 0) with the decrease in years of having either title. The results indicate that BIM skills have a weak relationship with the decrease in years of having the title project manager or assistant project manager. This analysis does not suggest that there is a direct relationship between possession of BIM skills and quicker promotion to project manager.

Table 3: Logistic regression results on having the title and correlation coefficients on the decrease in years of having the title project manager or assistant project manager for BIM skills

Analysis	Logistic regression								Correlation	
	β <sup>a</sup>	S.E. <sup>b</sup>	Wald <sup>c</sup>	df <sup>d</sup>	Sig. <sup>e</sup>	Odds ratio Exp(β) <sup>f</sup>	95% C.I. for odds ratio <sup>g</sup>		Pearson Correlation	
Skill/Variables							Lower	Upper		
<b>Project manager</b>										
3D	-0.051	0.039	1.730	1	0.188	0.951	0.881	1.025		0.013
AutoCAD	-0.031	0.015	4.024	1	0.045	0.970	0.941	0.999		-0.030
BIM	-0.015	0.011	1.845	1	0.174	0.985	0.964	1.007		0.002
CAD	0.004	0.017	0.043	1	0.836	1.004	0.971	1.037		-0.017
Construction drawings	0.055	0.018	9.589	1	0.002	<b>1.056</b>	1.020	1.093		0.017
Metal fabrication	0.001	0.054	0.000	1	0.990	1.001	0.901	1.111		-0.078
Modeling	0.043	0.053	0.642	1	0.423	<b>1.043</b>	0.940	1.158		-0.009
Navisworks	-0.046	0.028	2.791	1	0.095	0.955	0.905	1.008		0.052
Renovation	-0.033	0.016	3.925	1	0.048	0.968	0.937	1.000		0.028
Revit	0.008	0.012	0.494	1	0.482	1.008	0.985	1.032		-0.032
Steel	-0.020	0.030	0.430	1	0.512	0.980	0.924	1.040		-0.055
Steel detailing	0.087	0.031	8.145	1	0.004	<b>1.091</b>	1.028	1.159		0.000
Submittals	0.016	0.010	2.628	1	0.105	1.016	0.997	1.036		0.027
Sustainable design	0.000	0.013	0.000	1	1.000	1.000	0.975	1.025		-0.012
<b>Assistant project manager</b>										
3D	0.216	0.416	0.271	1	0.603	<b>1.242</b>	0.549	2.806		0.171
AutoCAD	-0.139	0.083	2.795	1	0.095	0.870	0.739	1.024		0.083
BIM	-0.018	0.058	0.099	1	0.753	0.982	0.876	1.100		0.051
CAD	-0.337	0.232	2.119	1	0.145	0.714	0.453	1.124		0.127
Construction drawings	-0.102	0.122	0.694	1	0.405	0.903	0.711	1.147		0.061
Metal fabrication	-6.107	761.687	0.000	1	0.994	0.002	0.000	-		-
Modeling	-8.731	335.892	0.001	1	0.979	0.000	0.000	-		-
Navisworks	-0.293	0.310	0.895	1	0.344	0.746	0.407	1.369		0.169
Renovation	0.146	0.084	2.977	1	0.084	<b>1.157</b>	0.980	1.365		-0.036
Revit	0.085	0.062	1.865	1	0.172	<b>1.088</b>	0.964	1.229		0.032
Steel	-0.178	0.348	0.261	1	0.609	0.837	0.423	1.657		0.024
Steel detailing	-0.032	0.419	0.006	1	0.940	0.969	0.426	2.203		0.173
Submittals	0.003	0.047	0.005	1	0.944	1.003	0.914	1.101		-0.135
Sustainable design	-0.141	0.145	0.948	1	0.330	0.869	0.654	1.153		0.087

<sup>a</sup> β = logistic coefficient; <sup>b</sup> S.E. = standard error of estimate; <sup>c</sup> Wald = Wald chi-square values; <sup>d</sup> df = degree of freedom; <sup>e</sup> Sig. = significance;

<sup>f</sup> Odds ratio Exp(β) = exponentiated coefficient; <sup>g</sup> 95.% C.I. for odds ratio = 95% confidence interval for odds ratio.

### 3.3 Relationship between other skills and “project manager” titles

Table 4 shows other skills that having at least a positive low correlation with BIM skills, while increases the likelihood of having either a “project manager” or “assistant project manager”, or having at least a positive low correlation with the decrease in years of having either title. “Zoning” increases the likelihood of having the title project manager; while “architectural drawings”, “architectures”, “comprehensive planning”, “design management”, “MEP”, “Microsoft Office”, “MicroStation”, “site plans” and “tenant

improvement” increases the likelihood of having the title assistant project manager. No skills have at least a positive low correlation with the decrease in years of having the title project manager; while “Microsoft Word” and “PowerPoint” have a positive low correlation with the decrease in years having the title assistant project manager. From these skills, “zoning” and “architectural drawings” increase the likelihood of having the title project manager and assistant project manager, the highest at 18.6% and 48.6%, respectively.

Table 4: Logistic regression results on having the title and correlation coefficients on the decrease in years of having the title project manager or assistant project manager for skills that have at least a positive low correlation BIM skills

Analysis	Logistic regression								Correlation
	$\beta^a$	S.E. <sup>b</sup>	Wald <sup>c</sup>	df <sup>d</sup>	Sig. <sup>e</sup>	Odds ratio Exp( $\beta$ ) <sup>f</sup>	95% C.I. for odds ratio <sup>g</sup>		Pearson Correlation
Skill/Variables							Lower	Upper	
Skills that increases the likelihood of having the title project manager or assistant project manager by at least ten percent for each additional endorsement									
Project manager									
Zoning	0.171	0.129	1.755	1	0.185	<b>1.186</b>	0.921	1.528	0.011
Assistant project manager									
Architectural drawings	0.396	0.159	6.196	1	0.013	<b>1.486</b>	1.088	2.029	-0.059
Architectures	0.136	0.218	0.390	1	0.532	<b>1.146</b>	0.748	1.755	0.185
Comprehensive planning	0.265	0.142	3.479	1	0.062	<b>1.303</b>	0.987	1.721	-0.016
Design management	0.340	0.319	1.135	1	0.287	<b>1.404</b>	0.752	2.623	-0.268
MEP	0.145	0.093	2.417	1	0.120	<b>1.156</b>	0.963	1.387	0.187
Microsoft Office	0.193	0.115	2.811	1	0.094	<b>1.213</b>	0.968	1.519	0.001
MicroStation	0.108	0.488	2.359	1	0.125	<b>1.114</b>	0.813	1.502	0.171
Site plans	0.295	0.378	0.610	1	0.435	<b>1.344</b>	0.640	2.819	-0.330
Tenant improvement	0.109	0.120	0.812	1	0.367	<b>1.115</b>	0.880	1.412	0.072
Skills that have at least a positive low correlation with the decrease in years of having the title project manager or assistant project manager									
Assistant project manager									
Microsoft Word	-1.281	0.638	4.035	1	0.045	0.278	0.080	0.969	<b>0.209</b>
PowerPoint	-0.268	0.659	0.165	1	0.684	0.765	0.210	2.784	<b>0.218</b>

<sup>a</sup>  $\beta$  = logistic coefficient; <sup>b</sup> S.E. = standard error of estimate; <sup>c</sup> Wald = Wald chi-square values; <sup>d</sup> df = degree of freedom; <sup>e</sup> Sig. = significance;

<sup>f</sup> Odds ratio Exp( $\beta$ ) = exponentiated coefficient; <sup>g</sup> 95.% C.I. for odds ratio = 95% confidence interval for odds ratio.

Table 2 also shows correlation coefficients between skills that having at least a positive low correlation with BIM skills. “Submittals” has a positive low correlation at 0.203 with “zoning”, which increases the likelihood of having the title project manager by 18.6% for each additional endorsement. Two BIM skills have a positive moderate correlation with skills that increases the likelihood of having the title assistant project manager for each additional endorsement. Those skills are “sustainable design” with a correlation at 0.421 with “comprehensive planning” that increases the likelihood by 30.3%; and “AutoCAD” with a correlation at 0.405 with “Microsoft Office” that increase the likelihood by 21.3%. There are also several other BIM skills that have positive low correlations with skills that increases the likelihood of having the title assistant project manager. “AutoCAD” and “CAD” have a positive low correlation with both “Microsoft Word” and “PowerPoint”, which have a positive low correlation with the decrease in years of having the title assistant project manager. The results indicate that there might be a relationship between BIM skills and skills that increases the likelihood or decreases the years of having the title project manager or assistant project manager. In other words, there might be an indirect relationship between BIM skills and project manager titles.

From the results, the authors identified “BIM”, “Revit”, “CAD”, “3D”, “steel detailing”, “Navisworks”, “submittals”, “modeling”, “construction drawings”, “AutoCAD”, “sustainable design”, “metal fabrication”, “renovation” and “steel” as BIM skills. BIM skills increases the likelihood of having the title project manager and assistant project manager at 9.1% and 24.2% the highest, respectively, while having a weak relationship with the decrease in years of having either title. On the other hand, BIM skills are correlated with other skills that are not correlated with “BIM.” These other skills increases the likelihood of having the title project manager and assistant project manager at 18.6% and 48.6% the highest, respectively, or having a positive low correlation with the decrease in years of having the title assistant project manager. These results indicate that there might be an indirect relationship between BIM skills and project manager titles.



Although the results indicate BIM skills has a weak relationship with the title project manager compared to other skills that are not correlated with “BIM”, the authors does not claim BIM skills has none or minimal value to individuals’ career success. Instead, this could indicate that the newness of BIM technology might influence the lack of correlation between BIM skills and project manager titles. On the other hand, while BIM is increasingly deployed into the current curricula, the speed of deployment also can be influenced by understanding the current situation in the real field. In this case, the question becomes is it worthy to increase the speed of deploying BIM in education or should the education community assess the impact of BIM implementation beforehand? To validate this, future researches may perform follow-up studies by checking back on individuals’ profile to understand if possession of BIM skills by assistant project managers leads to faster promotion into project managers in the long run. If so, it might indicate that BIM skills could influence career success. Conversely, if possession of BIM skills by assistant project managers do not lead to faster promotion into project managers, or it leads to other titles, future research may perform studies to understand the implications of adopting BIM education into the AECO curriculum. The output from this follow-up research may assist the education community and individuals to better understand and design the desired BIM education contents.

#### **4. LIMITATIONS AND FUTURE WORKS**

This research offers insights into the relationship between BIM skills and project management success, but it does have some limitations. The authors only analyzed profiles from Phoenix, Arizona. Ideally, profiles from other areas could have been gathered. It is possible that individuals in different locations may have different skills that are linked to BIM and project management success. Also, there were a small percentage of profiles (10%) that were excluded due to limited access to private profiles. This provides an opportunity for future research to improve the results by including profiles from other locations or analyzing all profiles that are available.

Additionally, this research focused on analyzing skills that are correlated with “BIM”, without taking into account skills that are highly regarded with the title project manager such as leadership skill and project management skill. This research attempts to understand the general relationship between BIM skills and project manager titles, therefore does not analyze the relationship between BIM skills and the different type of project managers and other skills that might have a higher significant relationship with the title project manager. Future efforts may further analyze the relationship between BIM skills and the different types of project managers, which may have different or more specified responsibilities and required skills.

Furthermore, the titles are unverified peer-reported titles since the data was obtained through social media. The information may be altered to improve the attractiveness of the individual if the profile is mainly utilized as a medium for job hunting. On the surface, this would seem to be a major limitation to this work, but if users were truly using LinkedIn as a platform to “inflate” their professional profiles, the results observed would seem unlikely. For example, if users wanted to make it look like they had more skills than they actually do, they might be inclined to accept more skill endorsements on their page. This was not observed in the collected data. There might also be a possibility for individuals that utilizes the platform minimally so that they do not list their full information including employment history or not utilize the skill feature. The authors could not validate all the data collected because this research uses observation method for data collection. Therefore, future effort should analyze the relationship between BIM skills and career success through other methods such as interviews or questionnaire surveys.

#### **5. CONCLUSION**

This research analyzes AECO professionals’ profiles to understand the relationship between BIM skills and AECO project management success. BIM skills increases the likelihood of having the title project manager and assistant project manager at 9.1% and 24.2% the highest, respectively, while having a weak correlation with the decrease in years of having either title. On the contrary, BIM skills are also correlated with other skills that are not correlated with “BIM.” These other skills increases the likelihood of having the titles the

highest at 18.6% for project managers and at 48.6% for assistant project managers, or having a positive low correlation with the decrease in years of having the title assistant project manager. These results illustrate that there might be an indirect relationship between BIM skills and project manager titles.

This research does not attempt to suggest BIM skills has a weak relationship in having the title project manager compared to other skills that are not correlated with “BIM.” Instead, this situation could indicate that the newness of BIM technology may influence the lack of correlation between BIM skills and project manager titles. To validate this, future efforts should perform follow-up studies by checking back on individuals’ profiles to understand if the possession of BIM skills by assistant project managers leads to faster promotion in a long run. The output may assist the education community and individuals to better understand and design the desired BIM education contents.

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# DEVELOPING AN INTERNATIONAL FRAMEWORK FOR BIM EDUCATION IN THE HE SECTOR

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## ABSTRACT

There has been an increased use of Building Information Modelling (BIM) over the past decades by the global construction industry. The increased use has been contributed to governments, large clients, architects, builders & contractors, & various engineering specialisms recognising its importance across the building lifecycle. The increased use by industry has seen a number of higher education (HE) institutions rethinking their Architecture, Engineering & Construction (AEC) provisions. This paper will concentrate on those institutions in Australia, USA, & the UK. There has been much debate about how BIM is currently employed in the teaching & learning of undergraduate students in Australia, USA, & the UK. The debate surrounds the inclusion of BIM as a stand alone subject in a programme, or whether BIM should be an underlying theme across the programme. Alongside this dilemma research has been conducted around theories of practice of how BIM education should look like in the future. Increased use will only increase the complexities of this debate.

This paper describes research conducted as part of an Office of Learning & Teaching funded project from the Australian Federal Government. The project is called codeBIM. The paper begins with a literature review of current theories of BIM teaching across global HE institutions in AEC. This is followed by a summary of good practice. A framework for the inclusion of BIM in undergraduate education is described – the IMAC Framework. The framework represents increasing levels of BIM inclusion at different levels of learning. These levels are: Illustration; Manipulation; Application; & Collaboration & they correspond to the increasing levels of learning across undergraduate education. The paper describes a case study of using the IMAC framework before reflections & conclusions are drawn.

**Keywords:** Building Information Modelling (BIM); IMAC Framework; Architecture, Engineering & Construction (AEC)

## 1. INTRODUCTION

Due to the success of some BIM software vendors' marketing campaigns, many members of the construction industry believe that one or more of these vendors invented or patented BIM & that by buying the vendor's software, their company is automatically 'doing BIM'. However, this is false; no single person can claim to have invented BIM, though Eastman, generally, is credited with coining the term (Yessios, 2004). BIM is process-driven & does not rely on any single piece of software to work. It does not have to be a single building model or single database. It can (more accurately) be described as a series of interconnected models & databases. The increasing adoption of BIM has been instrumental in some of the major changes that are occurring in the broader building industry. Over the past 30 years, we have witnessed

the change from the drawing board to the two-dimensional (2D) electronic CAD (computer aided design) drawing, with little change in the format of the drawings, or the process by which they are produced. The CAD drawing is still generally composed of lines that have no intelligence associated with them. Changing from 2D CAD to 3D BIM requires a shift not only in the technology used, but also in the way design & construction teams work together.

Unfortunately, some of the loudest 'BIM evangelists' have assisted in BIM washing & keeping the focus on the 3D modelling aspects of BIM. Many current BIM managers have come from a drafting background, working their way up from 2D CAD to 3D CAD to 'BIM' & commanding large salaries & elevated titles due to the demand for BIM skills. Many do not have professional qualifications beyond drafting-related qualifications, & have a tendency to approach problems from the tools/modelling perspective, not necessarily from an information-management perspective. The industry really needs to examine what skills are actually needed for the new BIM paradigm. This paper describes efforts to determine what these skills are & how they can be taught at the higher education level.

## 2. BIM IN GLOBAL AEC EDUCATION

In order for industry to change to a new, collaborative, way of working, significant changes are needed in the way future AEC professionals are educated. The current shortage of building design professionals, trained in collaborative design & construction practices, remains a barrier to universal adoption of collaborative working practices in the industry. Just as industry must undergo a paradigm shift from its old combative culture to one of integration & information sharing, so must academia.

McGraw-Hill has published various reports based on surveys of North American AEC firms. The 2009 SmartMarket Report (McGraw Hill, 2009) stated that more internal staff with BIM skills, more external firms with BIM skills, more incoming entry-level staff with BIM skills & more readily available training in BIM were required in order to realise the potential value of BIM. The 2012 report (McGraw Hill, 2012), shows slight decreases in the percentages allocated to BIM skills required (possibly reflecting uptake by the industry), but BIM training was still placed among the top three targets for investment by industry. Henderson & Jordan (2009) suggested that some of the skill-sets that modern construction professionals need to acquire, in addition to their traditional uni-disciplinary training, include: "knowledge of data management, information technology, energy & material conservation, integrated building design, systems thinking, life cycle analysis, the design processes, business & marketing skills, & project finance" (p.35).

Educators should be able to instil in undergraduates the concepts of collaborative design & the full potential of BIM, before they learn about the "old ways" of working in the industry. These new graduates would then be able to have a profound effect on the industry & to lead the charge in adopting BIM & developing innovative approaches to working practices. Many educators still view BIM as just another CAD program that students should learn in their own time. Some argue that it is not the university's role to produce "CAD technicians" & that there is no educational value in using CAD, or that CAD "threatens creativity" (e.g. Becerik-Gerber *et al.*, 2011). These concerns are reasonably justified, whereby the adoption of computers & 2D CAD has coincided with a decrease in documentation quality & productivity (Engineers Australia, 2005). However, this argument misses the point that BIM is not merely a new CAD tool or computer application: it is a new paradigm & its benefits extend much further than mere visualisation. Students cannot be expected to "teach themselves BIM" any more than they could be expected to "teach themselves structural engineering". From a pedagogical point of view, there is little difference between learning manual drafting techniques & learning 2D CAD. However, BIM provides opportunities to model every part of the design & construction process & can allow multiple design proposals to be compared & building performance to be modelled. 2D (& even 3D) CAD merely provides a way of documenting information about the building whereas BIM actually represents the building in virtual reality with all the crucial information within it. Thus, analyses can be performed with greater speed & accuracy, & design team professionals can be provided with critical information at earlier stages of the design & build process.

In addition to the resistance to using new technologies in teaching, the current structure of AEC faculties is a major barrier to collaborative teaching practice. Since engineering & architecture emerged as separate

professions from the historic job title of “Master Builder”, students of the different AEC disciplines have been educated in isolation from each other. According to Pressman (2007: p3), “...*many academic programs still produce students who expect they will spend their careers working as heroic, solitary designers. But integrated practice is sure to stimulate a rethinking of that notion. Pedagogy must focus on teaching not only how to design & detail, but also how to engage with & lead others, & how to collaborate with the professionals they are likely to work with later.*”

Starzyk & McDonald (2010) note that the focus of architectural education in the past was on developing individual skills such as being able to draw. Now, however, they state, “the importance of personal skill is yielding to the primacy of collective knowledge”. In the majority of universities in US, Europe & Australia, AEC students continue to be educated in separate departments, with little or no integration or collaboration between the disciplines. Often the first time that students from each AEC discipline are exposed to working with design team members from other disciplines is in the workplace after graduation. It is important for graduates to have an understanding of the roles played by other construction professionals & the impact that their design decisions have on projects overall. However, the isolated manner in which they are currently educated does not provide this understanding.

The complexity of modern building projects & technologies means that nobody can be a master of all anymore. Often the separate professions do not have a deep understanding of the information that each requires at different stages of a project. Time is thus wasted stripping out & even rebuilding models, when the models could have been set up more efficiently from the start of the process & unnecessary detail excluded prior to model exchange. If students are educated to work collaboratively & to learn the requirements of the other disciplines before they graduate, this level of misunderstanding is likely to be removed in future & trust improved. BIM actually provides a great opportunity to engage students more effectively & to aid understanding of how buildings are constructed. Hardy, quoted in Deutsch (2011, p202) states: “When I look at the logic of construction means & methods that BIM inherently teaches, I see the potential to educate...”. Nawari (2010) states, “students need to know how each discipline is related to the other & how one discipline impacts the other”. However, In order to bridge the disciplinary silos in industry, we need to start by breaking down the silos that exist in academia.

A potential framework for breaking down these silos is presented in the paper with an example of a case study from a construction project management programme from an Australian university is described.

### 3. RESEARCH METHODOLOGY

Quantitative methods dominated research until the late 1960s/early 1970s. After this time, qualitative methods emerged & increasingly gained acceptance, though this was not a smooth process, particularly during the period of the “paradigm wars” (Punch, 2009). Many researchers firmly adopted either a quantitative methods or a qualitative methods stance, & would never cross into the other domain. As Punch (2009, p.289) stated, “*the idea of mixing the two types of methods & data was not popular*” until the late 1980s or early 1990s, when the foundations of mixed methodology research were laid. Since this time, various researchers have sought to define what is meant by mixed methods design, & these definitions have variously focused on the methods, research processes, philosophy & design of the research (Creswell & Plano Clark, 2011). Using a mixed methods stance is a pragmatic approach to research, that generally focuses on the methods necessary to answer the given research questions. The “*fundamental principle of mixed methods research*”, according to Johnson & Onwuegbuzie (2004, p.18) is to: “*combine the methods in a way that achieves complementary strengths & non-overlapping weaknesses.*”

Johnson, Onwuegbuzie & Turner’s 2007 paper provided a composite definition of mixed methods research, based on 19 published definitions by 21 authors, which was: “...*mixed methods research is the type of research in which a researcher or team of researchers combines elements of qualitative & quantitative research approaches (e.g., use of qualitative & quantitative viewpoints, data collection, analysis, inference techniques) for the purposes of breadth & depth of understanding & corroboration...*” (p. 123). As this research study was concerned with the potential impact of the IMAC framework on collaborative learning of students, a mixed methods methodology appeared to be the most suitable.

#### 4. IMAC FRAMEWORK

The majority of the literature in this field has tended to focus too much on the learning of BIM tools, without an overarching educational purpose or curriculum framework. The aim of the research described in this paper is to develop a framework to assist academics in developing their students' collaborative working skills, using BIM tools to help, rather than just focusing on how to use specific BIM software.

Mark *et al.* (2001) proposed “the ideal computer curriculum” framework for architectural education, which modified the existing curriculum to take advantage of computing technologies without having to introduce new subjects &/or remove existing ones. In fact, they offered two alternative frameworks; one that merged technology into an existing traditional architectural curriculum, & a more radical approach that displaced some existing subjects. Both frameworks were split into Basic, Intermediate & Advanced level courses. Unfortunately, the frameworks only focused on using new computer technologies to teach modelling for visualisation or analysis within the architectural discipline alone; they did not consider collaboration with the other disciplines.

The challenge for academics wanting to educate undergraduates to be able to work effectively within a collaborative team, putting together virtual (& eventually real-life) buildings, is *when & how* to introduce elements of disciplinary knowledge, BIM technologies & development of team working skills. BIM education should be developed in stages, increasing in complexity as the students' knowledge of the building design & construction process grows (e.g. Gordon *et al.*, 2009).

In developing a framework to assist academics in developing more collaborative, BIM-enabled curricula, the approach taken followed principles of constructivism & mastery learning. In essence, constructivism holds that students “construct” knowledge based on their (active) learning experiences. A related concept (of experts assisting novices to learn) is the idea of “scaffolding” of learning, &, indeed the terms “scaffolding” & “zone of proximal development” are sometimes used interchangeably in the literature. The use of the term “scaffolding”, in relation to learning, appears to have first emerged in a paper by Wood, Bruner & Ross (1976). Bruner described scaffolding as “the steps taken to reduce the degrees of freedom in carrying out some task so that the [learner] can concentrate on the difficult skill [they are] in the process of acquiring” (Bruner, 1978, p.9, cited in Mercer, 1994). Scaffolding provides much support to learners in the early stages of developing a particular skill, thus reducing the steepness of the “learning curve”. The support gradually lessens as the student progresses, until they are able to achieve learning goals by themselves.

The term “Mastery Learning” was coined by Bloom in 1968; Bloom believed that “perhaps over 90 percent” of students could master a subject, given the right support materials & tuition (Bloom, 1968). In Mastery Learning, students are required to master a (prerequisite) simpler subject before moving on to the next, more complex one. Recent applications of Mastery Learning include the self-paced or flipped learning approach (e.g. Suen, 2014; Driscoll & Petty, 2013, Bergmann & Sams, 2012), where technologies are harnessed to allow students to work through topics at their own pace, moving on to the next when they are ready. This is an approach that could be encouraged for the earlier stages of the proposed collaborative curriculum, for topics than can be studied by students in their own time, without the need to work with others. For example, students might be required to work through online-based tutorials on certain software tools at their own pace, before they are allowed to take more complex courses requiring them to apply their software skills.

Collating the recommendations from the educational taxonomies & industry guides, a four-stage framework for implementing collaborative curricula is proposed. Part of the reason for choosing four stages was to correspond, roughly, with the typical four-year undergraduate program provided in Australia & other countries. However, the framework does not dictate in which academic year each stage should be introduced; students may start at a higher stage if they have previous experience of a topic, or may progress through two or more stages within a single course or year. Students from the different AEC disciplines study programs of varying lengths & some skills are introduced earlier in some programs than in others. For example, students of architecture tend to be introduced to modelling tools from first year whereas students of structural engineering might only be introduced to them in third year.

The four stage structure was also influenced by the revised version of Bloom's taxonomy by Anderson *et al.* (2001), & the uni-structural to extended abstract categories of the SOLO Taxonomy (Biggs, 2014). It therefore follows a constructivist, scaffolded approach to learning, with each stage building on experiences gained in the previous stage. As the IMAC framework aims to assist development of both technical (I.T & discipline-specific) & interpersonal (collaborative & teamwork) skills, it straddles the cognitive & affective domains of Bloom's Taxonomy. The expanded framework considers suitable delivery methods at each stage, aiming to achieve deeper levels of learning & understanding as a student progresses through their education. Koltich & Dean (1999), described two paradigms of teaching; the transmission model & the engaged critical model. The latter emphasises the need for students to engage with what they are studying & thus develop a deeper level of understanding, & promotes the use of teaching methods such as problem based learning.

The four stages of the IMAC framework are described in detail, below. The corresponding categories from the revised version of Bloom's Taxonomy of the Cognitive Domain (Anderson *et al.*, 2001) & Affective Domain (Krathwohl *et al.*, 1964) are shown in brackets. The descriptions include suggestions as to how BIM tools may be used to assist teaching & learning at each stage.

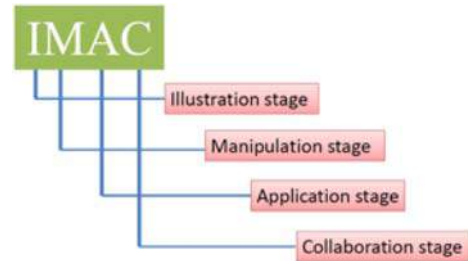


Figure 1: The IMAC Framework

#### *Illustration Stage* (Remember/Understand & Receiving/Responding)

This is an introductory stage. Building Information Models may be used to illustrate key concepts to students & students will typically be taught in their separate disciplines at this stage. Models will have sufficient detail to allow lecturers/tutors to highlight different components/connections to show how buildings are constructed, insulated & waterproofed for example. Students are introduced to basic concepts such as what BIM is, how the industry is changing, their role in the industry, & the role of the other disciplines. They will start to work on small (basic) projects with other students from their own discipline, with guidance on what is required to be an effective team worker.

#### *Manipulation Stage* (Understand/Apply & Responding/Valuing)

At this stage, students start to interact with & manipulate existing models themselves. They will be required to make simple changes &/or create basic elements within the models in relation to their disciplines. They are also continuing to develop their teamwork & basic IT literacy skills, in addition to developing discipline-specific knowledge.

#### *Application Stage* (Analyse/Evaluate & Valuing/Organising)

At this stage, students have acquired basic theoretical knowledge in their disciplines & are starting to apply this knowledge to solve discipline-related problems. For architecture students, they will start to build models from scratch & learn how to set the models up for effective inter-disciplinary collaboration. Engineers will start to use tools to analyse models using exports from models. Construction managers will develop 4D & 5D schedules, & plan logistics & materials ordering using models from other disciplines. All disciplines will be taught principles of Value Engineering & Sustainable design & how BIM tools can be used to assist these. They will also be introduced to the roles that the other disciplines play in a construction team, & how models are set-up to facilitate information exchange.

#### *Collaboration Stage* (Evaluate/Create & Characterising)

At this stage, the students from the different disciplines come together to work on joint projects. Ideally this will involve groups containing a student from each AEC discipline. Learning through teaching others can be encouraged by pairing senior engineering & construction students with junior architecture students, for example. Ideally, real-world problems will be given to the students to solve. To ease students into the process, they can be given partly-finished models to start with, & then be asked to make some changes to

these models due to “new project information” arising. The students will also learn about the types of contract that facilitate BIM & collaborative working, & will continue to learn about group dynamics & improving teamwork.

Having discussed the development of the framework, the next stage of the paper describes using the IMAC framework to develop the curriculum of a course that involved students from each of the AEC disciplines. The *Design Team Management* course offered within the Construction Project Management (CPM) degree program at the University of Technology, Sydney was used as a case study for this purpose.

## 5. CASE STUDY

As Felder *et al.* (2000, p.2) stated, “...the literature is full of articles by professors who have tried new methods & written about the results. However, the validity of a method must remain suspect if the only evidence on its behalf is one person’s testimony that “I tried this & liked it & so did the students...”. Educational research typically proceeds following either a paradigm-driven approach or a pragmatic approach (Punch, 2009). The former approach involves selecting a paradigm, describing it clearly, & then developing suitable research questions & methods aligned with that paradigm. The pragmatic approach, on the other hand, starts with defined research questions, & then methods are selected that are likely to yield answers to these questions. The authors realise that, while it is important to reflect on the philosophical underpinnings of any research project, their own preference initially was to adopt a pragmatic approach; starting from the basis of the research question, & then adopting the most appropriate methods to answer this question. However, after studying the various paradigms & arguments for their use, it was concluded that the proposed research questions, & the authors own observations of teaching & learning in practice, fitted the constructivist paradigm most closely. It is a paradigm that is widely accepted in education research, & is also linked to the type of small sample, human-centric research that would be most likely to yield answers to the particular research question outlined in this paper.

The *Design Team Management* course is core (required) within the CPM degree, but it is also offered as an elective course for students in Architecture, Interior Architecture & Civil Engineering degrees. Consequently, the student cohort that takes the course represents all of the AEC disciplines. The *Design Team Management* course was chosen as the case study for several reasons:

- A member of the authors of the paper was the sole coordinator & lecturer for the course & therefore had a good level of control over content & structure;
- The course is the only course currently taught at UTS that includes students from all three of the AEC disciplines, & one of the very rare examples worldwide of an undergraduate course that includes all three disciplines from across separate Schools & Faculties;
- The course corresponded to IMAC stage level “C” (Collaboration) & could therefore provide results related to both the effectiveness of the framework as a curriculum design tool, & as a tool for improving students’ collaboration skills.
- The course was split into twice-weekly sessions in Autumn 2014, allowing for comparison between a large class format “control” group & a smaller studio class format “IPD” group within the same cohort of students.
- The assessment tasks allowed for the gathering of a large quantity of data without appearing too obtrusive in questioning of the students

The case study offering of *Design Team Management* was delivered in the Autumn (first) semester of the third year of the CPM program in 2014. When the author took over the (elective) original course, it had no fully established structure or content, & the teaching format consisted of traditional-style lectures, with a final essay-based exam as the main assessment task. Topics covered themes around management & team practices in construction. The course had not been very popular with students, receiving fairly low feedback scores (below 3/5 overall). The author was thus given relative freedom in how to deliver the course, though the School administrators emphasised their wish to “include BIM”, while not specifying how exactly they



wanted that to be done. This course therefore appeared to be a good choice for implementing & testing the principles of the IMAC framework for curriculum design, as described above.

The course as taught for the case study involved two separate versions taught on Tuesday & Thursday evenings over a 12 week semester. The Tuesday night class was delivered in “*blended learning mode*”. The first hour was dedicated to student-led assigned topic discussions. The students were each assigned 3 topics spread over the course of the semester. Each week, assigned students had to present their topic to their small groups based around working pods. This was followed by them facilitating a discussion related to that topic, & summarising the outcomes of the discussion. Each topic was given 30 minutes to conclude, before swapping to the following topic. The following hour, either the author or a guest would deliver a lecture or practical demonstration or case study presentation on a topic related to the following week’s student discussion topics (maintaining consistent themes over the course of the semester).

The Thursday night class involved students working in multidisciplinary groups of 3-6 students. The groups were given a basic (architectural) Revit model provided by final year architecture students from the Queensland University of Technology. The students were given some basic parameters & asked to determine their own final project scope based on these minimum requirements & their group size/experience. They then worked on this project brief for the remainder of the semester.

The majority of the students attending the *Design Team Management* course in 2014 were studying CPM. There were 86 students in the class. There was one architecture student (1.16%), five engineering students (5.81%) & 80 construction management students (93%) that made up the class. The rest of the students were all at undergraduate level, with the number of students in each year level being: second year 3.28%, third year 83.6%, fourth year 11.5% & postgraduate 1.64%. The prior BIM & collaborative experience of the students is important to the results of the case study. The third year CPM students had generally all been exposed to some BIM concepts (at Illustration to Manipulation level), & a smaller number of the full time students who had taken Digital Design & Construction 1 had used tools such as Revit & Navisworks (at Manipulation to Application level). The sole architecture student was a (mature-age) fourth year student, & had had the greatest exposure to Navisworks (& other modelling & rendering tools such as Rhino & Grasshopper).

### 1.1 Assessment Instrument

The curriculum assessment instrument used was similar to that described by Mills (2002), based on earlier work by Rosier & Keeves (1991), Treagust (1987) & Goodlad (1979). Rosier & Keeves (1991) had adopted the framework for a global investigation of science & mathematics education in schools. Goodlad’s (1979) original tool was based on the premise that there is not one, but several different views of any curriculum, depending on the viewpoint considered. It has been shown (e.g. Prawat, 1992), that instructors will typically interpret a new curriculum based on their own epistemologies & that the actual curriculum delivered may be a variation of that intended. Treagust (1987) modified Goodlad’s original evaluation instrument to include the perceptions of students, & van den Akker (1998) further modified it to include the learning outcomes achieved (Friedel & Treagust, 2005).

The instrument, as adopted for the research described in this paper, divides the curriculum development & implementation into four stages: intended; implemented; perceived; & achieved. Mills (2002) summarised the details of the stages, see **Table 1**. Some authors have used slightly different names for each of the stages, but the same intent is implied. Jackson (1992) described a similar four-step approach (in brackets in Table 1) to evaluating the curriculum, he suggested: official; enacted; delivered; & experienced.

There were a number of methods adopted to collect the information for the analysis. These included: classroom observation, note-taking, tutor discussions; student blogs; pre & post course questionnaires; focus groups; & artefact review. Results are still being worked on and it is the intention of the authors that these will be discussed in future papers.

Table 1: The four stages of curriculum used for evaluation (adapted from Mills, 2002)

Stage	Description
Intended (Official) Curriculum	The original vision underlying a curriculum, possibly in the form of a national curriculum document or accreditation criteria. Within a particular course, this may be presented in the form of a course document
Implemented (Enacted) Curriculum	The actual instructional process as implemented
Perceived (Delivered) Curriculum	The actual learning experiences as perceived or experienced by the students
Achieved (Experienced) Curriculum	The resulting learning outcomes of the students

## 6. CONCLUSIONS & FUTURE WORK

This paper has highlighted issues surrounding the teaching & learning of BIM at the university level. In order to negate some of these issues research has been conducted & described to develop a framework for implementing BIM into the teaching & learning of AEC education around the world. A case study from a leading Australian university has shown how the framework can be implemented with some reflections & observations (& the instruments used to make these) have been described.

It is clear from the paper that there is still much to do to implement BIM into the teaching & learning of the graduates of the future, but the design & development of the IMAC framework may go some way to help educators with this implementation.

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# KNOWLEDGE TRANSFER INTO A BIM COURSE THROUGH TECHNOLOGY-DRIVEN SOLUTIONS FOR REAL-WORLD CONSTRUCTION PROJECTS

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## ABSTRACT

The traditional education model is quite difficult for our students in-and-out of classes which involve use of construction technology. Invited guest speakers are notorious in bringing value to classroom through current, updated information and best practices from the companies they are representing. Transferring knowledge this way and making it even available after the fact may benefit every student enrolled in a dedicated Building Information Modeling (BIM) course.

Blending technology-driven solutions applied to construction projects enhance even more student understanding of real-world practices. Specifically, it enables our students, practitioners and even community members to learn by accessing knowledge derived from specific BIM applications in construction project management. When video lectures, software tutorials or other industry presentations and webinars are viewed outside of class time, the in-class time may become available for students to receive one-on-one attention from their professors or practitioners to work collaboratively. Therefore this time is more valuable as knowledge transfer and enriched experiences stemming from case studies presenting real world technology-driven solutions.

The paper will reveal some hands-on collaborative activities during class time involving various industry participants. The author created a model that can motivate students' success because it allows them to truly understand BIM applications by immersing into situational, real project challenges. Also, students are encouraged to practice or play specific roles if they are having difficulties understanding the case scenario exposed by industry materials. With industry support and participation, this educational model (project technology-driven solutions) starts with the belief that students really do care about their BIM understanding and its applications to solve industry problems. Using a reversed model (technology-based, industry-oriented) will enable students to account effectively for the challenges and duties they will face to their future jobs, therefore becoming more marketable into a thorough and technology-driven job market.

**Keywords:** BIM course, knowledge transfer, project management, technology-driven solution, job market

## 1. INTRODUCTION

Contemporary computer technology changes rapidly, forcing people to adjust the way they work in accordance with new challenges. Construction and architectural design are some of the businesses affected by such change. From the process of manual drawing and drafting buildings and other construction projects of more than twenty years ago, the profession has moved on and adopted CAD (computer-aided design) for the presentation and production of architectural, structural and systems within buildings documents, especially with construction drawings.

The transformation has been fast moving forward so that one can barely find an office still practicing manual drafting. New graduates are more accustomed to CAD and BIM (Building Information Modeling) programs than the drafting table. Computer representation allows clients to see the project in which they are investing serious dollars the very tiniest details before the construction process begins. The more the client sees, the further they can question, investigate or work to protect their investment, therefore computer technology allows them to take advantage of this opportunity. This characteristic coincides with the reality of growing complexity in the business of construction design. A building needs to respond to several simultaneous issues: energy consumption, meeting green building standards, LEED (Leadership in Energy and Environmental Design) requirements, cost-effective facility management, environmental impacts, and construction uncertainties, among others. Because of these competing agendas, the CAD technology begins to reach its limit, as it is best used in the static presentation of architectural drawings and scaled models. BIM extends some of the CAD limitations. In addition to the capacity to creating drawings and scaled models, BIM can also embed information into the representation of building parts and elements. (BIM Academic Forum, 2013)

BIM allows the building owner, architect, contractor, building manager and other users to predict the future performance of buildings, using techniques of simulation to anticipate and prevent problems before the actual construction process begins. Also, new virtual BIM software will help them reduce risks in their projects and therefore reduction in the risk is going to make the adoption of technology solutions easier for construction companies. Various BIM applications automates the change while detecting change automatically between iterations in 3D models and 2D design drawing sets. Consequently, applications make things easy to understand to all stakeholders. They can help understand the design and the change in design more easily, so it will also help anticipate different issues. When problems have been analyzed in an earlier stage, stakeholders have the chance to work collaboratively and remove them before they occur and that means decreased construction costs. Construction management students are in definite need to be exposed to situations like this in which the risk is better controlled and construction costs reduced. Risk factor is definitely going to be minimized with the help of BIM applications. Transferring knowledge this way and making it even available after the fact may benefit every student involved in such applications. These applications are essential constituents of the dedicated BIM course within the Civil Engineering and Construction Management department.

By providing constructability analysis capabilities, technology-driven solutions applied to construction projects augment even more student understanding of real-world construction practices. They are enabling our students and future practitioners to learn by accessing knowledge derived from specific BIM applications in construction project management. A better understanding of construction risks and the need to reduce construction costs may be effectively taught through BIM applications into the real project circumstances.

## **2. BIM APPLICATIONS AS TECHNOLOGY-DRIVEN SOLUTIONS**

### **2.1 Real-world construction projects solutions**

Applications for construction permits are now transforming; in some cases when more progressive contractors are involved, BIM models with a specific level of development specification may be submitted in lieu of traditional construction drawings (BIM Points Blog, 2013). BIM allows for the clear inspection of every detail in the virtual building or on the potential site concerns prior to the issuance of construction permits. Some construction companies and several other specialized construction services have already begun to require BIM files in the application for construction permits.

Another solution for the practice of constructing a data-rich BIM model is the investment into a virtual model that is capable of constructability analysis and simulation of actual construction, including changes for materials, methods and means of building construction, therefore requiring specialized knowledge and skills. Architects or architectural firms who produce the architectural designs are not really performing constructability analysis. But creating a data-rich BIM model would require additional

expertise and labor hours to put into and usually drive up expenses. Added to regular design fees, normally this modification would be acceptable to project owners because these additional expenses would counterbalance costs that could be saved during various construction phases. Furthermore, if BIM modeling were to be used in the post-construction period to assist building maintenance and operations, the project would require a higher level of detail in design documentation that would make it even more expensive.

## 2.2 Real construction projects scenarios in classroom environment

When we address BIM workflow, we always make a strong mention of the way it redefines approaching to projects. Studying how BIM will affect your design workflow cycle, project deliverables and internal quality will not only allow organizations to retool the project approach, but more importantly how to obtain resources, staff projects and make deliverables. These are difficult to convey into a traditional education model. Students in-and-out of classes use technology for various purposes. Their “smart phones” can wake them up, provide with access to information, and direct students to places they would like to go. Various digital devices may use calendars, date books, and “apps” that assist with many daily functions. Also, everyone nowadays use technology in homes, schools, work places, or in our health care facilities.

Virtual software programs in our work places design buildings, analyze potential structural problems, and suggest materials for construction. Technology runs business, keeps track of money and inventory, facilitates “meetings” with people from all over the world by way of virtual “meeting rooms” and provides us with information that allows for business decisions and tracks international markets. Our students also are now used to go to school “on-line” in virtual classrooms where all the students in those “classrooms” are literally from many distant locations. Our government has mandated that health care facilities track health information using an electronic medical record (EMR) that will be linked in order to provide instant health information about patients anywhere they may travel and need this information in order to be treated effectively. Because of the dependence on technology in the professional world, higher education must prepare students to be able to use both basic and specific technologies required for job performance in their selected professional pursuits after graduation. However, there is a growing concern about the extent that students’ educational preparation may not be keeping pace with the demands and expectations of corporations and companies who will employ college graduates (Hart Research Associates, 2013). Therefore the rising questions is: How well are graduates prepared to be able to transfer/transport classroom learning to workplace applications?

Invited guest speakers are notorious in bringing value to classroom through current, updated information and best practices from the companies they are representing. Transferring knowledge from industry professionals and making it even available after the fact may benefit every student enrolled in a dedicated Building Information Modeling (BIM) course. Blending technology-driven solutions applied to construction projects enhance even more student understanding of real-world practices.

Students need to comprehend and be assessed on the overall workflow plan that will define project programming, design-development through construction management and hand-over to the customer. The workflow should showcase how BIM requires an entirely new approach to design tools from documentation, visualization and even engineering calculations. In author’s opinion, the basic portable skills the course students need to be able to apply in real-world scenarios are:

- Workflow of the construction process
- The role of technology within the workflow
- Roles and responsibilities of designers/owners/construction managers
- Collaboration and integration of individuals in the construction delivery
- Interoperability/capabilities of the software used

Construction Management program in the College of Engineering and Information Technology at Georgia Southern University offers the BIM for Construction Management course which is based on the belief that when video lectures, software tutorials or other industry presentations/webinars are viewed outside of class time, the in-class time may become available for students to receive one-on-one attention from their

instructor and practitioners to work collaboratively. Therefore, the author believes that the actual time used in class is more valuable to the knowledge transfer needed to perform in construction industry environment.

Enriched experiences stemming from case studies are presented into real world technology-driven solutions. This paper will reveal some hands-on collaborative activities during class time involving various industry participants. The instructor of the course created an environment which motivates student to succeed because it allows them to truly understand BIM applications by immersing into situational, real project challenges. Along with industry support and participation, this educational model (project technology-driven solutions, figure 1) starts with the belief that students really do care about their BIM understanding and its applications to solve industry problems. The industry involvement in the course is complementing the understanding of how technology applications are meant to solve company-based problems through use of various case studies presented during the semester-long course.

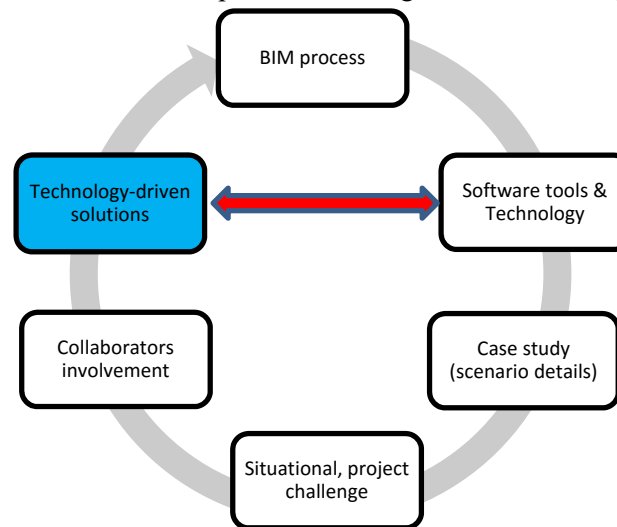


Figure 1: Project technology-driven solutions conceptual framework

### 3. COLLABORATIVE ACTIVITIES INVOLVING BIM APPLICATIONS TO FACILITATE KNOWLEDGE TRANSFER

#### 3.1 Site logistics – A simulation for obtaining permits

In this practical project, students work in small groups to look at some of the simple modeling tools that can be used to create a fairly comprehensive site logistics plan. The site logistics plan exercise creates scenarios analyzed by the teams to produce and establish efficient and safe working conditions for all involved parties adjacent to and within the construction zone. The plan is inclusive of major equipment placement, pedestrian and vehicular travel paths, staging of facilities and required temporary functions, lay down areas as well as means of emergency operation routes (see Figures 2 and 3, one created example). The assessment of this activity requires only electronic site logistic plans for every considered construction site, therefore students have the opportunity to understand and analyze in-depth the challenges of site location and conditions prior to obtaining a building permit. In addition, a preliminary estimating exercise is rewarded with bonus points if they calculate the cost on the fence installation needed to surround the jobsite by estimating the total cost for the type of fence used in the site logistics project. All of them are advised to consider latest material costs, the units in the family imported in the model or basic linear feet cost. Then, students are advised to calculate the perimeter where that site fence is placed. Considerations of renting vs. buying the fence can be made. However, the students are further instructed to document the sources obtained on the web, from contractors, vendors, etc. for cost of units or for renting the entire fence and for the construction time the respective fence will be used on site. This

way they are forced to analyze what type of building will be constructed on site and the magnitude of project seeking construction permit.



Figure 2. Example of site logistics exercise – 3D view and analysis

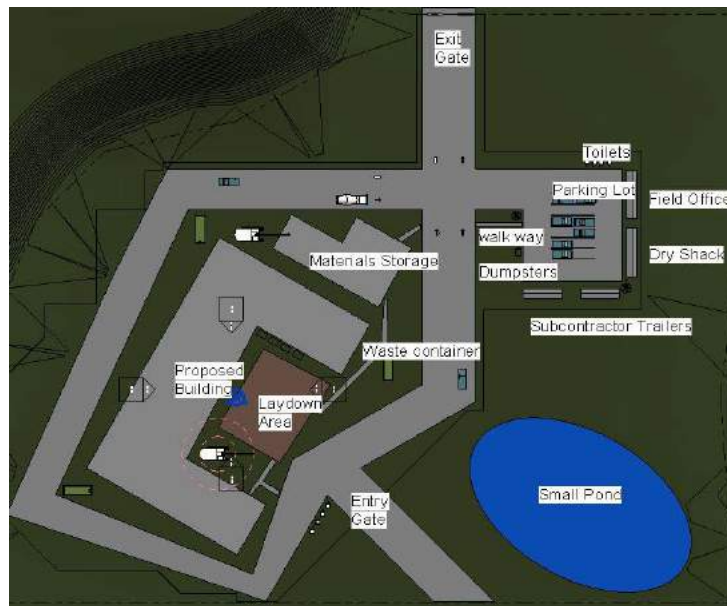


Figure 3. Site logistics exercise – top view analysis

The site logistics plan for each student is assessed as site specific plans that are considered strategic for each particular site conditions and produced to establish efficient and safe working conditions for all parties involved in the site work. As mentioned before, when the organization of the site is assessed, the plan should be inclusive to five categories of site elements in the respective models: 1. major equipment placement; 2. pedestrian and vehicular travel paths; 3. staging of facilities and required temporary functions; 4. lay down areas for materials handling; 5. means of emergency operation routes (site accessibility for emergencies). Categories with points that may be obtained for each rubric assessment are provided in the followings (in parenthesis, the maximum percent that can be obtained) and they are measuring the comprehensiveness of the above five areas for the site logistics exercise:

- Missing most components, plan not well-developed (up to 25)
- Not a well-developed plan, missing a few components (up to 50)



- Well-developed, but missing a few components (up to 75)
- Well-developed plan with all components in place (75 - 100)

### 3.2 ADA compliant house design – a project application for relevant building codes and regulations

On this application module, students work in larger groups and guest speakers from local industry are invited to present and help towards the project completion. In the first phase, students are provided time to review and practice some video tutorials and pick up quickly the modeling skills to the intermediate levels or even more advanced levels that will help and guide them throughout this project assignment. From the very beginning, students are directed to focus on the level of details and the code compliance of the proposed design instead of the overall appearance of the BIM model. They are also encouraged to explore creative designs that fit into the context of local community. Plenty of resources are provided in the online learning management tool of the university system. The project intends to respond to an emerging market demand on senior-friendly housing by a rapidly increase of senior population. The proposed housing design requires the students to take into account the specific design features (e.g. Universal Design criteria) and applicable code requirements (e.g. ADA accessibility guidelines, State and Federal regulations regarding accessibility codes, etc.) for the main floor of the proposed house design.

The housing design is discussed collaboratively in the first sessions in order to reflect realistically the seniors' needs for floor level of a basic residential unit. Students are encouraged to form groups of at least five individuals to distribute the working load. This activity is completed during class time and various roles are assigned to each individual within a team: construction manager, architect/interior designer, project superintendent, code compliance official/building inspector or project engineer. The required project deliverables are worked out in collaboration with invited industry speakers from local community and consist of a completed senior-friendly housing design model including basic design documentation (site plans, floor plans, elevations, sections views, detail views and renderings) and a comprehensive narrative report on design process and the outcomes of the implemented housing features. Figure 4 below is a delivered example of a main floor plan and a section view through a kitchen and bathroom design.

Peer evaluation of teamwork is part of this project assessment and it is a ranking-based evaluation. The individuals within a team are receiving factors (multipliers) applied to the team score, based on a points distribution system created by instructor to reflect on the overall contribution reported by the peers. Categories students are asked to evaluate their peer contributions to the project are based on the following questions:

- (a). How well is her/his attendance to team meetings in class?
- (b). How well is her/his communication with the team?
- (c). Did this team member work well with other group members?
- (d). How well did s/he bring energy/can-do attitude/excitement to the team?
- (e). How well did s/he provide initiative and/or leadership?
- (f). How well did s/he seek consensus and/or bring out best in others?
- (g). How well was her/his contribution to important points/issues in the assigned tasks/projects?
- (h). How well did s/he complete assigned tasks/projects?
- (i). How good was her/his overall participation/contribution in this group?
- (j). Would you like to work with this member again in a similar group for a different project?

As one of the students reported after completion of this project, it was a great learning exercise, interactive and collaborative: "This project was a good way to get us thinking out of the box and pay attention to ADA codes. ADA is not something most of us think about every day but it does have real world use. Many of the simple things we take for granted must be changed in order for someone who is confined to a wheelchair to be able to use them. I enjoyed working on this project and it made me realize some of the real world applications and difficulties construction managers actually face. This is a good use of BIM to ensure all aspects of an ADA household are met before the project is built." The duration of this particular applied project is about one full month considering the two weekly sessions of the

course schedule and the invited industry/guest speakers sessions. Depending on the speed of the teams' design and their navigation through the building codes and ADA requirements and accessibility, the overall duration vary slightly from semester to semester.

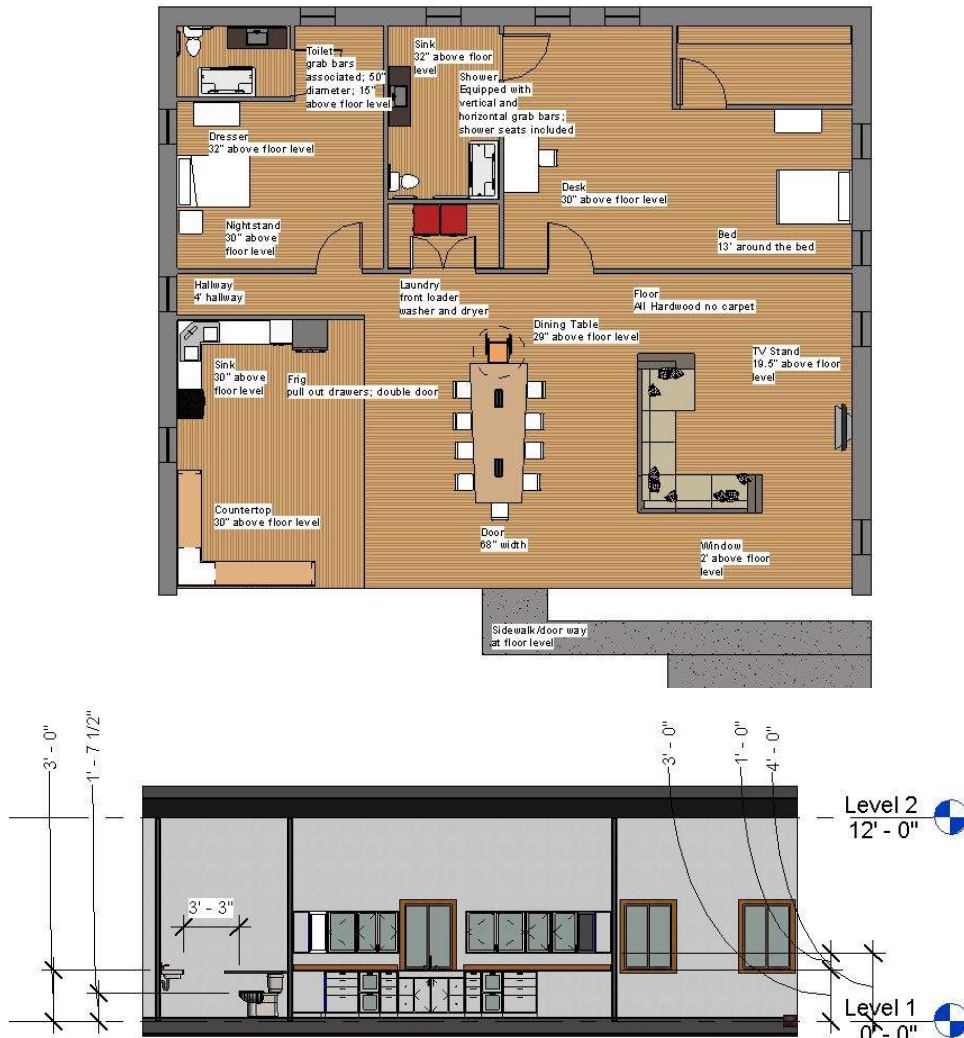


Figure 4: Floor plan and section view of a residential ADA compliant model

### 3.3 Electronic surveying - improving accuracy on a BIM-driven project

The collaborative work on this project (teams of 4-5 students) is also showing how including electronic surveying with BIM in MP (Mechanical-Plumbing) systems plans increases productivity in large-scale projects, such as hospitals, residential complexes, and hotels with repetitive floor plans (selected by students with industry collaborators invited to class). In order to complete this project, actual company statistics are needed to be provided, therefore this project involves heavily construction professionals. The statistics are coming from companies that are surveying for their MP construction plans and companies that are not using this innovative technology. The selection of these companies will be conducted based on the ratio of MP systems cost with forecast of total project cost and the suitability with these type of projects. Also larger-scale projects with repetitive floor plans are considered to be undertaken on these highly interactive "student-professional" projects (see figure 5).

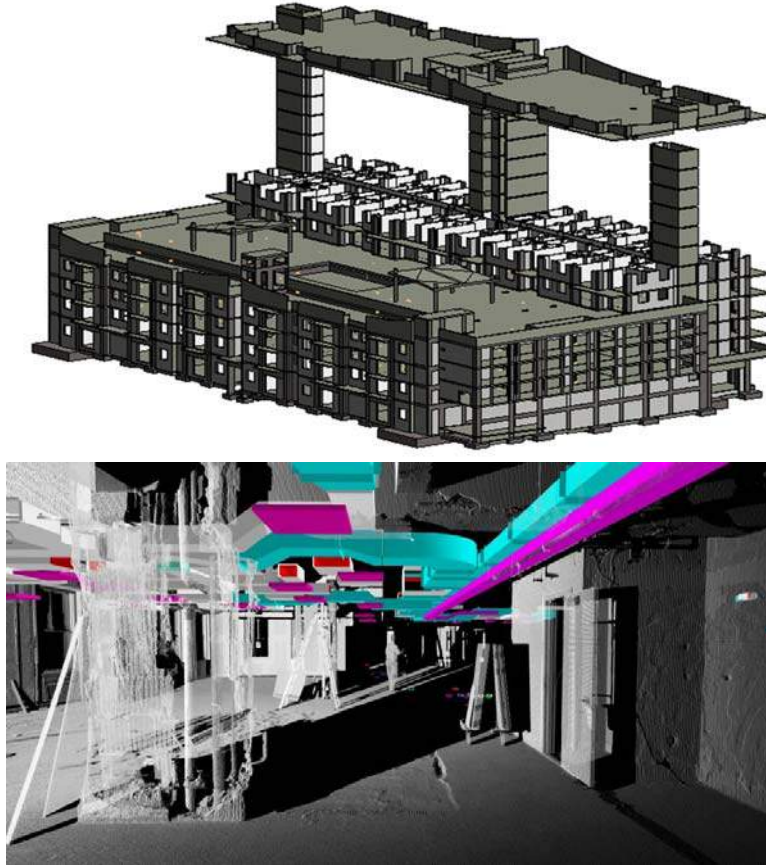


Figure 5. Multi-floor tower construction, mesh of point-cloud data and MP elements for installation of equipment

Use of a total station data, laser scanning equipment and MEP modeling software on these projects is expected to decrease tolerances for installation of this equipment. Another expected benefit of knowledge transfer on these cases is improvement of specialty crews' on floor plan logistics, therefore reducing planning time. Differences of construction companies using electronic surveying are quantified against companies that are not using this surveying system and use of models for the jobsite coordination. On large-scale projects, implementing electronic surveying with BIM technologies to mechanical and plumbing systems can greatly improve construction productivity and quality work of the crews. The students are asked to report on the findings into a comprehensive research report. The initial assumption would be the fact that using electronic surveying technology with BIM may cut certain percent of budget costs, reduce valuable construction scheduling time and minimize conflicting information between subcontractors and general contractor. The students are further reporting and presenting as group how implementing electronic surveying with BIM on MP systems will not only improve large-scale projects, but will also allow for numerous technological applications resulting in better specialty subcontractor performances (topographic site surveys, concrete slab flatness, interior measurements, faster installation time, better control over tolerances when installing HVAC equipment, better crew coordination, etc.). Their reports are evaluated based on the completeness and thoroughness of the overall project performances and experienced savings.

#### 4. CONCLUSIONS AND FUTURE WORK

Using a reversed model (technology-based, industry-oriented) is enabling students to account effectively for the challenges and duties they will face to their future jobs, therefore becoming more marketable into

a thorough and technology-driven job market. Some of the graduating students may become in the near future the BIM job captains or BIM Managers for their employers, and through their careers they may experience complex roles and responsibilities. BIM students need to understand the business thoroughly and the primary function to manage the process of virtually constructing a building and documenting the design contract documents accurately. This would encompass managing a team of professionals, designers and technicians of multiple disciplines and own the construction-documents set through as-built submittals. It is also critical for them to lead model management and BIM planning, collaboration and coordination on projects they will lead (Joseph, Autodesk University 2011). The position is finally responsible on the project for modeling, documentation and verifying design intent during the construction documents phase. As educators, we have to make sure they are exposed enough and capable of taking charges in various roles and responsibilities:

- Coach, mentor and supervise the process of virtually constructing a building by production (modeling and documenting tasks)
- Lead the effort of putting together a set of construction documents
- Produce construction documents for one or more disciplines (architectural, structural, MEP, interior design, etc.)
- Lead BIM coordination meetings: spatial coordination of disciplines, gathering all disciplines BIM models including civil, site, landscaping and performing coordination tasks
- Fostering high level of communication and teamwork to assemble a work environment for different individuals representing multiple disciplines

The largest percentage of Architecture/Engineering (A/E) firms and General Contractors (GC) seek project management skills and knowledge of construction processes in their senior staff (McGraw-Hill, 2012) with a significantly higher percentage of GC seeking these type of skills and knowledge. However, it is notable that, according to the same SmartMarket Report, well over half of the A/E firms consider knowledge of construction processes to be important when seeking experienced staff, therefore suggesting an emphasis on a more holistic view of design and construction. The skills firms ranked as most important for student and recent graduates they would hire largely correspond to emerging technology trends in the profession (McGraw-Hill, 2012).

Through a few examples used in a BIM course as highly collaborative projects, this paper has revealed how certain technology-driven solutions to real construction projects may impact, enhance and create a deeper understanding of the most BIM Manager's future roles and responsibilities. The transfer of the most needed construction project management skills in industry can start during these projects exercises in the BIM classroom environment. The author is currently working with other educators to expand the range of technology-based applications on other course offerings within the same department.

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# DIGITAL PROJECT COORDINATION EXPERIENCE IN UNDERGRADUATE CONSTRUCTION EDUCATION

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## ABSTRACT

This paper presents an experiment of a pedagogy through collaborative BIM (Building Information Modeling) education at UTSA: real-time BIM coordination meeting in class. Clash detection and coordination play a key role in implementing the benefits of BIM, such as reducing design errors. Therefore, for undergraduate BIM education, it is critical that students learn to master the fundamental function and process of performing clash detection and coordination with different trade sub-contractors. Despite increasing adoption of BIM education for undergraduate students, there is insufficient student involvement in collaboration and coordination in BIM practice. The designed BIM for construction management syllabus covers this skillset in lab sessions with trade subcontractor models, focusing on the software tools' function of running clashes and solving problems within software. This approach helps the students not only understand the software perspective of clash detection, but also to understand the coordination between different trades and how the GC BIM coordinators resolve conflicts between the trades. This new approach has been adopted for undergraduate BIM classes at UTSA. A real-time BIM coordination meeting is conducted in one lab session. The BIM Coordinator from the general contractor lead students to perform clash detection, experiencing how to use Autodesk Navisworks to color code for different trades, detect conflicts, perform a 3D "constructability review," prepare the BIM model for weekly meetings with subcontractors and explained the cyclical process of coordination work.

**Keywords:** Collaborative learning, BIM coordination, BIM education

## 1. INTRODUCTION

A construction project usually involves a multi-disciplinary team combining valuable and unique input of stakeholders from various domains, including owners, architects, engineers, contractors and facility managers. Serving as an effective communication and coordination media, Building Information Modeling (BIM) becomes a standard practice in the Architecture-Engineering-Construction-Operation (AECO) industry. Many universities and colleges offer construction related programs with integrated BIM components into their programs (Sacks and Pikas 2013). Johnson (2010) reasoned that BIM is one of the most recent trends to be addressed by construction education programs, and at the same time, it is also one of the most challenging topics. With the rapidly increased adoption of BIM among contractors in North America, by 2012, there is already 70% rate of adoption for BIM among contractors. Of these contractors, more than 36% have six or more years of experience, greater than twice the number that were at that level in 2009 (McGraw Hill Construction, 2014). Although there are various definitions of BIM, most researchers and practitioners agreed that BIM is not only a product or technology, it is a process that can improve the project success through project life cycle (Leite 2015). Thus, teaching BIM requires more emphasis on the process improvement rather than solely technology or software functions.

This paper describes an undergraduate level BIM for construction management class term project, which focused on learning the coordination process of BIM instead of the modeling skills. CSM 4533 was an elective class which became a required class for all construction science major students in 2015. It is also an elective for students pursuing a minor in construction. CSM 4533 was first offered in fall 2012, and since then, the course has attracted high interest from the student body. It was offered once a year in 2012 and 2013, and because of the high demand for the students, it has since been offered each semester. Each semester, it is registered to its full capability. Currently the class has 28 students each semester. Students gain hands-on experience with different software platforms for various different projects. This course is also supported by several industry practitioners who are willing to share their experience and their project information with our students. This paper focuses on the discussion of one term project for this course.

## **2. PREVIOUS RESEARCH**

BIM has gained wide recognition in the last decade in both academia and AEC industry. Some research has indicated that BIM adoption is increasing in the AEC industry (Joannides et al. 2012). Based on the survey distributed to members of the Associate School of Construction, as of 2008, less than 1% of the construction programs had a stand-alone BIM course, while 9% incorporated BIM as part of the existing courses (Sabongi 2009). By 2013, 54% of the programs had dedicated and fully-developed BIM classes included in their curriculum. 52% claimed BIM content was embedded in conventional courses (Wu and Issa 2013). In BIM education, researchers found that BIM is one of the most challenging topics for construction programs (Casey 2008). As the demand for construction students with BIM skills is increasing, it is important for the current construction program to provide an effective course that can help students achieve the corresponding knowledge and skills. However, there are several challenges in BIM education. First of all, there are many different understandings of BIM in academia and industry. Depending on the roles of the BIM practitioner, their understanding and implementation of BIM can be different. It is critical to help the students understand the difference and master the core concept of BIM. Second, there are many BIM platforms and business processes that can be used in the construction industry. It is almost impossible for the instructor to cover all platform offerings in merely one course. Thirdly, technology has been changing rapidly over the past few decades, and what is taught in class might be “obsolete” soon after students’ graduation. Instructors of BIM should train the students to keep an open mind for changes instead of following the same procedure(s). Critical thinking and adaptability towards technology development should be addressed. Finally, BIM technology is used to solve the business problems. The most effective way to teach the students is by educating them about current/typical challenges on construction projects, the problems that can be solved, problems currently being solved by industry BIM experts, and how the industry is utilizing BIM technology for business applications. In order to better the education experience, partnership is built between the Construction Program at University of Texas at San Antonio and the BIM professionals from local construction companies. Front-line practices were introduced to the students as guest speakers and mentors.

## **3. COURSE DESCRIPTION**

### **3.1 Course Overview**

The “BIM for Construction Management” course at UTSA is offered as three-credit hour required course. The instructor meets the students for 85 minutes twice per week. All the class sessions were assigned to a computer lab. A background survey is conducted at the beginning of the class each semester to evaluate the students’ education level and background. The results shows that the class was mainly composed of senior and junior construction majors who had already completed basic construction courses such as plan reading, estimating, scheduling, and project management. Because it was the only BIM course in the curriculum at the time, the course was designed to cover a wide variety of BIM topics such as clash

detection, constructability review, design, visualization, model based quantity take-off (QTO) and estimating, and 4D scheduling (Liu et al. 2015).

The course final grade is consisted of one midterm exam (10% of the grade), one final exam (10% of the grade), homework projects (30% of the grade), quizzes (10% of the grade), and two term projects (40% of the grade). All homework projects are designed to equip the students with the proper skills for the term projects. There are two term projects throughout the semester. The Term Project I focuses on the technical skills of the software functions (Liu and Hatipkarasulu 2014). The Term Project II focuses on collaboration and communication amongst general contractors and subcontractors during the construction phase. In previous semesters, students were asked to detect clashes with real-life models and find solutions for the conflicts. In fall 2015, in order to help the students understand the cyclical and iterative coordination workflow, Term Project II involves model updates, template setup and conflict re-examination.

Each class session started with a lecture and were followed by the lab exercises. The lectures were utilized to teach fundamental BIM concepts and BIM documentation including BIM Execution Plans, BIM contracts, implementation processes, case studies. In addition, during the lecture, specific steps to use the software platforms were also demonstrated. The lab portion provided students with hands-on skills and applications. As there are two platforms that the class focuses on, the semester was divided into two parts. The first half of the semester focused on the skills for Autodesk Revit 2014. The purpose was to provide basic modeling skills, teach database concepts and structure. A term project was assigned after all of the Revit tutorials were finished in the class. The second portion of the semester focused on trade coordination utilizing Autodesk Navisworks Manage 2014, a model aggregation platform well-known in the industry for BIM coordination and collaboration. The purpose was to allow students to understand clash detection process during the construction phase, master the skills to color coding models for different trades and coordinate with different trades to solve the problems.

### **3.2 Term Project Example**

In previous semesters, the clash detection and coordination term project was addressed in one cycle which required the students to solve the clashes from various subcontractors with the provided NWC files. The term project example can be found in this article (Liu et al. 2015). Since fall 2015, an innovation of this course is that the project focuses on process instead of product. Emphasis has been placed more on understanding BIM as a project management and problem solving process. With the rapid development of BIM technology, it is not enough for the students to master one or two software platforms. Instead, it is more important for them to understand why they need to use the tools and how to implement these technologies in order to produce successful project execution. In addition, this project emphasizes the communication and coordination cycles amongst the general contractors and subcontractors. Even though technology is important, the way to communicate efficiently with technology is even more important.

In the preparation phase, four tutorials were used as step-by-step instructions for the functions and procedures in Navisworks. One in-class exercise and one homework were assigned in order to practice the skills in the tutorials and master the process of setting up projects and performing clash detection.

### **3.3 Industry Involvement**

In the meanwhile, two guest lectures from general contractors were provided to introduce the daily practice of BIM managers and BIM coordinators. One of the lectures is about the generic BIM implementation for each phase of a project, beginning during design & preconstruction. The other lecture was the detailed explanation project BIM/trade coordination and communication with subcontractors. BIM coordinators from the general contractor and some from the subcontractors showed up to the lab, and other subcontractors were attended virtually through GoToMeeting. The BIM coordinator from the general contractor first explained to the class what clashes he had found from the models when preparing

for the meeting. He then lead the meeting and facilitated the conflict resolution process by working collaboratively with the subcontractors to propose solutions for each of the conflicts identified.

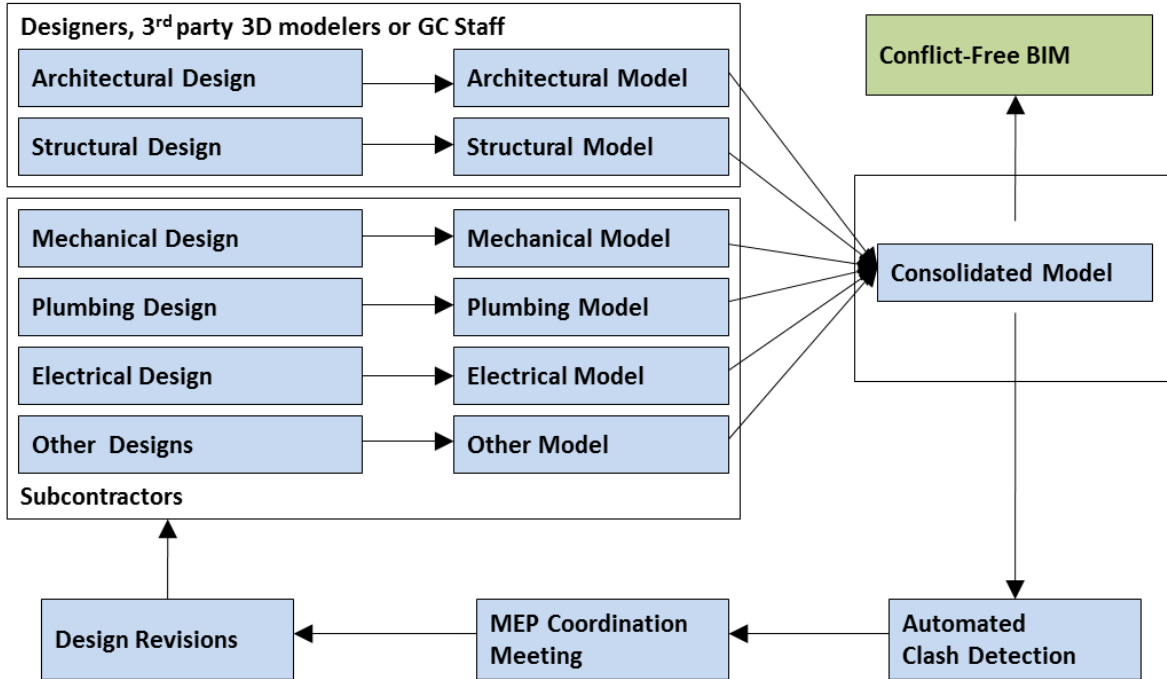


Figure 1: Coordination Iteration

### 3.4 Term Project Example

The students were assigned a project to mimic this coordination process. The project description is as follows.

General Contractor BC has recently been awarded a new clinic project. As a project BIM coordinator, you have received 3D BIM drawings for its architecture, structure, mechanical, electrical, plumbing and fire sprinkler system models from the subcontractors. You are required to color code different disciplines and find possible conflicts in the models for the weekly coordination meetings. Download all models in the CHCS folder from the shared project server:

Required Elements:

- a. Model Alignment: Align all the models (2 points)
- b. Color Code Models: Reset the models color according to the following table (5 points)

Architectural	
Structural	
Ductwork/Mechanical Equipment	
Plumbing	
Electrical & Lighting	
Fire Protection	



- c. Create a Selection Set: Select the highlighted elements as shown in Figure 1 from your selection tree and save this selection as a set (3 points)
- d. Clash Detection: Run two clash detection tests between the following disciplines.
  - Test 1: FIRE vs. PLUMBING
  - Test 2: PLUMBING vs. STEEL
- e. Viewpoints
 

Find at least 8 clashes for each test above. Markup using clouds and comments for the clashes and save them as viewpoints. Create folders in the “Save Viewpoints” window, name your folders name according to the disciplines such as “FIRE vs. PLUMBING”. Create one folder for each clash detection test. Each folder should contain at least 8 clashes with markup. (10 points)
- f. A 3D Walkthrough Animation: create walkthrough animation for your model in Navisworks with highlights of some exterior and interior features. Then export this animation as “lastnameWalkthrough.avi” (10 points)
- g. Clash Detection Iteration (20 points)
 

Repeat steps a-d with the updated set of NWC files from the subs. Compare the new clash detection results with the first round.

#### Project Deliverables

- Save your finished Naviswork file after the first iteration as “LastnameTermProjectW1.nwd”
- Save your finished Navisowrk file after the second iteration as “LastnameTermProjectW2.nwd”
- lastnameWalkthrough.avi

### 3.5 Student Deliverables Examples

The students were required to setup the clash detection for the first week and markup the clashes in Navisworks. In the second week, new sets of NWC (Navisworks cache files) were distributed to the students and they were asked to update their NWF (Navisworks file) with the updated models. Some of the clashes captured by the students in week 1 were shown as in Figure 2. One comparison between the first week’s clash detection and the second week’s detection was shown in Figure 2. The students can find out what the subcontractors have revised in their model to solve the clash problems in the second round. And they can find potential clashes after the subs make changes.

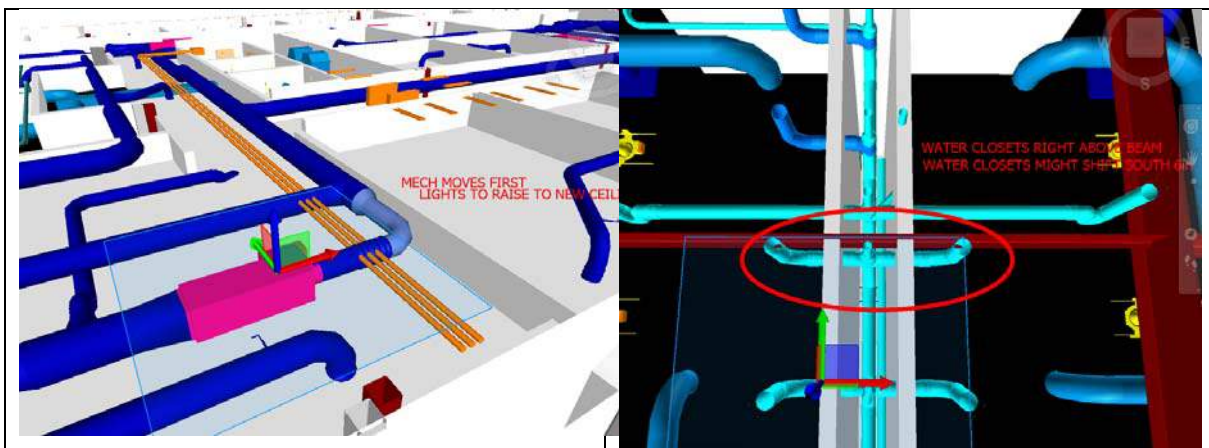


Figure 2. Clash Detection Examples

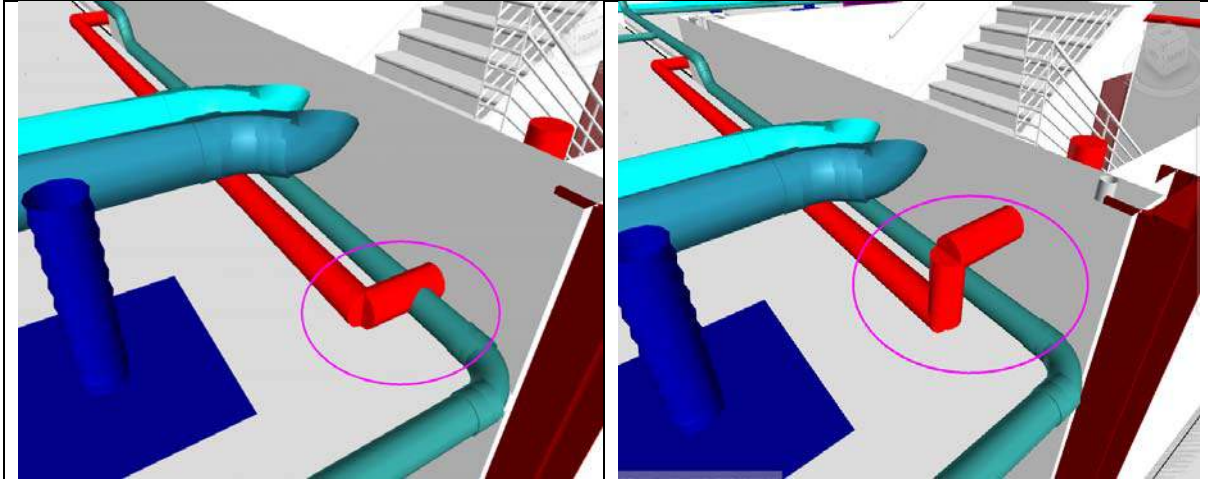


Figure 3. Comparison between week 1 and week 2

#### 4. DISCUSSION

There are several aspects from the experience of teaching this course that may be helpful for future instructors. First of all, BIM education should emphasize the business process instead of specific software skills. With the understanding of the construction business and coordination process, the students can understand the utilization of BIM and are more adaptable to apply the skills they learned in the process even if the software packages are different than what is taught in class. Secondly, industry connections and involvement from local practitioners are valuable. With the front-line practitioner's involvement, students are more motivated and understand the concept much better. With the real-life project experience, the students can apply their skills and ask questions to the practitioners, which help them master their skills faster. Thirdly, keep the student open minded. Because technology evolves so rapidly, as a future BIM professional, they will have to adapt to new technology throughout their careers. The ability to evaluate technologies, make wise decisions and choose the appropriate technology to use is more important than mastering the current software. Finally, students' interest in BIM technology should be maintained through the semester. How to make complicated software easier for the students to learn is a lesson a BIM instructor should keep learning, especially when there are some students with weak computer skills.

#### 5. CONCLUSIONS

This paper focused on explaining one term project on the use of BIM for construction undergraduate classes. As BIM education should emphasize the process instead of the product, the term project is revised and improved from previous semesters to incorporate the cyclical and iterative BIM coordination process. Understanding the core value of BIM processes, while applying critical thinking and problem solving, is more important than the skills for any software platform.

#### ACKNOWLEDGMENTS

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# A Comparison Study: SketchUP Pro and Revit Architecture in a Sophomore Construction Engineering Management Class

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## ABSTRACT

Building Information Modeling (BIM) in construction engineering management undergraduate curriculum introduces fundamental changes to curriculum content development, implementation and assessment. Through collaborations by industry and academia, many software applications are available to address various design and construction solutions. Yet, there are few studies by academia specifically addressing which software applications are best suited for freshman/sophomore construction engineering management students in a dedicated stand-alone BIM course. This paper addresses North Carolina A&T State University's (NCATSU) Construction Management Program's approach to introducing BIM-enabled learning at the freshman/sophomore levels. Essential to this effort is understanding students' acceptance of problem solving in a 3D environment for construction. This paper presents the authors' use of exploratory teaching methodology and observational research findings to better understand and evaluate freshman and sophomore students' BIM experiences. This paper discusses the issues and challenges faced in a freshman/sophomore construction management class experiencing the use of SketchUP Pro and Revit 2015 for the first time.

**Keywords:** BIM Education, BIM curriculum, CM Curriculum, Construction Engineering Management, SketchUP, Revit, Bentley, Learning Environments, Curriculum

## 1. INTRODUCTION

BIM software has progressed substantially in the architectural, engineering and construction industry. Many BIM platforms have evolved such as Graphisoft, ArchiCad, Bentley, DProfiler, Autodesk Revit, Vectorworks, Tekla structures. These BIM platforms all have similar BIM features and support pre-defined and user defined parametric modeling (Eastman, et. al, 2011, p. 76). Most, if not all BIM platforms must have parametric modeling as the core of the BIM's software capability. These BIM platforms assist the AEC community in production of designs, construction documents, estimating, scheduling, management, energy analysis, etc. However, finding and implementing a singular BIM platform into a construction management curriculum is not without its own challenges. Clevenger, et. al, states that: Construction education needs to embrace the opportunities and overcome the challenges presented by Building Information Modeling (BIM) to remain current and relevant. Although a growing number of university architecture, engineering and construction (AEC) programs have begun to offer courses that include BIM content, few programs have strategies in place to fully integrate BIM across curriculum (p1).

To address this challenge, faculty in NCATSU's construction management (CM) program are currently implementing exploratory teaching methodologies by introducing two BIM applications; SketchUP Pro to its CM 100 freshman class and Revit 2015 to its CM 256 sophomore class students. This paper discusses BIM software features/tools of SketchUP Pro and Revit 2015 and the issues and challenges faced in a freshman/sophomore construction management class experiencing the use of SketchUP Pro and Revit 2015 for the first time.

## 2. GENERIC BIM FEATURES

Brightman (2013,) defines "BIM as a concept, not a software program" (p.21). He further states "there are software programs that use the BIM concept to execute the design process. There are no official BIM features list, but here are a few popular features that most people expect to find in a BIM program: 3D modeling, model life-cycle use with the building from predesign to demolition, interoperability with consultants and their cad platforms, dynamic links between the 3D model and the construction documents, photorealistic rendering and raytracing, parametric modeling input and output, clash detection, energy analysis, cost analysis, 4D construction phasing and schedule management"(p.21). Brightman further states "SketchUP lacks parametric modeling features" (p.28).

## 3. SKETCHUP BIM FEATURES

To address SketchUP's lack of BIM parametric features many SketchUP plugins continue to be developed as identified by Brightman (2013) Cost Analysis - BimUp: [www.bimup.co.uk/](http://www.bimup.co.uk/), SpaceDesign: [www.renderplus.com/wk/SpaceDesign\\_Features\\_w.htm](http://www.renderplus.com/wk/SpaceDesign_Features_w.htm), Energy Analysis- EnergyPlus: [http://apps1.eere.energy.gov/buildings/energyplus\\_about.cfm](http://apps1.eere.energy.gov/buildings/energyplus_about.cfm), IES V-Ware: [www.iesve.com/Software/VE-Ware](http://www.iesve.com/Software/VE-Ware), NREL OpenStudio: <http://openstudio.nrel.gov/>, HVAC – 3Skeng: [www.3skeng.com/en/index.htm](http://www.3skeng.com/en/index.htm), Parametric Modeling: SketchUPBIM: <http://www.sketchupbim.com/>, Instant Roof: [http://valiarchitects.com/sketchup\\_scripts/instant-roof](http://valiarchitects.com/sketchup_scripts/instant-roof), Instant Wall: [http://valiarchitects.com/sketchup\\_scripts/instant-wall](http://valiarchitects.com/sketchup_scripts/instant-wall), Dynamic Components: [www.sketchup.com/intl/en/product/dcs.html](http://www.sketchup.com/intl/en/product/dcs.html), Build Edge: [www.builledge.com/](http://www.builledge.com/), 4D Timeline: Superplan: [www.superplan.info/index.html](http://www.superplan.info/index.html), Photorealistic Rendering and Raytracing- Twilight Render: <http://twilightrender.com/>, Shaderlight: [www.artvps.com](http://www.artvps.com), and Podium: <http://suplugins.com> (p.28-29). Other SketchUP BIM feature issue(s) center on Industry Foundation Classes (IFC). These issues are addressed in the SketchUP Community Forums website <http://forums.sketchup.com/t/sketchup-in-building-information-modelling-bim/14139>. Many IFC, visualization, design and construction (VDC), MEP related issues continue to be addressed for SketchUP with the solution(s) being plugins.

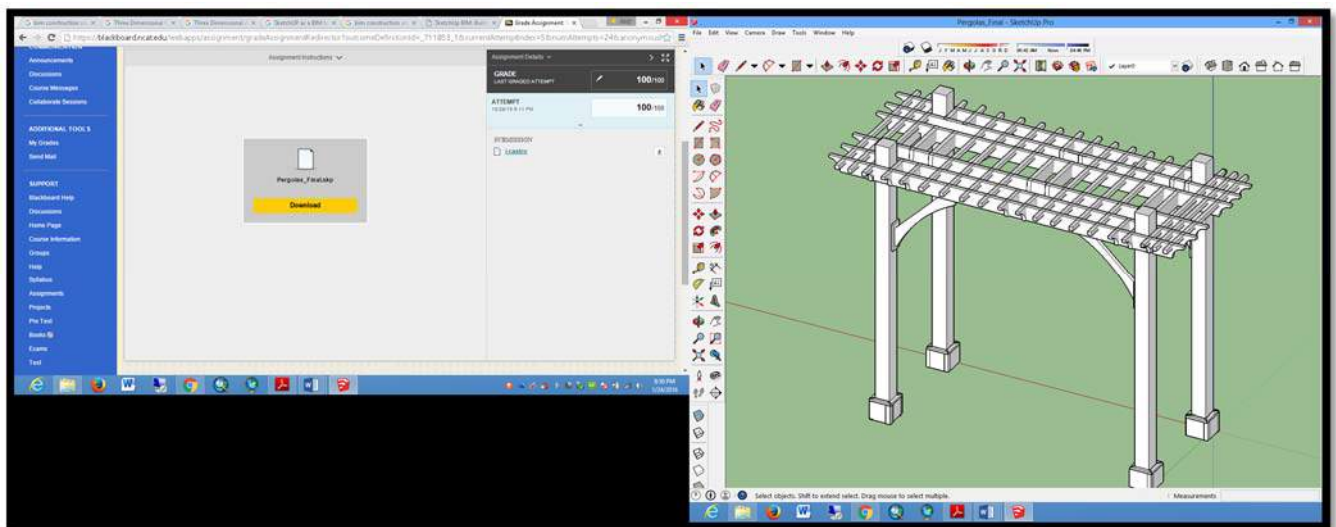
## 4. EXPLORATORY TEACHING METHOD: SKETCHUP AS A BIM TOOL FOR CONSTRUCTION PROBLEM SOLVING

What the author has observed in several past CM 100 freshman classes is that many freshman would like to design buildings and build them. Other observations made by the author of the freshman class is 100% of the students had smart devices such as iPads, smart phones and/or laptops. It was fairly obvious students are already using technology, now the task was to introduce BIM technology.

### 4.1 Project One: Pergola Construction

The CM 100 freshman class was introduced to construction of a project in the BIM environment using exploratory methods-Method one: each student was provided construction documents (CD) of a wooden Pergola project. This required students to read a set of construction documents (CD)

and become familiar with the various parts of the project. In addition students were given time to talk with each other about the CD's, and ask questions in class concerning construction of the Pergola. Method Two: After two class sessions, approximately one week, students were introduced to SketchUP Pro and instructed to use the CD's to build the Pergola project in SketchUP Pro. Students were given minimum hands-on instructions and students also were asked to construct the project without any formal training using SketchUP Pro. To further test students' critical thinking and reasoning, students were only given an introduction to SketchUP Pro and were tasked to perform this assignment without a SketchUP textbook. Students were shown various online YouTube tutorials and were instructed to use these online YouTube tutorials. Students were allotted the opportunity to collaborate with each other, to share data and assist each other. This project enforced team building, collaboration, critical thinking, reasoning, and development of 3D visualization skills. Students were given SketchUP Pro software downloads for their laptops, iPad and smartphone devices to use anywhere, anytime for completion of the project. Students were not restricted to face-to-face time. Students were allowed to work in class and out-of-class. Time to complete the assignment was four weeks. Students were also required to use Blackboard; a new learning delivery system for most of the students. Of the 28 students in CM 100 freshman class, 26 out of 28 students successfully completed the assignment with little difficulty.

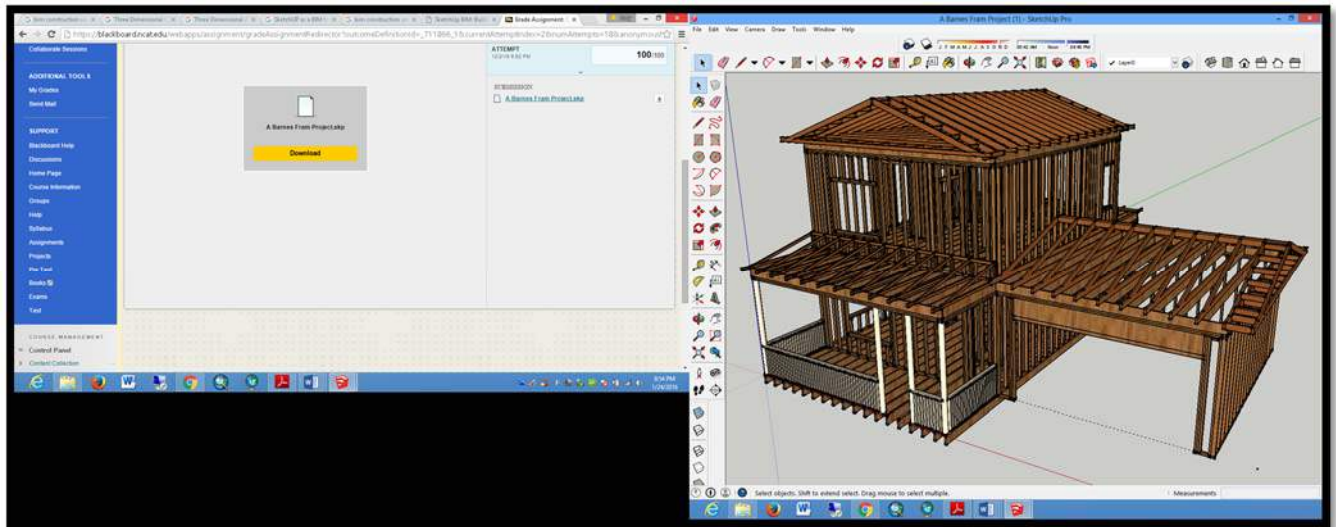


**Figure 1: Freshman Student Pergola Project using Blackboard and SketchUP Pro**

#### 4.2 Project Two: Two-story residential framing problem.

Project two was completely different in both format and complexity. The purpose of project two was to provoke students, to push their learning, to challenge their technical capacity, to use technology in construction, to get students to think outside the box. Students were tasked to design a 1200 – 1400 square foot (sf) two-story wood frame residence. Students were required to use various internet residential floor plan websites, select a floor plan of their choosing that met the sf requirement and to use SketchUP Pro in the construction of the project. Students had to research construction framing best practices for corners, door openings, window openings, roof rafter design, roof truss design, and exterior/interior wall construction. Students had to calculate the number of wood studs and estimate framing costs. Time to complete the assignment was four

weeks. Students were also required to use Blackboard learning delivery system. Of the 28 students in this class, 13 out of 28 students successfully completed the assignment.



**Figure 2: Freshman Student Residential Project using SketchUP Pro**

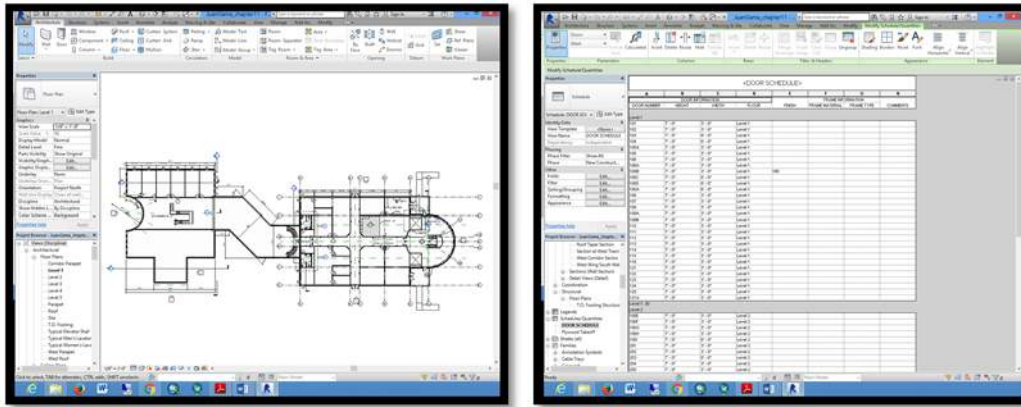
## 5. EXPLORATORY TEACHING METHOD: REVIT 2015 AS A BIM TOOL FOR CONSTRUCTION PROBLEM SOLVING

Project: Develop set of construction documents with interior/exterior renderings

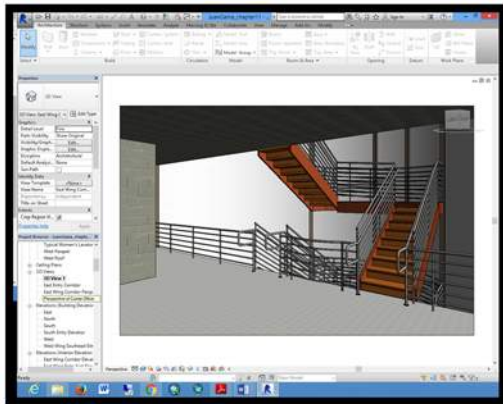
The CM 256 BIM sophomore class, offered only in the Fall second semester, is structured to introduce sophomore level construction students to Revit 2015 as a BIM tool that provides robust CD production capabilities. Revit 2015 and other Autodesk products have been used at the university for several years in the Engineering and Graphic Design programs, however CM faculty haven't embraced BIM technology. Clevenger, et. al, states that: Nearly 50% of the construction industry is using BIM today. Industry members are generally enthusiastic and propose that BIM can provide better project construction outcomes, reduced errors, omissions and conflicts, and assist business development. Employers who currently use BIM seek students capable in and comfortable with BIM processes, but do not require software expertise. The effective inclusion of BIM into the construction education curriculum will be critical in the preparation of future employees for industry (McGraw Hill, 2009) (p.1).

Students for this class are composed of students from the CM 100 class, which is offered in the Fall first semester, therefore, students are familiar with a semi-BIM software. The learning curve is much smaller and students aren't "BIM shocked". Students are required to use "Autodesk Revit Architecture 2015 – No Experience Required, by Eric Wing. This text was chosen because of its step-by-step approach. It affords the student opportunity to pace themselves and leaves little room for students to skip sections in the text to complete the project. It requires students to read every section and each section must be completed before moving on to the next section. Time to complete the assignment was eight weeks. Students were also required to use Blackboard learning delivery system. Of the 17 students in this class, 16 out of 17 students successfully completed the

assignment with little difficulty. Students were able to develop a set of CD's using Revit 2015. Figure 3 illustrates how students developed floor plans with necessary grid lines, section cuts, room tags, camera views and dimensions which were used to generate a parametric driven door schedule. Students understood the importance of parametric modeling. Figure 4 illustrates use of parametric modeling to generate interior elevations from the same floor plan in Figure 3.



**Figure 3: Sophomore Student using Revit 2015 for Schedules**



**Figure 4: Sophomore Student using Revit 2015 for Interior Rendering**

## 6. OBSERVATIONAL FINDINGS

Interesting to this study was the observations of construction students in CM 100 and CM 256. Both cohorts experienced similar anxiety and resistance towards acceptance of BIM technology in three dimensional critical thinking (TDCT), three dimensional analytical reasoning (TDAR) and three dimensional visualization (TDV). This was somewhat surprising given the fact that all cohorts had smart devices and were familiar using various 3D gaming apps. The CM 100 freshman students had initial problems fully understanding the tasks and the requirement for time management, therefore assuming the assignment was an easy assignment. Many CM 100 students resisted the fact they had to figure how to create various geometric shapes in SketchUP Pro from the CD's. This frustrated a number of students. Approximately 75% of the students took full advantage of YouTube videos and tutorials and developed very quickly a system to create different geometric objects. After three weeks, 95% of the students had embraced SketchUP Pro as a BIM



software with limitations and most, about 85% stated they would use another application if it had more BIM features built into the software.

The CM 256 students settled into using Revit 2015 very quickly. This was partially due to their experience with SketchUP in CM 100 and partially due to them hearing from several construction firms that BIM is being used as a management tool within their firms. Students embraced the text and actually followed the step-by-step tasks in each section. Students easily collaborated with each other; began to assist each other early in the semester; established after hours Revit study sessions and they addressed 90% of the BIM feature operations illustrated within the text. When asked which software preferred to produce CD's and renderings 90% liked Revit 2015 over SketchUP Pro due to the parametric modeling capabilities. While students liked SketchUP Pro, they didn't want to learn how to use plug-ins to achieve true BIM feature capability.

## **7. CONCLUSIONS AND FUTURE WORK**

Construction management programs across the country seek to integrate BIM into their curriculum. Motivations include desire by faculty to enhance student learning environments utilizing effective communication and visualization techniques; student desire to learn current design and analysis tools and methods; and desire shared by industry and academia to expose students to emerging BIM-enabled workflows and industry best practices (Clevenger, et. al., p.7). NCATSU's CM current curriculum requires all students to take CM 256 Introduction to BIM during their sophomore year. However it is not currently applied to any other CM course after the sophomore year which means CM students do not use BIM in the remaining five semesters of course work. Students agreed that this was a serious flaw and faculty have yet to understand BIM technology importance within the AEC community. Lack of faculty desire to enhance CM students' learning environment utilizing BIM as an effective communication tool at NCATSU's CM program is a missed educational opportunity. Future studies or research will involve bringing CM faculty together, using their areas of expertise, to promote BIM-enabled learning in the CM program.

## **ACKNOWLEDGMENTS**

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# LESSONS LEARNED: THE IMPACT OF PLANNING ON MODEL DEVELOPMENT AND MODEL MANAGEMENT

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## ABSTRACT

*Time spent planning is time well spent.* The statement seems intuitive, however students are often more interested in starting a task so that they can complete the task, instead of planning how to complete the task. Lack of planning can jeopardize the quality of the end product and result in significant rework to correctly complete the task. Creating an accurate BIM model requires comprehensive planning. Whether one is creating the model during design or creating the model for construction, a model development plan should be written first. The model development plan should be based on a comprehensive understanding about the project goals, along with the BIM use, purpose, and objectives for the project. The plan should address the parameters, attributes, and properties of the overall model as well as individual model elements. Only after completing the plan should modeling begin. While still in the preconstruction phase, a model management plan should also be developed. Its primary purpose is to coordinate multiple models based on standards for modeling as agreed upon by a project team. An effective model management plan will define file types, naming structures, file exchange, file sharing, planned models, coordination, and level of development (LOD). It is essential that the management plan be project specific and written to achieve the BIM use, purpose, and objectives for the project. In a recent senior level construction BIM course, students were given an assignment to create a model development plan and model management plan based on a set of 2D project drawings. The BIM uses were defined in the problem statement. This paper discusses the project assignment, challenges for students, and end products. Additionally, the need for instruction about general planning and process development were highlighted by the assignment submissions. Recommendations for improvement and implications for future instruction will be included.

**Keywords:** BIM, model development, model management

## 1. INTRODUCTION

The design and construction of a building results in the physical creation of goods, which is considered a manufacturing-type activity (<http://siccode.com/en/siccodes/20-39/manufacturing>), executed by an extensive process of time and resource planning. Although constructors are not responsible for design, they play a role in the process during preconstruction and even start planning the project construction at that time. As a result, construction produces tangible unique outputs that, based on the operations management literature, are considered a special project process that consists of tasks, flows, and storage of products and information (Tersine, 1980). In particular, the planning for and execution of a construction project occurs at the operational-level and is a process in which the ‘how-to’ implement activities and complete tasks are identified and described along with procedures (Solaimani & Bouwman 2012).

This paper discusses the instructional content about planning for the model development and model management processes delivered to students enrolled in a *BIM for Constructors* course. Students were assigned two separate, but interdependent, problems. One was to create a model development plan and the other was to create a model management plan to be used for the construction of a real-world project. Both required comprehensive knowledge about the project; therefore students were instructed to first breakdown the project's design, graphical elements, and specifications before beginning the planning process

Although BIM is best utilized as a collaborative tool with models shared between team members, until there is full integration of BIM it is reasonable to expect an incremental implementation approach for construction. The majority of architects, engineers, and constructors are currently using BIM for a variety of reasons, including different levels and purposes on projects (McGraw-Hill 2012; 2014). The results of a recent survey (Dodge Data & Analytics 2015) revealed that while all parties in a project may experience the benefits of BIM to different degrees, the impact of BIM on a project's schedule and duration is considered medium to very high by architects, engineers, contractors, and owners (AECO). In addition to schedule improvements, BIM's impact on cost control and reduction was also ranked medium to very high by the majority of survey respondents (Dodge Data & Analytics 2015). The reported impact of BIM on past projects that realized improved efficiency and increased productivity, has created an increase in the demand for BIM.

## **2. INSTRUCTION**

### **2.1 Problem-solving instruction**

Instruction for the model development plan and model management plan was delivered as lessons about problem-solving and were designed based on standard practices for instructional design (Smith & Ragan 2005). According to Smith and Ragan (2005), students must have learned the declarative knowledge, concepts, principles, and problem-solving strategies to successfully solve domain specific problems. Planning, scheduling, quantity surveying, and cost estimating for project construction are required topics for course work in U.S. construction programs; therefore only a general review of the topics were provided with an emphasis on the classification format for the organization of information. Additionally, students were expected to have learned the prerequisite declarative knowledge, concepts, and principles about construction in their previous courses.

The process of creating plans for model development and management are domain specific problems, for which students must expand beyond their declarative knowledge about concepts and principles to apply cognitive strategies in an effective problem-solving approach (Jonassen 2000). The course instructor provided lessons about problem-solving in the context of the real-world project provided with the assignment. Students received instruction about how-to breakdown the project; plan a solution; implement their solution; and then evaluate their solution.

### **2.2 Concept and principle instruction**

In addition to the instructor's lectures and activities about problem-solving, an industry partner provided lectures about the concepts and principles important in the design of both model development plans and model management plans. To clarify terms, a model development plan should be developed prior to the start of modeling. It should be used to identify and organize the elements of a model, along with the sequence of assembly in the software tool. Its purpose is to provide a plan for virtual construction of the project, and should align with the plan for actual construction. A model management plan is used to coordinate all the team members and the various models created by each discipline. Contingent on the project delivery method selected by the project owner, it may be developed early in the design phases as

with a design-build project, or it may be later prior to the start of construction. Given that its objective is to coordinate all team members, the management plan is developed with the construction team's input.

Instruction for both plans emphasized understanding that the creation of either plan requires in-depth knowledge about the project, including its spatial elements, material specifications, building assemblies, and site location. Students were provided specific instruction about how to perform an analysis by breaking the project information down into its constituent parts for building information modeling.

The industry partner applied the common planning principle of "beginning with the end in mind", followed by a series of question intended to evoke visualizations about the future construction of the building. Students were instructed to ask themselves: *What will the model be used for? How will the model be used? Who will be using the model?* By thinking about the end goal, expectations were that the students would better understand the role and function of the model, which in turn would support their breakdown of the project to determine all the parts and pieces that would need to be assembled for the project. The industry partner communicated the model development and management processes through a comparison of the two and with a recommendation that the students think in terms of the actual construction process.

Instruction was also provided about how to determine the purpose and use of the model for construction. According to the Uses of BIM Guide (Kredier & Messner, 2013), there are five purposes for using BIM on a project. The first purpose is to gather facility information. The second is to generate information about the facility. Third purpose is to analyze elements of the facility to gain a better understanding of it. The fourth purpose is to communicate information about a facility in a method that can be shared or exchanged. The final purpose is to realize a facility through the use of the facility information in the BIM. The Guide (Kreider & Messner, 2013, p. 6) defines BIM use as "*a method of applying Building Information Modeling during a facility's lifecycle to achieve one or more specific objectives.*" Typical uses for construction models include, but are not limited to, clash coordination, quantity take off (5D), schedule and sequence development and communication (4D), constructability reviews, site logistics or a combination of models.

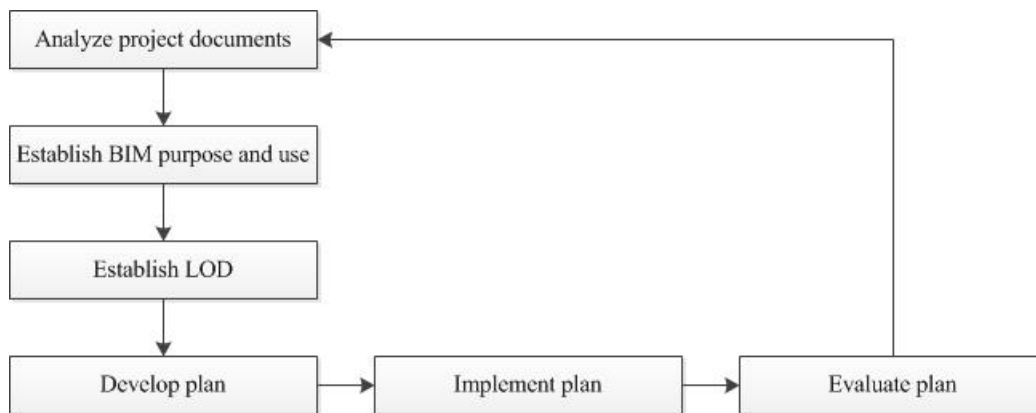
The students' previous exposure and experience with modeling software eliminated the need for instruction about the software; however students were expected to continue developing their skills through practice in previous course work. The instructor and industry partner agreed that it was critical for students to understand which software was best suited to use depending on the predefined BIM use; therefore, a review of each software's capabilities relative to the intended uses and modeling approach was provided.

Depending on the intended use of the model, the level of development (LOD) established for model elements will vary. For example, if the intended use is solely for the purpose of sequence coordination and schedule development, having all the wall elements developed to LOD 400 would be excessive. Instead of full information model elements, a high level sequence review would only require generic wall types. If the intended model use is a detailed schedule, then detailed wall assemblies might be required. Whereas, if the intended use is for both 4D and 5D then full information about each model element would be needed. Ideally the model development plan and model management plan would occur simultaneously; however depending on the project team and owner's requirements the planning activities may occur as separate activities. The ultimate goal is to design the development and management plans based on the model's purpose and use in the most effective, accurate and efficient way.

### **2.2.1 Model development plan instruction**

Lectures about model elements, project origin, grid lines, level elevations, and type properties were given by both the industry partner and course instructor. Additionally, the industry partner shared lessons learned and prior experiences from real-world projects for which there was no model development or

management plan. His objective was to provide students with insight about the value of the process in the real-world and to motivate students to think comprehensively about a project. Specific instruction was provided about how to identify the model's origin point; set up grid lines based on the origin point; plan construction phases; and sequence the construction of levels and areas. Students were instructed to think in terms of the construction process and were required to represent their process of modeling using diagrams and narratives about the elements, descriptions, and procedures for creating a model to meet its intended purpose and use. Critical to developing the plan was to develop comprehensive project knowledge; therefore students were instructed to allocate a significant amount of time to reviewing the project documents. The information processing steps required for developing a plan are displayed in Figure 1.



**Figure 1. Information processing for model development plan**

### 2.2.2 Model management plan instruction

Instruction about developing a model management plan was designed to integrate industry agreements, standards, and real-world BIM management experience. The AIA® Document 203™, G201™, and G202™ (AIA, 2013) documents were reviewed and discussed to provide an understanding about contractual responsibilities set forth for projects using digital data agreements. The BIM Project Execution Planning Guide (Computer Integrated Construction Research Program 2011) was used as the published document reference based on its adoption as a best practice standard by the National BIM Standard (National Institute of Building Science 2012). The Planning Guide provides a structured procedure designed to guide planning and direct communication by the project team during the preconstruction and construction phases of a project. Although the Planning Guide (2011) is considered an implementation plan for BIM at the project level, it was used in this course as a guide to develop the management plan as a control document for BIM implementation. Combined with the industry partner's experiences and company's procedures provided students with rich information and examples from which they could relate to and develop understanding.

Coordination of the model development plan with the model management plan was emphasized in terms of aligning the BIM purpose and use for the project. Instruction about process mapping, information exchanges, and supporting infrastructure was provided for students to develop an overall understanding of the procedure and the 14 categories of information to be included in the plan, which are listed in Table 1.

**Table 1. BIM Plan categories of information (Penn State, 2011)**

Categories	
1. BIM project execution plan overview information	8. BIM and facility data requirements
2. Project information	9. Collaboration procedures
3. Key project contacts	10. Model quality control procedures
4. Project goals/BIM objectives	11. Technology infrastructure needs
5. Organizational roles and staffing	12. Model structure
6. BIM process design	13. Project deliverables
7. BIM information exchanges	14. Delivery strategy/contracts

The industry partner's lecture provided students with an understanding about using the model management plan as a tool to establish standards for the project team. Additionally, the industry partner provided insight about important details that must also be specified in the plan, such as the model manager's responsibilities, frequency of team meetings, meeting objectives, and the goals for each meeting. He emphasized that the time spent planning in the early phases of the project would be time well spent by all team members.

### 3. ASSIGNMENT, ASSESSMENT, RESULTS, AND DISCUSSION

Senior level construction science students enrolled in a required BIM course were assigned the problem as their final project for the course four weeks before the deadline. Although it was an individual assignment, students were encouraged to seek input from their classmates. During the second week class session, students were required to exchange their draft plans with another student for a written peer review.

The instructional objective was to use plans submitted by each student as a summative assessment for the purpose of evaluating the effectiveness of their learning in the course. The student learning objective for the assignment was for students to create a development plan for the construction team's use and a model management plan for use by the project team, based on the project documents provided.

#### 3.1 Assignment description

The project for the assignment was new construction of a research laboratory on the university's campus. Students were given the full set of project drawings and specifications. They were informed that the university had selected CM at-Risk for the project delivery. In addition to the late entry of the construction manager to the project team as is typical in CM at-Risk, the owner would require the handover of a LOD 400 project model for facility management. The BIM goals for the construction team were prescribed in the problem statement as: 1) increase field productivity, 2) analyze options to reduce construction time, 3) develop accurate cost estimates, 4) track progress during construction, and 5) provide accurate record models for the facility management team. Given the goals specified, the construction team would be authorized to use the model for: 1) site utilization planning; 2) design reviews during preconstruction; 3) 3D coordination; 4) 4D phase planning; 5) cost estimation; and 6) record modeling.

Students were instructed to develop plans that would clearly communicate their plan for model development and management in a manner that another team member could effectively utilize the plan in their absence. A process diagram for the model development plan was required as one of the deliverables. The intent for the diagram was to aid the authoring student in the plan development process by using a visual representation, as well as support communication of the plan to others. The quality of

written communication would be evaluated in addition to the content within the documents. Quality communication was described as providing written and visual content in a professional manner. In addition to the plans, students were required to submit their assumptions with justifications for each plan.

### 3.2 Assessment

A rubric comprised of both objective assessment and subjective assessment was used to evaluate each student's performance. The decision to utilize this approach was two-fold. First, the problem itself has no 'correct' answer; therefore a pure objective metric was not feasible to assess student performance. Secondly, as stated in the learning objective, it was important that student's demonstrate their ability to create plans based on the documents provided. Although industry documents, standards, and guides were referenced, students had to interpret the documents then align them with the project requirements to create their two unique plans for the project.

A single rubric with five categories was used to evaluate submissions. Each of the five categories were evaluated independent of the other and contributed to the overall grade based on a weighted evaluation. Objective assessment was used for the model development plan, model management plan, and project knowledge. Both the development plan and management plan were each weighted 30%, contributing 60% to the total assignment score. Demonstrated project knowledge was weighted 15% of the score. Subjective assessment was used to evaluate document quality, which was weighted 15%; and the oral presentation was weighted 10%.

Assessment was designed based on the Bransford and Stein (1984) IDEAL problem solver process and strategies associated with four of the five stages in the process. The fifth stage – Look Back - was intentionally left out because students were not required to review and evaluate the effects of their activities. The problem solving category, strategy used, and brief description selected for this assignment are shown in Table 2.

**Table 2. Strategies for assessing problem solving (adapted from Bransford and Stein, 1984)**

Problem solving category	Assessment strategy	Description
Identifying and recognizing problems	Identify the problem	Assess how well the student identifies the problem to be solved.
Defining and representing problems	Model the problem	Assess how well a student's diagram represents the sequence of project elements.
Exploring possible solution strategies	Solve backward	Assess how well the student uses backward solution strategies to develop their plans.
Act on problem solution strategies	Evaluate the quality of a solution	Assess how well students acted on their selected strategy for developing their plans.

### 3.3 Results

The students' average performance score for the assignment was 85 out of 100 total points, which in qualitative terms was considered a 'good' score. Average score for each category however was: Model Management Plan 75; Model Development Plan 77; Project Knowledge 71; Document Quality 90; Presentation 86. Evident in the students' model development plans was an understanding of construction

sequencing and phasing, along with knowledge about model element assemblies identified for the project. Figure 2 displays an example of one student's structural model development plan that meets the requirements for the assignment.

**Structural** – The top of slab at gridline intersection M7 will be designated the origin (0, 0, 100). A separate model for each section A, B, and C shall be made for each level S, 1, 2, and 3. All elements shall be named in accordance with these parameters. All notes, including equipment required, connection types, element description, lead time, assembly code, concrete type, beam type, concrete depth, type of joist, etc. shall be integrated into the element. All elements should be created before modeling begins. Examples of naming elements are as follows:

- Piers: Structural – Pier – 18" Round – SA (sizes include 18, 24, 30, 36, 42, 48, and 60 inch)
- Pier caps: Structural - Pier cap – 4'6"x1'6" - SB
- Grade beams: Structural – Grade Beam – 2'x1' – SA
- Continuous strip footings: Structural – 2' Continuous strip footing - SA
- Slabs: Structural – Slab – 4" - SC
- Columns: Structural – Column – HSS7x7x1/4 – 1A
- Beams: Structural – Beam – W24 – 1A
- Joists: Structural – Joist - 18K3SP01 – 2C

**Figure 2. Excerpt from sufficient model development plan**

Deficiencies in the students' model development plans was a general lack of detail about organizing information in areas such as the identification of model elements to be created and the establishment of levels within the model. Additionally, details about the process, procedures, and methods to be used for model development were less than required. Displayed in Figure 3 is an excerpt from one student's submission that did not meet the model development plan requirements.

## **1. MAJOR COMPONENTS**

### **1.1. Structural Steel**

- 1.1.1. All primary, secondary structural steel members, gusset plates, bolts, clip angles and any item that may impact coordination with other disciplines to at least a LOD of 400.

**Figure 3. Excerpt from deficient model development plan**

Evident in the students' model management plans was the ability to utilize the AIA® documents and the Planning Guide sections required by the assignment. Figure 4 displays an excerpt from one student submission that met the model management plan assignment requirements.

Deficiencies in the model management plans were attributed primarily to incomplete information about the items included and a lack of detailed descriptions from the AIA® documents and the Planning Guide sections required by the assignment. There were also a number of sections missing from the plans submitted. Displayed in Figure 5 is an excerpt from one student's submission that did not meet the model management plan requirements.



### 3.6.1 Design Coordination and Clash Detection

- It is the Design/Construction Team's responsibility to conduct and manage an adequate and thorough Clash Detection and Design Coordination processes so that all major interferences between building components will have been detected and resolved before construction. It shall be the goal of the Design/Construction Teams to reduce the number of changes during construction due to major building interferences to zero.
- The BIM Manager shall assemble a composite model from all of the model parts of each design discipline for the purpose of performing a visual check of the building design for spatial and system coordination. Vertical shafts should also be reviewed to ensure that adequate space has been allocated for all of the vertical mechanical systems and that all of the shafts line up floor to floor. Prior to each scheduled coordination meeting, an updated clash report will be issued by the BIM Manager to the technical discipline consultants.
- The models may need to be split on a level-by-level basis for coordination
- Coordination software shall be used for assembling the various design models to electronically identify, collectively coordinate resolutions, and track and publish interference reports between all disciplines. The technical disciplines shall be responsible for updating their models to reflect the coordinated resolution.
- The team shall review the model and the Clash Reports in coordination meetings on a regular as-needed basis throughout the design phases until all spatial and system coordination issues have been resolved.

**Figure 4. Excerpt from sufficient model management plan**

**3D Coordination**

- The Project Team will use clash detection software during the coordination process to:
  - Determine field conflicts by comparing 3D models of the project
  - Eliminate the major system conflicts prior to installation
  - Visualize construction
  - Increase productivity
  - Reduce construction cost
  - Decrease construction time
  - Create more accurate As-Built drawings

**Figure 5 Excerpt from deficient model management plan**

### 3.4 Discussion

One possible reason why scores on the model development plan were higher is that the development plan may be associated with the student's ability to relate more their specific prior learning experiences in courses such as print reading, quantity surveying, scheduling, and cost estimating to the development plan requirements. In the previous courses students received instruction about how to create a work breakdown structure (WBS) and how to perform core construction project activities within each subject. As a result, senior level students have had multiple learning activities focused on building assemblies and sequencing, which may have contributed to their ability to create a model development plan at the construction operations level. In contrast, developing a model management plan would require more

knowledge about management concepts and more strategic thinking about interactions between team members' and the integration of information from multiple perspectives.

Given the results presented above, the assignment was revised and distributed in the next year's course offering. The revised assignment requirement was for a model development plan only and focused on improving the students' ability to plan in advance of starting a project. The decision to delete the model management plan was due, in part, to the fact that the course did not permit for a multi-disciplinary team experience, thus resulting in a purely hypothetical plan with no input from the design team. The revised assignment's time of distribution was also changed to be the course mid-term instead of the final. Changing the point at which the assignment was distributed in the semester was done to allow students the time to actually create an architectural model for the project using the model development plan they had just written. The idea was that by first creating a development plan, students would then use their plan as a guide while they were actually modeling the building from a set of 2D drawings and specifications.

In addition to a revised assignment, the rubric was also revised and categories of evaluation were weighted differently. The revised rubric included the same measures, but distributed the weights as plan content 40%; project knowledge 35%; and document quality 25% of the total score. The revised rubric also included more definition for each metric. Although assessment of the results for the revised assignment in the second year was not complete at the time of this paper, there appears to be incremental improvements based on initial student feedback about their lessons learned during the modeling activity and how those lessons influenced revisions to their model development plan.

#### **4. IMPLICATIONS FOR FUTURE INSTRUCTION**

As contractors continue to implement BIM for preconstruction and job site activities, the need for BIM knowledge and skills expected of construction graduates is increasing. The use of BIM for job site planning, 3D coordination, 4D planning, cost estimating, and safety planning have all gained momentum (McGraw-Hill, 2012; Dodge Data & Analytics, 2015). Industry wide the importance of safety planning has become critical and multi-national companies such as Balfour Beatty, Turner Construction, and Skanska are utilizing BIM to model the job site, safety elements, and construction details for the purpose of identifying risks and mitigating those risks before they become a problem (Dodge Data & Analytics, 2015). One of the biggest challenges recently expressed by Turner Construction's national BIM manager, Jennifer Downey, is "...the modelers must be very knowledgeable, understand the modeling process, and construction phases and processes." (Dodge Data & Analytics, 2015, p. 20).

The fact that industry's experience with BIM use has revealed that modelers must understand both the modeling and construction processes provides support for further instruction and classroom experiences like the example discussed in this paper. Instruction and course activities that require: 1) finding solutions to problems that have no single correct answer, 2) integrating the construction process into modeling, and 3) planning before beginning the modeling process, are needed to prepare students for their future career as a construction professional. Plans to revise the assignment before the next course include additional instruction about the model development process, followed by practice problems in which students will practice developing a plan to model one work package before preparing a plan for the entire project. The additional instruction will focus on the more general aspects of planning and representing the plan with a process diagram.

#### **5. CONCLUSIONS**

Based on the experiences reported by the course professor and industry partner, providing instruction to students about how to create a plan before starting a task was a greater challenge than originally expected.

The challenge for students seemed to be centered on solving an ill-structured complex problem. Ill-structured problems are described as having no explicit means for determining appropriate action and require that students express personal opinions or beliefs about the problem, while making judgments about the problem (Jonassen 1997). Additionally, ill-structured problem solving is an iterative process that adds to the complexity of the problem solution. Observations by the instructor and industry partner about the students' problem solving process was that it was linear instead of iterative. Students were also uncomfortable with the lack of clarity about the correct answer, or more specifically what the correct plan was for developing the model. There were many questions from students that reflected their discomfort with uncertainty. Typical questions from students were: "Where do we start?" "What is right and what is wrong?"

Many students were challenged with understanding the planning concept and its value to the modeling process. They had an impulse to just "do" and start modeling in the software. The task of planning was definitely not the first step in their typical process of developing a model. Even with the industry partner sharing his negative experiences about modeling without a plan, and the value added by planning the management of BIM on a project, students were hesitant to create their own plans. The hope is that this assignment and the challenge of creating a plan to solve a unique problem will help students realize how *time spent planning is time well spent*.

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# SITE-BUILDING INTEGRATED BIM MODELS: LESSONS LEARNED IN EDUCATION

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## ABSTRACT

This paper presents a review of different approaches taken over the last ten years in developing site-building integrated BIM models for educational purposes and 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.

The authors have been dealing with many challenges throughout their professional and educational experiences in teaching courses, advising student projects and theses as well as in conducting research in promoting site-building integration as part or as the main emphasis of their educational activity. This paper describes and compiles the more significant of these experiences in terms of lessons learned from which some basic principles related to the development of site-building integrated BIM models are established and applied to current and future curriculum development

**Keywords:** BIM, Site-Building Integrated Modeling, BIM-based Educational Activities

## 1. INTRODUCTION

Integrating the site and building together into one model allows one to no longer design, analyze and plan for the construction of a building in isolation from its surroundings but incorporates extremely helpful short-term and long-term information for the owner, designer, and builder regarding the neighborhood, site topography, landscaping, access roads, ground conditions and the location of site utilities.

Traditional curriculum educational design in civil, environmental and architectural engineering undergraduate programs is composed of fragmented elements specializing in specific knowledge domains. When one thinks of the built environment there is a natural major division separating buildings from infrastructure facilities. Coursework content typically reflects this breakdown.

With the continuous but rapid change in software development supporting the delivery of course work in design and construction planning this traditional fragmentation is gradually being blurred. The information content and 3D visualization capabilities of this software is becoming richer and more powerful facilitating and promoting collaboration among multiple design and construction disciplines. Thus leading to the design of course work that integrates students learning of separate disciplines or by providing a richer and broader context for learning specialized knowledge.

Geographic Information Systems have been, for many years now, the technological platform used for the capture, manipulation, management, analysis and 2D graphic representation of all types of spatial or geographical data. On the other hand, Building Information Models (BIM) use parametric modeling and object oriented technology to create 3D visualizations from a database that contains information about the building components. The relative recent technological movement to integrate GIS and BIM is starting to take place in the market thus facilitating the development of site-building integrated models (Przybyla, 2010). In January 2014, the Transportation Research Board AFH30 and the building SMART Alliance conducted a joint workshop to attract interested parties in discussing strategies for digital project delivery as an expected product for the building and infrastructure industry moving into the information age (Smith, 2014). Participants from both vertical (buildings) and horizontal (infrastructure) capital projects discussed research efforts to have both platforms used in the development of site-building models emphasizing Construction and Facility Management (Dossick, 2014), Horizontal (Civil) Information Modeling (Christian, 2014), and Bridge Information Modeling (Chen, 2011). Among other important conclusions the following needs were recognized:

- to develop metrics for setting baseline goals and measuring progress
- to continue development of open standards
- to focus on education at all levels
- to develop an overall high level information architecture to connect all the dots

## 2. EDUCATIONAL OBJECTIVES WITH SITE-BUILDING INTEGRATION

In an educational setting, traditionally, students use and learn GIS and BIM technologies in the support of different subjects taught in separate courses. However, buildings do not exist in the vacuum but in the geographical context of the site on which they are built. The question for the educator becomes how to efficiently package and coordinate the body of knowledge of traditionally separated subjects into an integrated approach that a current and constantly evolving technology is becoming more and more capable to support. There is also the question of how much time and effort should students dedicate to the learning of the technological tools without distracting their learning efforts on the academic subjects.

With open standards and software interoperability improving every day one only hopes that these challenges disappear soon enough. However, this have been a seemingly perennial expectation regardless. New software applications as well as updated versions of existing software and the use of internet-based servers and applications (cloud) continue to challenge educators to constantly update their teaching material to accommodate for changes in the technology while at the same never lose track of the educational objectives of the subject being imparted.

There are essentially two Building Information Modeling courses imparted at WPI for which the above stated challenges seem to be ever present: an undergraduate course CE3031 “BIM: Software & Tools”, and a graduate course CE587 “BIM Advanced Concepts”. CE3031 introduces students to fundamental software applications for design and construction planning throughout the different phases of the development of civil engineering projects. The course covers the principles of basic 3D software environments, object creation and manipulation, assemblies of objects, surface and terrain modeling, building modeling, geographic and building information databases. Emphasis is given to the adaptability of this software to changes in design and to the production of graphic design documentation. Application software such as Autodesk Civil 3D®, Revit® and Navisworks are used in this course. Throughout the term, students work in groups applying the knowledge acquired in class to develop a Term Project that includes components involved in the planning and design of a fictitious industrial park. CE587 reviews fundamental concepts for collaboration and integration; it also reviews technologies that support the BIM approach and provides discipline specific as well as global perspectives on BIM. The course format includes formal lectures, computer laboratory sessions, student presentations based on assigned readings and a project developed collaboratively by the students throughout the course. Guest speakers are also invited based on the topics covered and discussed in class.

The development of an integrated site-building model is part of these two courses. In CE3031 the students first use Civil 3D® software to subdivide a large parcel of land into industrial lots. Subsequently the students use REVIT® software to design and plan the construction of a warehouse building in one of the previously subdivided industrial lots. Ideally, the DWG site should be imported into REVIT® to serve the basis for the warehouse building design (architectural, environmental and structural) and construction planning (site logistics and 5D modeling) Unfortunately this apparently simple interoperable operation requires additional time of execution and instruction not available in the course.

This very same operation is conducted as part of one lab in CE587. However, the specific way in which this lab is conducted needs to be adapted every year as the interoperability issues change with software updates. At one time, the photographic view of the site was imported from Google Earth into the Civil 3D® file at the same time the topographic contour of the site was also imported directly from USGS database into the Civil 3D® file. Then the DWG file was exploded to create a 3D site file to be imported into REVIT®. This is no longer possible since Civil 3D® does not support the Google Earth interaction. At some other time, it was attempted to reverse the process and import a REVIT® file exported in ADSK format into Civil 3D® which works fine but the 3D visibility is relatively poor since the images are rendered as wireframes. Alternatively the 3D DWG file is imported into REVIT® software and linked to another REVIT® file containing the building. As it stands right now, the instructor has been attempting to replace the use of Civil 3D® with Autodesk Infracore which in theory improves the interoperability and quality of the 3D visualization but brings with it some new issues that need to be addressed in a satisfactory manner before it can be implemented in any of the two courses.

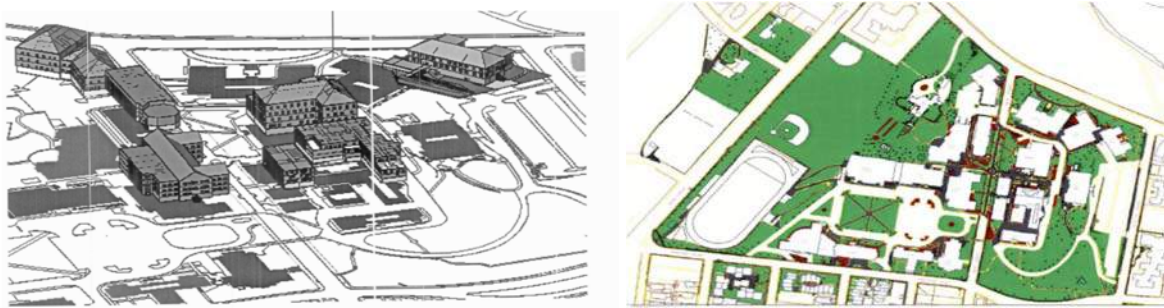
### **3. STRATEGIES FOR COURSE MATERIAL DEVELOPMENT & LESSONS LEARNED**

In order to develop material that could be efficiently used in course work, the instructors rely on work that explores and implements the constantly changing technological software and information technology developments through graduate theses and projects as well as undergraduate Interactive and Major Qualifying projects (Conron and Salazar 2008), (Salazar et al. 2013). The following section briefly describe these experiences and summarizes the results through lessons learned in these activities.

**WPI e-campus.** A series of Interactive Qualifying Projects advised by one of the authors and Prof. Fabio Carrera from WPI were conducted by several groups of students between 2004 and 2007. In these studies GIS (supported by MapInfo software) and BIM (supported by REVIT® software) were first combined in an attempt to produce integrated site-buildings models for the WPI campus. The studies included the development of a geographically –based information system:

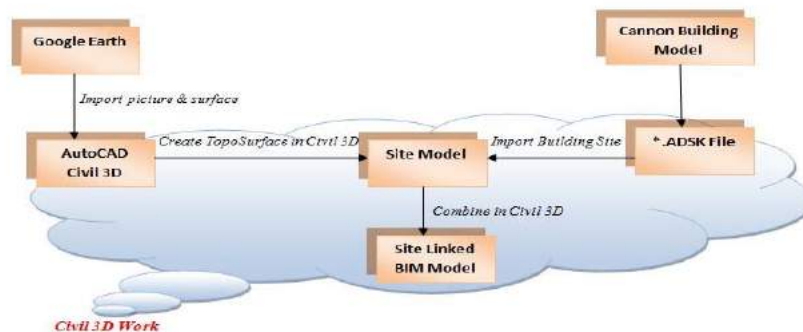
- to track environmental hazards and fire safety equipment on five campus buildings (Brault et al. 2005). See Figure 1 left frame below
- to support coordination of maintenance and preservation of grounds (Currier et al. 2004), (Prestileo et al. 2005),
- to analyze efficiency of parking areas (Dumas et al. 2004) .. See Figure 1 right frame below
- to support maintenance of trees and planting beds on campus (Ahmed et al. 2006)
- to support maintenance of building systems (Halilaj and Mills 2006).

This extensive set of studies produced a very rich information database as well as a very valuable graphic information. However, the three dimensionality of the BIM models produced in REVIT® for the buildings needed to be made available in 2D form to be of practical value for the ultimate users of the information who in general do not have access nor know how to operate REVIT® software.



**Figure 1 E-Campus: Buildings-Site; Trees and Planting Beds**

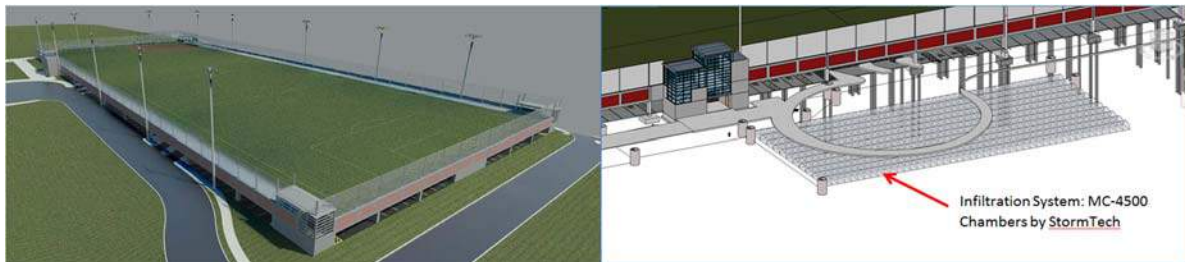
**WPI Site and Recreation Center.** In September 2011 a graduate thesis dealing with site-building integration was completed (Wang 2011). The objectives of this thesis were to explore current organizational and technological issues preventing this integration and to investigate a feasible method to create a site-linked BIM model. It also discussed the benefits and limitations of bringing BIM concept to the site conditions. Current applications of Geographic Information Systems (GIS) were reviewed as well related BIM software developed by three different vendors. A case study based on the design and construction of the WPI Recreational & Sports Center, was developed to explore and understand the details that are involved in creating a new site model and to link it with the existing 3D building model. It was recommended to create 3D BIM Campus Map using primarily Civil 3D® (see Figure 2) because most of the site modeling work, in particular the underground site utilities is better supported by Civil 3D® rather than Revit®. However, 3D visibility using Civil 3D® is rather limited. It was recommended to explore the use of Bentley software for the development of the 3D site model.



**Figure 2: Recommended Approach for Site-Building Integrated Model**

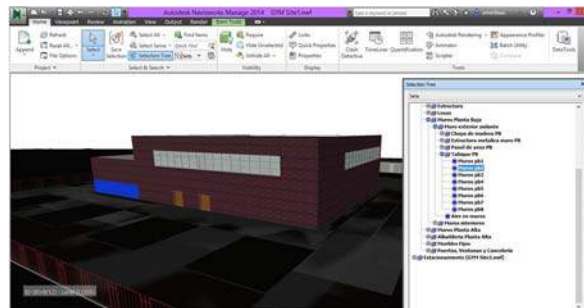
**WPI Parking Garage and Rooftop Athletic Fields.** In spring 2012, two PhD students carried out an independent study on Integrated Design using the WPI athletic field/parking garage case (Alvarez and Gomez 2012), (Salazar et al. 2014) The study objective was to evaluate the advantages and feasibility to use a BIM-Enabled Integrated Design approach in a real project for the design development stage. In the actual project two BIM models were used but not shared, the architect had its architectural model that was used for project presentation and for producing some of the construction drawings; the structural fabricator had its own structural model of the precast concrete structure and he used the model for fabrication purposes. The students produced a third model that included the structure, the architectural, the site and some of the plumbing, mainly the rooftop field drainage and the concession's zone plumbing. The development of the students' model was two weeks behind the actual design process since the information presented in the design review meetings was used for creating the model. The creation of the students' model allowed to detect some of the actual issues found later in the construction stage. The integration of the site to the model was a key to detect some of these issues, such as the need of two

retaining walls that were not considered in the initial design. The site was imported from the existing conditions file provided by the civil engineering contractor. The file format was Civil 3D® and was imported into the Revit® model and converted to a topo-surface entity. All of the grading, sidewalks and pavements were modeled in Revit®. Even when it was possible to model the proposed site design inside Revit®, its tools are basic and a lot of effort was necessary to achieve the proposed site design. The same result could had been obtained with less time and effort using the proper tools in Civil 3D®, and then import the proposed site into the Revit® model. This model was further developed through a CE587 Term Project (D'Angelo 2014) by adding: 1.Storm water drainage at the structure's southern area. 2.Sanitary pipes under the locker room and bathroom areas in the western region. 3.Electrical conduits in the garage for lighting. These added elements were created with a LOD 100. Figure 3 below shoes the model



**Figure 3 WPI Parking Garage and Playing Fields site-building integrated model**

**WPI-UADY Virtual Construction Methods course.** In 2013 a sponsored project was conducted on the design of a course for teaching construction methods using a virtual design construction approach (Salazar et al, 2015). Typically bringing the student the large amount of information as a first time exposure makes it difficult the retention and deep understanding of the implication inherent to the construction method; the proposed course includes a term project of a hypothetical but realistic construction project, defined in the context of a typical scenario where a contractor is preparing the response of a request for proposal. The scenario confronts the student to the challenge of defining the construction strategy for the project, where decisions need to be made for selecting the appropriate construction methods and evaluating each alternative with a "What if?" approach, using Virtual Design and Construction Tools. An important part of a successful construction strategy is to take into account the existing conditions and site utilization, therefore the BIM model used in the course has a detailed site, with both, existing conditions and proposed design. The site model has excavations, grading, pavements, sidewalks, trees, for the existing and proposed site. The site was modeled using Civil 3D®, for both, existing and proposed states, then imported into the BIM model with the building. The course has been taught twice and so far the students achieved to understand the main complexity of defining a construction strategy taking into account the existing conditions of the site. Figure 4 shows the model



**Figure 4 Site-Building Integrated Model for Virtual Construction Methods Course**



**WPI 3D campus.** In the spring 2014 as part of the work agenda for a group of four visiting students from UADY to WPI, a short project was developed using Infracworks 360® to integrate 20 BIM models of WPI buildings in a campus site. The project scope was to learn the software, bringing the site from the USGS into Infracworks 360®, insert the buildings in the proper location, orientation and elevation into the site, model the roads of the campus, model the sidewalks of the campus, model the landscape of the campus including yard zones and main trees. Bringing the site was the easy part as this is one of the strengths of Infracworks 360® which automatizes this procedure, importing the site including elevations and satellite images; the roads, sidewalks and landscapes were modeled by using satellite imagery as reference, sacrificing some accuracy but speeding the process; the most challenging part was to bring the models from Revit® into Infracworks 360®, as most of the models had high complexity and LOD from 300 to 400, making the software inoperable due file size, the solution was to export the models to a light non-editable version in order to properly manipulate the campus model. The students were able to create a virtual fly-trough video for final presentation of the project, all this was achieved in a period of three weeks. Figure 5 shows the model.



**Figure 5 3D Site-Building Integrated model for WPI campus**

**WPI 3D campus with Underground Utilities.** In the Spring and Fall 2015 two Independent Graduate Studies were conducted as a follow-up to the work conducted by the four UADY students in the winter. Originally, it was intended to further develop the material created during the winter by adding the underground utilities to the previously BIM-based 3D WPI campus. It was also intended to apply the lessons learned in the development of class material for the CE3031 and CE587 courses. However, the files created using Infracworks 360® could not be opened by the software installed in the students' PCs and laptops. Therefore the first study (Padhye 2015) was dedicated to document the necessary steps to create the 3D site by importing all necessary USGS layers into Infracworks®. The second study (Atanasova 2015) built upon the first and recreated a small section of the 3D campus that included the surface and underground infrastructure and the BIM models of two surrounding buildings. In this case the most challenging part of the work was importing the Revit® file into the site as well as sharing the Infracworks® database between student laptops. Figure 6 shows the model.



**Figure 6 Site-Building Integrated model with underground utilities**

In conducting these studies, many challenges and obstacles had to be overcome. Infraworks® files grow in size very quickly as one adds objects and information to the combined site-building model. File versioning and geo-positioning can also present challenges and must be carefully planned and coordinated including the use of auxiliary software like Navisworks®. Modeling piping tools in Infraworks® still needs improvement. There is no full certainty on the accuracy of vertical dimension on the underground infrastructure unless the information is created with as-built documents.

#### 4. CONCLUSIONS AND FUTURE WORK

The above experiences have produced insightful and practical concepts as to how to develop and implement a site-building integrated model. These have been used to a large extent in the production of course material for CE3031 and CE587. The creation of the integrated site-building model is certainly one that depends on the interoperability between a primarily site-based software application and a building – based software application. The site and the building can certainly be integrated. However, due to constant changes on the software features and capabilities the interoperability process to integrate the two models requires constant research and updates. Table 1 below summarizes the major features and capabilities of two software applications REVIT® and Civil 3D® that have been used in the development of course material for CE3031 and CE587. A third column shows Infraworks® a site –based software that certainly promises improvement particularly in the area of 3D visualization. Nonetheless, this is a relatively recent application and a implementation of this software is still in the learning curve stage.

Functionalities	Building (REVIT)	Site (Civil 3D)	Site (Infraworks)
3D visualization	Good	Fair	Good
Modeling Underground Utilities	Limited (MEP)	Good	Good
Toposurface Modeling	Fair	Good	Good
Grading	Fair	Good	Good
Cut & Fill Calculation	Good	Good	Good
File Size Integrated Model	Limited	Limited	Limited

**Table 1: Comparison of Site & Building software Functionalities**

Based on the above study and lessons learned it is the purpose of the authors to gradually move to Infraworks® as the site-based software application in the production of course material for the development of site-building integrated models. This should result in streamlined interoperability procedures but it requires additional research work not only in exploring the design, visualization and applicability features of this software. One should also consider the way that the software vendor will continue to deploy it. The increase use of cloud-base software applications can be a “double-edge sword” in the sense that it would allow faster processing and larger file size creation but as it has been observed so far it limits access to students due to user licensing cost.

Much better online software tutorial materials are also becoming available for students and instructors at reasonable costs. These resources simplify dramatically the amount of effort that instructors need to invest year after year in updating their knowledge and updating their software-based course material.

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## COLLABORATION WITH BIM: AN EXPERIENTIAL LEARNING CASE

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### ABSTRACT

Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward. It is clear that BIM is the trend of the future, with increased use documented in the construction industry in the last few years. To sustain the momentum of BIM, effective workforce development that aims to balance the supply-demand equation in the labor market is essential. This paper presents an experiential approach adopted to BIM-enabled learning to investigate collaboration with BIMs. Around many uses of BIM, the researchers selected their primary roles creating a BIM team and explored the interoperability of selected tools to operate their tasks. In this creative and collaborative process the researchers gained some skills for BIM capabilities of the integrated design project by using various course materials and software licenses provided for their use in a limited time frame. This methodology allowed the researchers to experience integrated design process in a realistic way and helped them to learn how different tools and methods integrate with each other. Experiences in integrating BIM in terms of learning by doing into the 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 engineers/architects of the future who will be actively using BIM routinely.

**Keywords:** BIM, Experiential Learning, Interoperability, Integrated Design, Sample Courses

### 1. INTRODUCTION

The proposed definition of Building Information Modeling (BIM) by the US National BIM Standards Committee (NBIMS) is "The digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it and forming a reliable basis for decisions during its life cycle, from earliest conception to demolition."

BIM is not simply a software package, but a human activity that ultimately involves broad process changes in the construction industry. Procurement of building projects has become more complex and technically demanding. We need to recognize that all sorts of people populate the territory of BIM: (1) design professionals such as architects, architectural engineers, structural, civil and MEP services engineers, specialist subcontractor designers (cladding, building envelope design, MEP building services, and environmental technologies), specialist consultants (acoustics, environmental applications) and technologists; and (2) construction professionals such as the quantity surveyor, project manager, construction manager, planning consultant, regulation specialist and others all have to be integrated into the project delivery process.

Working with BIM increases the need for co-ordination, and management of design and construction processes and collaboration. Although a growing number of architecture, engineering, and construction programs have begun to offer courses that include BIM-related content, few programs have strategies in place to fully integrate BIM across the curriculum. This paper presents an experiential approach adopted to BIM-enabled learning to investigate collaboration with BIMs. Around many uses of BIM, the researchers selected their primary roles creating a BIM team and explored the interoperability of selected tools to operate their tasks. In this creative and collaborative process the researchers gained some skills for BIM capabilities of the integrated design project by using various course materials and software licenses provided for their use in a limited time frame.

## 2. LITERATURE

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.

Educational institutions are either already providing, or preparing to provide, BIM education at both undergraduate and graduate levels. The industry's reluctance to change, and a shortage of experienced/educated BIM practitioners/ technicians/ educators is slowing the inevitable uptake of BIM in the AEC industry (NATSPEC 2013, 2014).

The technology is advancing in a rapid fashion. The next decade the acceleration of change will be much more. Knowledge and skills can always be acquired and learned. The real skill is to adapt the change and see possibilities in new situations by following the agenda (BIM Handbook, 2010). According to Turk and Gerber (2011), the rapid movement from CAD to BIM by professional architects, engineers and construction managers has created several challenges and opportunities for educational programs. Most of the programs started offering BIM courses during the 2006 to 2009 timeframe. Architecture programs started offering BIM courses earlier than the engineering and construction management programs.

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 Arditi, 2014).

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. Succar et al. (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.

The value that degree education adds to the professional and to the industry needs to be determined. Industry always wants to employ individuals with experience; as a result, it is rare for companies to offer placement to students with no experience who want to work on site. For professionals, it is important to acquire managerial skills and to understand the process. Soft skills and team-working skills are needed. Graduates can leave university with a broad picture of the industry if they are exposed to a realistic simulation of construction projects in their studies. For many, experience with BIM begins in academia. The challenges reside in the classic gap between academic focus on disciplinary principles and the industry needs for specific application proficiency. As a result, architecture and civil engineering education needs to embrace the opportunities provided by BIM and overcome the challenges presented by BIM to remain current and relevant.

### 3. LEARNING METHODOLOGY: EXPERIENTIAL LEARNING

According to Felicia (2011) experiential learning is the process of learning through experience, and is more specifically defined as "learning through reflection on doing". The general concept of learning through experience is ancient. As Aristotle also stated around 350 BCE "for the things we have to learn before we can do them, we learn by doing them". But as an articulated educational approach, experiential learning is of much more recent vintage. Beginning in the 1970s, David A. Kolb helped to develop the modern theory of experiential learning, drawing heavily on the work of John Dewey, Kurt Lewin, and Jean Piaget (Dixon, Adams and Cullins, 1997).

Experiential learning outline reproduced in Figure 1 (Kolb, 1984) focuses on the learning process for the individual. The concrete experience forms "the basis for observation and reflection" and the learner has the opportunity to consider what is working or failing (reflective observation), and to think about ways to improve on the next attempt (abstract conceptualization). Every new attempt is informed by a cyclical pattern of previous experience, thought and reflection (active experimentation).



Figure 1: David Kolb's Experiential Learning Model (ELM), reproduced (Kolb, 1984)

Experiential learning requires self-initiative, an "intention to learn" and an "active phase of learning" (Moon, 2004). According to Kolb (1984), knowledge is continuously gained through both personal and environmental experiences. Kolb states that in order to gain genuine knowledge from an experience, the learner must have four abilities: (1) be willing to be actively involved in the experience; (2) be able to reflect on the experience; (3) possess and use analytical skills to conceptualize the experience; and (4) possess decision making and problem solving skills in order to use the new ideas gained from the experience.

Kolb's cycle of experiential learning is used as a framework for this study. And the research process in this study is designed through "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 researchers are individually encouraged to directly involve themselves in the different and diverse experiences in using BIM 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, construction and operation and supposed to retain the information for a longer time.

### **3.1 Software Packages and Training Materials**

Autodesk Revit Architecture and Structure, Navisworks Manage and Green Building Studio; Sefaira, Tekla Structures, Vico Office, and Synchro Professional software packages are provided; and, related online training and support materials such as video tutorials, webinars, help files, training manuals and community networks are used to investigate the design integration and interoperability of the BIMs created by the researchers for this study.

### **3.2 Industry Partnership**

#### ***Collaboration Workshop: A Real Life Experience with Industry Partnership***

Researchers participate in a Collaboration Workshop hosted and held by Environmental Systems Design (ESD, a leading MEP Design Consulting Company) as the Industry Partner for experiencing worksharing and an integrated design environment. The workshop involves solving a real life problem and is facilitated by the instructor and an industry partner. In this workshop, students experience being in a worksharing environment, being a part of an integrated design team, understanding the use of information in different formats such as design files (DWG, RVT, RFA, IFC, DB1, DB2, INP, CSV, IDF, DWF, DWFx, SP, NWD, NWF, NWC, GBXML, VICO, REPX etc.), spreadsheets (XLSX), documents (DOC, REPX, PDF), and all kinds of files containing multi-media information such as rendered images (JPEG, BMP, PNG), and animations (AVI, MOV). After the workshop, researchers are expected to understand that (1) implementing BIM is much more than learning how to use a software suite, (2) effective BIM requires integrated teamwork and collaboration, and (3) interoperability between platforms is a key issue. Participation of industry professionals who present best practices for working in an interdisciplinary team using BIM and provided feedback from the professionals help the researchers with a support system for advancing their knowledge and skills in the areas of decision-making and facilitate the selection of alternative project solutions based on valid information from credible sources.

#### ***Design Review: Role Playing and Oral Presentation***

With the collaboration of ESD as the Industry Partner researchers hold a design review session which helps them improve their oral presentation skills and understand real world cases by role playing. Role-playing emphasizes the social nature of learning, and see cooperative behavior as stimulating researchers both socially and intellectually. A list of roles and responsibilities of the researchers at the design review workshop held through role playing in this study is presented in Table 1.

#### ***Research and Development Expo: Poster Presentations***

A R&D Expo for Engineering Undergraduate Summer Research Immersion Program is organized by Armor College of Engineering at Illinois Institute of Technology in the final week of the study. Researchers use their poster presentation skills and get a feedback about the research.

Table 1: Defined Roles and Responsibilities.

	Researcher 1	Researcher 2	Researcher 3	Researcher 4	Researcher 5	Researcher 6
<b>Role</b>	Architect	Structural Engineer	Model Coordinator	Cost Estimator	Scheduler	Energy Modeler
<b>Task</b>	Program architectural model Create architectural model Design architectural model Analyze daylight	Design structural model Analyze structural system Coordinate with models	Coordinate with models Review design Detect clashes Report clashes	Coordinate with models Take off quantity Estimate cost Analyze cost	Coordinate with models Plan phases Visualize Simulate: produce and control animations	Manipulate model Analyze environmental inputs Analyze energy use Create feedback for design options
<b>Skill</b>	to manipulate, navigate, and review a 3D model knowledge of design means and methods design experience to assess a model through daylight analysis tools	to manipulate, navigate, and review a 3D model knowledge of construction means and methods design and construction experience to assess a model through structural analysis	to manipulate, navigate, and review a 3D model to model photo realistically easily navigable by using different software or plug-ins strong sense of coordination. understanding roles and responsibilities of team members understanding of how building systems integrate with one another	to define specific modeling procedures to identify quantities to manipulate models	knowledge of scheduling and general construction process. to manipulate, navigate, and review a 3D model. knowledge of 4D software	knowledge of basic building energy systems knowledge of compatible building energy standard knowledge and experience of building system design to manipulate, navigate, and review a 3D Model to assess a model through engineering analysis tools
<b>Tool</b>	Revit Architecture, Sefaira, BIM Glue	Revit Structure, Tekla Structures	Revit Architecture, Revit Structure, Navisworks Manage	Revit Structure, Vico Office	Revit Architecture, Revit Structure, Synchro Professional	Revit Architecture, Green Building Studio, Autodesk 360 Cloud Service

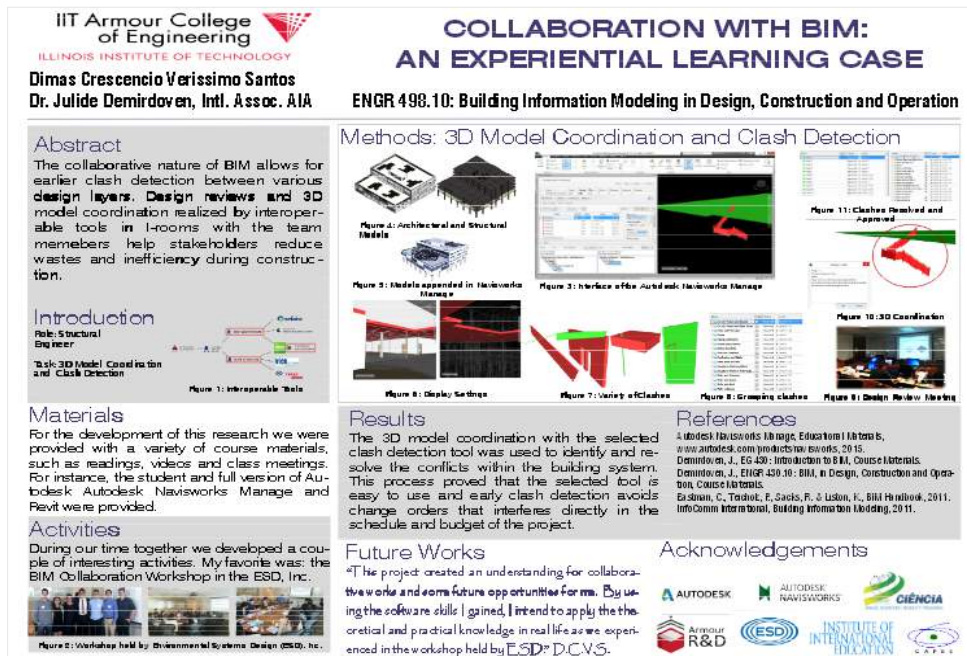


Figure 2: A Sample Poster Presentation-Model Coordination and Clash Detection with BIM



### **3.3 Shared Research Contents**

#### ***3D Modeling for Integrated Design Purposes***

The shared research content for 3D modeling and integrated design purposes covers all design aspects and tools of BIM. In addition, the BIM workflow, parametric modeling, interoperability, sustainability, and collaboration issues are discussed using hands-on software training. The instructor focuses on providing instruction for students on the processes and tools that would enable the students to perform the responsibilities for their specific disciplines.

#### ***Management and Control with 4D and 5D Models***

The shared content about management and control with BIMs aim to demonstrate how construction management functions are impacted by BIM and helps students to understand the fundamentals and practical uses of information technologies in the construction industry. The content covers the informative solutions (1) to understand the concepts of BIM, (2) to review software and technology available for BIM, (3) to understand how to use a model created by a BIM software in construction management, (4) to use BIM to check for interferences and conflicts on a building construction project, (5) to explore construction scheduling using BIM, (6) to explore cost estimating using BIM, (6) to explore how BIM can assist in facility management, and (7) to use different software packages as a construction management tool to create and present construction analysis and reports.

#### ***BIM Project Execution Plan: Experiencing Teamwork and Strategic Planning***

Teamwork begins with identifying the BIM goals for the project. Traditionally, the goals are based on project performance, and advancing the capabilities and experience of the project team members. The BIM Project Execution Plan provides a framework for the fundamental coordination strategy that the student teams can use for their projects and a template for the teams to define the BIM goals and uses, the execution process, the deliverables and also the infrastructure for the implementation of the projects (CIC, 2011). The research team is formed by defining their primary role in the group. The researchers are aware of the general project background. This information allows them to develop and complete the BIM Project Execution Plan and practice it for design integration. Integrated practice requires collaboration among team members, and BIM depends upon unrestricted information exchange between all team members involved in the building process. In order for this collaboration and information exchange to work successfully in BIM, a project team must create and implement a detailed comprehensive plan for the project (AIA, 2007).

## **4. EDUCATIONAL FOUNDATION OF BIM ENABLED LERANING AT IIT**

The increased use of BIM has brought about new roles such as the BIM manager, coordinator, leader, champion, 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. According to Demirdoven and Arditi (2014) the role of the BIM profession is to form an interface between the design and construction processes by minimizing information overload and producing only what is needed. The BIM curriculum at IIT targets improving BIM software skills (ability to create, understand and interpret BIMs), covering design and construction processes in an integrated environment, and stimulating BIM professionals' collaboration with other construction professionals. This curriculum helps students to understand the plurality in the construction professions.

A study conducted by Yalcinkaya and Arditi (2010) investigated the extent to which BIM was being taught in civil engineering programs in the US and came to the conclusion that a set of courses need to be offered that cover not only the basic aspects of BIM but also the management of a project designed using BIM. The potential for a joint undertaking was then explored between the Engineering Graphics Program

and the Construction Engineering and Management Program at IIT. Finally, the Department of Civil, Architectural and Environmental Engineering incorporated BIM into its curriculum in 2011 through the introduction of two course offerings: (1) EG 430 -Introduction to BIM, the senior level elective in the Engineering Graphics Program; and (2) CAE 573 - Construction Management with BIM, a graduate level elective in the Construction Engineering and Management Program.

## 5. SELECTED ROLES AND MODEL COORDINATION TASKS

Identifying the interoperability issues remains difficult without leaning towards areas of generalization and gaining software skills. Nine different BIM tools are utilized in this research to address this issue. Such approach is adequate for most project requirements. Software vendors play substantial role in addressing interoperability issues, as it is to their interest to advance the software programs in response to the market and to win the customers.

### 5.1 Architectural Design And Daylight Analysis

*Design Authoring:* Architectural design is a process in which 3D software is used to develop a BIM based on criteria that is important to the translation of the building's design. Architectural design authoring tools are used to create BIMs. Architectural design authoring tools are a first step towards BIM and the key is connecting the 3D model with a powerful database of properties, quantities, means and methods, costs and schedules. Through architectural design authoring tasks, Researcher 1 experiences the potential value created by BIMs such as: (1) transparency of design for all stakeholders, (2) better control and quality control of design, cost and schedule Powerful design visualization, (3) true collaboration between project stakeholders and BIM users, and (4) improved quality control and assurance.

*Daylight Analysis:* The Researcher 1 also experiences the daylight analysis which is a process where analytical modeling software utilizes the architectural BIM in early design to get feedback from the behavior of a given lighting system including artificial (indoor and outdoor) and natural (daylighting and solar shading) lighting. Based on this analysis further development and refinement of the lighting design takes place to create effective, efficient, and constructible lighting systems. The application of this analysis tool allows for performance simulations that can significantly improve the design, and performance of the facility's lighting over its lifecycle. Through daylight analysis tasks, Researcher 1 experiences the potential value created by BIMs such as: (1) save time and cost on creating extra models, (2) easier transition BIM authoring tools allowing new firms implementing this use model, (3) improve specialized expertise and services offered by the design firm, (4) achieve optimum efficient design solutions by applying various rigorous analyses, (5) faster return on investment with applying audit and analysis tools for lighting analyses improve the quality of the design analyses, and (6) reduce the cycle time of the design analyses.

### 5.2 Structural Design and Analysis

*Design Authoring:* Structural design is a process in which 3D software is used to develop a BIM based on criteria that is important to the translation of the building's structure. Structural design authoring tools are used to create BIMs. Through structural design authoring tasks, Researcher 2 experiences the potential value created by BIMs such as: (1) transparency of design for all stakeholders, (2) better control and quality control of design and visualization, (3) true collaboration between project stakeholders and BIM users.

*Structural Analysis:* The Researcher 2 also experiences the structural analysis which is a process where intelligent modeling software uses the BIM model to determine the most effective structural engineering method based on design specifications. Development of this information is the basis for what will be passed on to the owner and/or operator for use in the building's structural systems. Structural analysis tools and performance simulations can significantly improve the design of the facility. Through structural analysis tasks, Researcher 2 experiences the potential value created by BIMs such as: (1) automating analysis and saving time and cost, (2) analysis tools are less costly than BIM authoring tools, easier to learn and implement and less disruptive to established workflow; (3) improve specialized expertise and services

offered by the design firm, (4) achieve optimum, energy-efficient design solution by applying various rigorous analyses, (5) faster return on investment with applying audit and analysis tools for engineering analyses, and (6) improve the quality and reduce the cycle time of the design analyses.

### 5.3 Design Review and Clash Detection

*Design Review:* This is a process in which stakeholders view a 3D model and provide their feedbacks to validate multiple design aspects such as evaluating meeting the program. Through design review tasks, Researcher 3 experiences the potential value created by BIMs such as: (1) eliminate costly and timely traditional construction mock-ups, (2) different design options and alternatives may be easily modeled and changed in real-time during design review base on end users and/or owner feedbacks, (3) create shorter and more efficient design and design review process, (4) evaluate effectiveness of design in meeting building program criteria and owner's needs, (5) enhance the health, safety and welfare performance of their projects, (6) easily communicate the design to the owner, construction team and end users, (7) get instant feedbacks on meeting program requirements, owner's needs and building or space aesthetics, (8) greatly increase coordination and communication between different parties, and (9) more likely to generate better decisions for design.

*Clash Detection:* Design review is also a process in which clash detection software is used during the coordination process to determine field conflicts by comparing 3D models of building systems. The goal of clash detection is to eliminate the major system conflicts prior to installation. Through design review tasks, Researcher 3 experiences the potential value created by BIMs such as: (1) coordinate building project through a model, (2) reduce and eliminate field conflicts; which reduces RFI's significantly compared to other methods, (3) visualize construction, (4) increase productivity, (5) reduced construction cost; potentially less cost growth (i.e. less change orders), (6) decrease construction time, (7) increase productivity on site, and (8) more accurate as built drawings.

### 5.4 Cost Estimating and Analysis

*Cost estimating and analysis:* This is a process in which BIM can be used to assist in the generation of accurate quantity take-offs and cost estimates throughout the lifecycle of a project. This process allows the project team to see the cost effects of their changes, during all phases of the project, which can help curb excessive budget overruns due to project modifications. Specifically, BIM can provide cost effects of additions and modifications, with potential to save time and money and is most beneficial in the early design stages of a project. Through cost estimating and analysis tasks, the Researcher 4 experienced the potential value created by BIMs such as: (1) precisely quantify modeled materials, (2) quickly generate quantities to assist in the decision making process, (3) generate more cost estimates at a faster rate, (4) better visual representation of project and construction elements that must be estimated, (5) provide cost information during the early decision making phase of design and throughout the lifecycle, including changes during construction, (6) saves time by reducing quantity take-off time, (7) more value adding activities in estimating such as: identifying construction assemblies, generating pricing and factoring risks, which are essential for high quality estimates; (8) added to a construction schedule (such as a 4D Model), a BIM developed cost estimate can help track budgets throughout construction, and (9) easier exploration of different design options and concepts within the owner's budget and (10) quickly determine costs of specific objects, and (11) easiness to join new estimators through this highly visual process.

### 5.5 Phase Planning (4D Modeling) and Simulation

*Phase Planning:* This is a process in which a 4D model (3D models with the added dimension of time) is utilized to effectively plan the phased occupancy in a renovation, retrofit, addition, or to show the construction sequence and space requirements on a building site. 4D modeling is a powerful visualization and communication tool that can give a project team the including owner a better understanding of project milestones and construction plans. Through phase planning and simulation tasks, the Researcher 5

experienced the potential value created by BIMs such as: (1) better understanding of the phasing schedule by the owner and project participants and showing the critical path of the project, (2) dynamic phasing plans of occupancy offering multiple options and solutions to space conflicts, (3) integrate planning of human, equipment and material resources with the BIM model to better schedule and cost estimate the project, (4) space and workspace conflicts identified and resolved ahead of the construction process, (5) marketing purposes and publicity, (6) identification of schedule, sequencing or phasing issues, (7) more readily constructible, operable and maintainable project, (8) monitor procurement status of project materials, (9) increased productivity and decreased waste on job sites, and (10) conveying the spatial complexities of the project, planning information, and support conducting additional analyses.

## 5.6 Energy Modeling

*Energy Modeling:* This is a process in the design phase which one or more building energy simulation programs use a properly adjusted BIM model to conduct energy assessments for the current building design. The core goal of this BIM use is to inspect building energy standard compatibility and seek opportunities to optimize proposed design to reduce structure's life-cycle costs. Through energy modeling tasks, the Researcher 6 experienced the potential value created by BIMs such as: (1) save time and costs by obtaining building and system information automatically from BIM model instead of inputting data manually, (2) improve building energy prediction accuracy by auto-determining building information such as geometries, volumes precisely from BIM model, (3) help with building energy code verification, and (5) optimize building design for better building performance efficiency and reduce building life-cycle cost.

## 6. CONCLUSIONS

With the complexity of the AEC projects today, coupled with complex technologies rapidly entering the industry, the members of distributed interdisciplinary teams would not succeed without implementing alternative methods and tools of project delivery. Such technology and process advances have been captured by BIM, its power of information management, its concept of integrated design, and finally its desire of interoperable process for project delivery. BIM in turn introduces vast amount of specialist software applications for the build teams to extend these into collaborative projects.

The integration of BIM based tools into research curricula in an experiential approach has the potential to increase design and construction management skills. Reflection is a crucial part of the experiential learning process, and like experiential learning itself, it can be facilitated or independent. Facilitation of experiential learning and reflection is challenging, but "a skilled facilitator, asking the right questions and guiding reflective conversation before, during, and after an experience, can help open a gateway to powerful new thinking and learning". While it is the learner's experience that is most important to the learning process, it is also important not to forget the wealth of experience a good facilitator also brings to the situation. The instructor in this study leads the group towards a critical reflection on their experience, and an understanding of how they can apply the learning to their own life. Considering experiential learning in developing research immersion program content, provides an opportunity to create a framework for adapting varying teaching/learning techniques. The IIT strategy relative to BIM is successful and expected to help architecture, engineering, and construction professionals to be prepared for the needs of the industry in the future.

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# ENHANCING BIM EDUCATIONAL EXPERIENCES WITH INTEGRATED KEYSTROKE CAPTURE SOFTWARE

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## ABSTRACT

Building Information Modeling (BIM) is quickly becoming a standard in the AECO industry and as such, new graduates are finding an increased expectation that they achieve competency in BIM processes. Instructors of BIM courses have the unique challenge of teaching software packages to students, both undergraduate and graduate, which challenge their preconceived notions of 2D plan development. Furthermore, students tend to have a hard time following along with the instructor while simultaneously taking notes to remember the steps required for various modeling activities. This can lead to missed steps and the need for the instructor to repeat steps multiple times to help each student master the skills being taught. In this regard Autodesk Screencast records the computer screen and keystroke input of the user in Autodesk software, eliminating the need to write down the steps taken to accomplish various modeling activities. The goal of this research was to assess the impact of Autodesk Screencast on students BIM learning experience. During the instruction of Autodesk Revit, in a graduate BIM course, students were introduced to Autodesk Screencast and instructed to use it to record their work during class. The integration of Screencast with Autodesk platforms, coupled with web-based storage, allowed students to record and access recorded data from any computer with internet access that they used for their assignments. Students were asked to rate their experience with Screencast and elaborate on how they used it during the course. As BIM continues to become a standard in the AECO industry it is crucial for educators to find ways to best prepare students for their roles in the industry. This research offers insight into a tool which can be employed by instructors to enhance the BIM educational experiences of their students.

**Keywords:** BIM, Self-training, Screen Capture, Education, Autodesk, Screencast

## 1. INTRODUCTION

Every year the construction industry further embraces building information modeling (BIM) and virtual design and construction (VDC) processes. Researchers are continuously studying methods to improve VDC processes while software companies continue to develop and refine their products based on industry demand. Rather than the exception BIM has become the norm with 71% of practitioners in the architecture engineering and construction (AEC) industry reporting its use in their businesses. Of the AEC practitioners, contractors reported the highest BIM utilization rate at 74% (McGraw Hill 2012). This data is a positive sign for the technological advancement of the construction industry, however, the increase in utilization has not been paralleled by an increase in qualified BIM and VDC professionals.

The demand for new hires and professionals with BIM expertise continues to grow and construction management programs have the task of producing students well versed in this area

and prepared for their careers. The authors of this study believe that education can inspire students while solidifying their interest in self-exploration and development in the BIM and VDC fields. This task proves to be difficult due to the short timeframe that educators have to expose students to such a complex and multi-faceted part of the industry. This challenge is one which all educators in the AEC industry face and must be addressed in order to meet the need for qualified BIM professionals, stopping the reported decline in those beginning BIM careers (McGraw Hill 2012).

This study focuses on a pedagogical technique which can improve students' ability to comprehend and master the complex BIM curriculum. Students tend to have a difficult time following along with the instructor in class while simultaneously attempting to take notes so that they can recall each step required to complete a task. This is a unique challenge found when attempting to teach the underlying concepts of BIM while developing an acceptable level of proficiency in the software students are most likely to encounter in the industry. Often, the instructor must repeat steps multiple times to facilitate mastery of the topic making it difficult to move onto higher level concepts. Screen capture software has been around for many years and has been used to develop countless tutorials and class lectures. Traditional screen capture technology can leave out details necessary for student comprehension. There are countless steps involved in every BIM task and students often miss a single step hindering their ability to complete the task.

Autodesk Screencast has been developed to record the screen as well as all keystroke activity or user interaction related to its software. The goal of this research was to provide an initial assessment of the impact Autodesk Screencasts keystroke capturing could have on students BIM learning experience. This study focused on its use during the instruction of Autodesk Revit, focusing on structural modeling and information management. The most important aspect of BIM is the "I", information, and tools which can help students master the basic modeling concepts effectively allow the instructor more time to focus on this important component. The software was introduced to the students and they were subsequently asked to rate their experience with the Screencast recordings, while offering their insight into its effectiveness. This research offers insight into one potential tool which can enhance the educational experience for students studying BIM processes and techniques, regardless of their prospective industry affiliation.

## **2. BACKGROUND**

### **2.1 BIM in Graduate Education**

As BIM evolves into standard practice in the construction industry there is a growing need for qualified professionals who are eager to learn. Educators strive to develop the most effective methods for teaching BIM and preparing students for careers in an industry where BIM is becoming a reality for professionals regardless of their roles on a project team. Dedicated BIM personnel are no longer the only members of a project team exposed to BIM and everyone involved must understand the process. Basic modeling skills need to be developed for students to grasp higher level processes and management concepts however, instructors must consider that the majority of students will not be involved in model creation during their careers (Lee et al. 2013). In this regard, knowledge of BIM processes and management strategies takes precedence over product based skills (Wang and Leite 2014). Research (Lee and Yun 2015; Sacks and Pikas 2013) has found that industry professionals seek knowledge related to the BIM process and management skills, including its benefits and use cases, especially from those with graduate degrees. In this regard, there are currently a wide range of BIM courses offered at colleges and universities across the United States, which address these needs.

According to one study, 78% of the architecture and construction institutions surveyed report including BIM as part of their curriculum (Joannides et al. 2012). Of the responding construction schools, 53% stated having a dedicated BIM course and approximately half of the responding institutions expected their students to have basic to intermediate BIM knowledge upon graduation (Joannides et al. 2012). Barison and Santos (2012) noted three levels of BIM courses; introductory, intermediary and advanced. The introductory level provides basic tool knowledge with intermediary courses introducing analysis and management tools (e.g. clash detection, 4D, 5D etc.). The advanced courses are interdisciplinary using group projects to simulate real world team functionality and BIM implementation strategies (Barison and Santos 2012). There is a wide range of skills and processes which students must grasp when developing their knowledge of BIM. There is a need for instructional tools and methods capable of aiding in the development of technical skills, to allow more time to be spent by the instructor on higher level concepts.

## **2.2 Digital Learning Techniques in Higher Education**

In the current technological age colleges and universities are adapting to increasingly digital means of delivery. Online learning is pervading higher education with many institutions offering online components as part of traditional on-campus degrees and courses. The combination of digital learning environments with traditional face-face learning in equal shares has been called blended learning (Garrison and Kanuka 2004). This concept has led to the evaluation and development of techniques for the use of digital instruction as part of traditional learning. This is of great interest for BIM educators as the topic inherently requires a combination of digital skills and conceptual understanding. The encouragement for self-learning through effective tutorials would allow instructors to spend less time on software functionality and more time on the conceptual knowledge which is crucial for effective BIM personnel (Sacks et al. 2013).

Folkstead and De Miranda (2002) conducted an extensive study on how screen-capture technology could be used to develop self-learning tutorials as a supplement to instructor delivered material in class. It was found that pre-recorded software presentations, while requiring additional time for development, were as effective as text and could be an acceptable supplement to classroom learning (Folkstead and De Miranda 2002). A 2015 study continued in this line of research assessing the effectiveness of a flipped learning environment on students' comprehension of BIM (Monson et al. 2015). It was found that in traditional BIM teaching environments some students would fall behind requiring the instructor to repeat steps, while other students who were further ahead had to wait. The researchers developed a set of "vignettes" (i.e. problems with limited scope demonstrated by the instructor through tutorials) which were to be viewed by the students to guide them through course topics (Monson et al. 2015). Similar to the results in the 2002 Folkstead study, the researchers reported a modest increase in scores for the exercises completed using the vignettes. As BIM continues to grow in the construction industry digital learning techniques will be an attractive option for educators and must be assessed for the potential benefits that they can offer.

## **2.3 Construction Information Systems Course**

The course used for this study is Construction Information Systems, an elective graduate level course at the M.E. Rinker, Sr. School of Construction Management at the University of Florida. This course engages students in a rigorous semester of coursework where they learn how BIM and VDC processes work in the context of the construction industry while simultaneously building technical and conceptual knowledge. The curriculum for this course is continuously assessed to ensure it is meeting the needs of students and employing the most current software and techniques.



Students attend class once a week in a three hour block. This format provides limited opportunities for practice of learned skills without relying on out of class exercises (Giel et al. 2012). A challenging combination of individual coursework and group assignments provides students a well-rounded BIM experience exposing them to a breadth of techniques ranging from introductory to advanced. Students are guided through architectural, structural and MEP modeling through individual course assignments which provide them basic modeling skills as well as a conceptual knowledge of how imbedded model information can inform the construction and design process.

Individual classwork assignments are completed using a set of standard plans developed specifically for this course. The standard plans allow for an elimination of unknown variables and can guide students through specific modeling tasks to help them build their skills (Giel et al. 2012). The standard plans concept was introduced in the early 2000's and a new set of plans was developed in 2015 to accommodate new capabilities of software and to provide additional real-world modeling challenges to the students. The skills learned through individual assignments are then applied to a group project which utilizes real-world construction documents of completed buildings in various locale near the university. The goal of the course is to meet the needs of the industry and provide students with a solid foundation for their educational and professional careers.

### **3. SCREENCAST INTEGRATION AND EVALUATION METHODOLOGY**

Construction information systems covers a wide range of topics with assignments aimed to help students develop the necessary skills and knowledge to begin or expand their BIM experience. This study focused primarily on the architectural and structural modeling portion of the course which took place over the first five weeks of the semester. During this portion of the course students attended five class periods and completed two assignments, one each for architectural and structural modeling. These topics were the first topics covered in the course and based on the experience of the researcher are the ones which most often lead to an increase in student questions and repeated topics in class. As students develop basic BIM skills, or refresh their memory, a great deal of time is often devoted to reviewing topics in class. For these reasons the architecture and structural modeling components of the course were ideal for the integration and evaluation of the screencast keystroke tutorials discussed in this study.

#### **3.1 Screencast Recording and Development**

The computer lab in which the course was conducted had Autodesk Screencast installed on the instructor station as well as on the student computer terminals. The students were shown how to record tutorials and were showed how to view the recordings which would be developed by the instructor during class. Students were also shown how to download the software onto their personal computers, as many of them used their own computer in class in lieu of the desktops in the computer lab. Students were encouraged to record their own Screencast videos based on their work in class but were able to rely on the instructor developed recordings. Autodesk Screencast records the screen and the keystrokes which occur within the software. Figure 1 is the playback interface, where the keystrokes are indicated at the bottom of the video and correspond to the screen capture. The icons visible in the keystroke section of the recording can be clicked on to receive additional detail about what was selected or clicked at that time. Each class period the lecture was recorded using these techniques, labeled according to its focus topic and shared with the class.

Each class period covered multiple topics within the context of architectural and structural modeling. Some class periods could have up to 3 separate recordings, depending on the complexity of the topics being covered. The recordings ranged from 15 minutes to an hour in length and were used to record specific modeling procedures rather than recording the entire class. During class each technique or process was typically demonstrated two or three times, showing various methods and techniques which could be used to accomplish point of this was to demonstrate to the students a variety of ways to accomplish a task in order to broaden their understanding of the topic. For the purposes of this study only the major elements of modeling were captured, e.g. column placement, beam system development, foundation creation and naming, etc. Screencast was used to capture the instructor screen as well as the instructor keystrokes throughout each of the demonstrations, with the instructors voice being excluded despite Screencasts capabilities. At the conclusion of the class period, the recordings were labeled based on their content and saved for distribution.

Topics which students requested more instruction on were accommodated through the development of supplemental recordings completed outside of class. Often, students would request information on more complex techniques or a review of a technique in greater detail. These topics ranged from roof drain and slope development to beam system tagging and classification. All of the students' requests were accommodated and the recordings were developed within 48 hours of the class period. These recordings captured the screen, keystrokes and the instructors voice, since the recordings were not created in class with the students present to listen. Throughout the course three such recordings were completed and distributed to the students based on their requests.



Figure 1. Screencast playback interface

### 3.2 Recording Distribution

The screencast recordings were shared with the students through the course Canvas website within 24 hours of creation. The Canvas page for the course is where the students would find resources, assignments, grades and announcements pertaining to the course. Autodesk Screencast recordings are automatically uploaded and hosted on an Autodesk server linked to a user's Autodesk account. The instructor logged into their Autodesk account prior to starting the recording to associate it with their "library". The web-based storage of the recordings allowed the instructor to access them from their personal computer after class for distribution. This eliminated the need to save them to portable memory or to personal cloud-based storage at the end of each class period.

Each recording has a unique link which was posted for the students on the Canvas site and led them directly to the specific video they were looking for. After following the link the students could see the recording, as well as the other recordings uploaded by the instructor to their Autodesk

account. This screencast “library” developed by the instructor was a depository for all recordings from the class and was accessible to the students anywhere they had an internet connection. Finally, the videos were downloaded by the instructor and saved as archive files for reference and use in future courses as supplemental materials if necessary. This also allowed the instructor to package videos and send them directly to students if an issue arose with the online file playback.

### 3.3 Student Survey

In order to assess the perceived effectiveness of the screencast recordings, the students were asked to complete a survey regarding their use of and opinions toward the Screencast recordings made available to them. The online survey platform Qualtrics was used to develop and distribute the survey in an online format which the students could access through any device with internet access (Qualtrics 2016). It was made clear that the survey was anonymous and had no correlation with their grade in the course. The survey consisted of three background questions followed by ten questions regarding the Screencast recordings for the course. The background questions established the students level of experience with BIM technology prior to enrolling in the course, the frequency with which they conduct research on their own and how frequently they use the course website. These questions, along with the ten regarding the Screencast recordings were evaluated using descriptive statistics in order to summarize the students’ responses.

## 4. RESULTS AND DISCUSSION

Over the course of this study eleven screencast recordings were developed and made available during the students with regards to architectural and structural modeling. The recordings covered basic and intermediary modeling techniques which were required for students to successfully complete their assignments and master the higher level concepts in the course. A total of 29 students completed the survey following the architectural and structural sections of the course, a response rate of 96.6%. Of those 29 students 55% indicated having at least a moderate amount of BIM experience prior to taking the course with the remaining students indicating little to no experience. The majority of the students, 79%, reported that they researched or learned new software on their own with some level of frequency. The questions regarding the Screencast recordings started with a yes or no question asking whether the student had used the recordings. If a student indicated that they did not use the recording they did not answer the following 7 Screencast related questions and skipped to the last two regarding their reason for not using the software and what would have encouraged them to use it.

Out of the 29 survey respondents 26 indicated that they used the Screencast recordings to aid in the completion of their assignments. Of those students 19% reported using the recordings only once, 58% reported using them 2-5 times and the remaining 23% used them greater than 5 times. When asked how long, on average, they spent viewing the recordings they reported spending an average of 39 minutes with a median response of 25 minutes. Next, the students ranked the Screencasts usefulness on a scale of 1 to 10, with 10 being most useful and 1 being not useful. The average ranking was an 8.2, with 88% ranking the Screencast recordings a 7 or higher on the scale and 1 ranking below a 6. Prior to the open response questions the 26 students who used the recordings were asked if they would consider using the technology to record their own work in class as they followed along with the lecture and the majority, 85% indicated that they would.

#### **4.1 Student Responses and Suggestions**

The students were given the opportunity to provide their opinions regarding the Screencast software in an open response format during the survey. The first question asked the students to identify the elements which were most helpful to them. Multiple students cited the keystroke capture portion of the recordings as the most useful. Two such responses were “The keystrokes were the most helpful as they can be easily followed and mirrored.” and “Screencast helps me remember the process and important key strokes which are used in lecture.” Approximately 42% of the responses reported that the ability to review what was covered in class, with a resource they had 24/7 access to, was the most helpful part of the Screencast recordings. Some students indicated its ability to help them review basic modeling techniques while continuing with complex modeling aspects, citing that generally they got stuck on one or two minor steps or otherwise would have miss one keystroke which would have kept them from continuing if not for the recordings.

Not all of the responses were entirely positive, with some students reporting that videos were too long or hard to follow due to the lack of instructor voice. Although, of the three students who indicated that they did not use the recording none gave a written response and they all indicated that the recordings were either unnecessary because they understood the topics or that they used their own resources to complete their work. Finally, all of the students had the opportunity to make suggestions for the improvement of the recordings and the most common response was the desire for voice recording of the instructor. The responses provided by the students are going to be vital for improving the way Screencast is used and as this research continues the authors will continue to assess the technologies effectiveness in enhancing BIM educational experiences.

### **5. CONCLUSIONS AND FUTURE STUDY**

This study used Autodesk Screencast software to record topics in a graduate BIM course, with the advantage of keystroke capturing, in order to assess its effectiveness in enhancing the educational experience of students. The recordings were largely developed during the course lectures in order to capture the portions of the topic which the students, in that particular class, were having difficulty with. These recordings were supplemented with recordings created by the instructor outside of class based on the requests of the students. This method departs from recording canned tutorials and focusses on the needs of the specific students with respect to each topic. Furthermore the students were able to use the recordings from the class as a reference when working on assignments and also for future courses. Interestingly, during the study students began increasingly requesting additional Screencast recordings.

Initial indications for the use of this technology were positive with the average usefulness rating being an 8.2 out of 10 and the majority of students reporting that they used the recordings multiple times. Through the class survey the students indicated that the Screencast recordings were useful as they worked on assignments citing both the keystroke capturing and ability to review the recordings on their own time as the most beneficial aspects. Keystroke capturing provides a definitive account of exactly what shortcuts or tools were used in class during various modeling activities. These are the most common questions raised during class and office hours on subsequent days. During the architectural and structural modeling portions of the course the instructor saw a decrease in technical software questions during office hours and students were instead asking about more advanced BIM concepts related to the imbedded information in the model elements.

These are positive signs that keystroke capture software may aid students’ modeling abilities, allowing instructors to focus on the important conceptual and advanced topics in BIM education. Based on the survey results and instructor observations, the recordings with keystroke capturing

were a positive supplement to the traditional course delivery method and require additional study. Preliminary findings in this study provide a foundation from which to build continued research which should be expanded to include looking at its impact on student learning outcomes.

Moving forward, the average grades in the course will be compared to previous and succeeding semester to begin evaluating the impact of the recordings on overall learning. Furthermore, the researchers have found that as students continue in their education they often return in later semesters with questions related to BIM components which are integrated into their other courses. The goal is for the recordings to serve as a resource for the students throughout their academic and professional careers beyond the course itself. However, further research will be conducted to develop a more comprehensive assessment of the overall effectiveness of using Screencast and ways in which it can be utilized to meet the needs of the students. New methods and technologies for the instruction of BIM, such as those reviewed in this study, must be explored as educators look for the most effective methods for enhancing the educational experiences of their students to help them towards long term success.

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# INCORPORATING BIM INTO THE PRECONSTRUCTION SERVICES COURSE AT BYU

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## ABSTRACT

The Preconstruction Services course at Brigham Young University has transitioned from the traditional Estimating II course. The traditional Estimating II course focused on bid analysis, quantity takeoff from 2d documents, pricing and productivity to include all the previous topics but now also includes model based takeoffs, clash detection and building sequencing using models. This paper focuses on topics covered in the course, the tutorials that have been made to add the BIM aspects to the course. Project-based learning is used to reinforce student learning. The course is a blend of projects in a quasi-studio format.

**Keywords:** BIM, Estimating, Construction, Coordination, Sequencing, Tutorials

## 1. INTRODUCTION

As the construction industry is incorporating Building Information Modeling (BIM) into many tasks, construction management and similar academic programs are looking for ways to incorporate BIM into their already-packed curriculum. Many universities have credit hour limits on the academic programs which often forces programs to delete an existing course if they want to add a new course. An alternate choice is to incorporate BIM into existing courses rather than create new stand-alone courses.

An additional benefit of incorporating BIM into existing courses is that BIM is viewed by the students as something that is integrated into topics such as estimating and project management rather than a standalone topic. This approach assists students in viewing BIM as a tool that everyone should be able to use rather than a specialized tool, similar to how a company could have a Microsoft Excel specialist or everyone could use Excel to accomplish their tasks at work.

## 2. INCORPORATING BIM INTO EXISTING COURSES

At Brigham Young University, BIM has been incorporated into the following courses:

- CFM 105 Introduction to Construction and Facilities Management
- CFM 155 Computer Modeling
- CFM 241 Electrical Systems
- CFM 411 Preconstruction Services

Prior to BIM being incorporated into these courses, either a hand drawing/sketching or CAD experience was included in these courses. This paper focuses on the transition that was made in the CFM 411 Preconstruction course and is a guide to the reader for resources that are available online to assist in incorporating BIM into their coursework.

### **3. ESTIMATING 2 BECOMES PRECONSTRUCTION SERVICES**

Between 2001 and 2007, the Estimating 2 course focused on performing takeoffs from commercial documents, bidding strategies, subcontract price and scope analysis, estimating general conditions, pricing strategies, and increasing the student's plan-reading skills. The format of the course is a blend of lectures and projects that take the lecture materials and apply the topics to projects that the students perform. The course takes on more of a studio format with the projects rather than a traditional lecture-based course. The takeoffs typically performed in the course focused on concrete, structural steel, and wall systems. The course transitioned in 2001 from takeoff performed from paper plans on digitizers to electronic plans where the 2D takeoffs were performed on the computer screen.

Around 2009, BIM was becoming more prevalent and computer applications became available to use to perform quantity takeoff from models. As tools were developed for takeoff, additional tools for coordination and sequencing also became available. During this time, one of the takeoff projects was changed from using 2D tools to using BIM-based tools. The tools were sometimes a little awkward to use, but provided insight into what would be possible in the future by using BIM for quantity takeoff.

Concurrently, the program was reviewing the required curriculum and making changes on which courses the students were required to take. The faculty saw how BIM was starting to impact construction and felt that BIM coordination and sequencing should be incorporated into the curriculum. The decision was made to incorporate BIM coordination and sequencing into the Estimating 2 course. To make this possible without losing too much content in the existing course, a credit hour was added to the course and a general business course was dropped from the required curriculum. This changed the course from a three credit hour course to a four credit hour course, allowing BIM coordination and BIM sequencing to be added. The Estimating 2 course was renamed Preconstruction Services.

### **4. RESTRUCTURING THE COURSE**

While the changes to the course allowed for BIM aspects to be added to the course, it was felt that since the majority of projects still being used in industry were 2D, 2D projects and experiences still needed to be included in the course. Over the next few years, several of the 2D projects were transitioned into BIM projects while keeping enough 2D projects that students understood how to work with both the 2D and 3D tools for estimating.

One of the first challenges encountered by adding BIM to the course was where to get models to be used in the course. The Facilities Services group on campus was at the same time making a transition to BIM and they were willing to share some of their models which could be used in the classroom. Additionally, alumni who worked with firms that were using BIM received permission to share models with the program; other industry professionals that were using BIM were generally willing to ask designers for permission for the program to use their models in the classroom. Generally, there was a positive response to sharing the models with academia.

One item that was learned during this process is that you often get what you ask for. When the request was made to receive a BIM model, only the architectural BIM was received. Often there are multiple models and the request should have been more specific to ask for all the models such as: architectural, structural, mechanical, electrical, etc., as well as the specifications, and 2D documents. Having the complete project documents provided the students with a fuller understanding of the project. With that said, even though the complete documentation of the project is in possession of the instructor, the author typically focused on selected scopes of work for homework assignments rather than doing the complete project. Doing the complete project becomes more overwhelming to the course and doesn't allow for the depth of understanding in a particular scope of work.

The next challenge faced was that the instructor didn't know how to use the BIM tools. To overcome this, multiple approaches were used. The first approach that was used was to hire a student that was good with technology as a teaching assistant. They were then given the task to figure out how to use the software and write a tutorial on how to use it. The student learned a lot of the material on their own, but they were also

referred to industry professionals who had insight on how to use the tools. The initial tutorial that was created by the student was used as a starting point that was then expanded by the instructor. The additions by the instructor often added more clarity to the tutorial, making it easier for students who struggle with computers.

The second approach was for the instructor to take the time to use the software to determine how the software could be used to accomplish the task at hand (such as quantity takeoff). While this required a substantial amount of time, the instructor then had a deeper understanding of the software which helped when students got lost in the software. The instructor also reached out to industry professionals for processes that they had used with the various software packages and tried to incorporate the best processes into the tutorials.

The instructor reached out to local companies to help with this effort. Additionally, the program funded the professor to visit companies around the US to analyze how different companies as well as different regions around the US were approaching BIM. This experience greatly influenced what topics were included in the course and developed in the faculty member a much deeper and broader understanding of BIM.

Using the above approaches, the instructor learned about a breadth and depth of what could be taught to the students about BIM. The a difficult choice was how deep to go into each subject and which software packages to use in the classroom. After careful thought and consideration, the author took the approach of using as few of software packages as possible to introduce the students to the breadth of tasks that can be accomplished with BIM. It was felt that once the students understood the concepts behind what could be done, the students could further their knowledge in the areas that interested them the most. With this in mind, the main software packages used are Autodesk's Revit and Navisworks. It is felt by the author that these approach has limited the number of software interfaces that needed to be learned by the student increasing the number of tasks that could be accomplished in the course.

The following BIM tutorials have been created:

**Clash Detection / Coordination**

This tutorial walks the user through using Navisworks for coordinating various systems and how to identify groups of clashes and how to filter through none clashes.

**Sequencing**

This tutorial uses Navisworks Timeliner feature to teach the basic of creating 4D sequencing of a project.

**Revit Schedule's Basic**

This tutorial uses the schedule features in Revit to create a basic list of materials for a project. The tutorial also addresses some of the shortcomings of this approach.

**Advanced Revit Schedules**

This tutorial builds upon the basic tutorial. In this tutorial the use of custom fields is introduced as well as creating calculations in a schedule.

**Aligning, Sectioning and Prepping models**

This tutorial using Revit to prepare models for use in clash detection and sequencing.

**Quantity Takeoff**

This tutorial leads the user through how to use Navisworks to perform quantity takeoff from the model. This tutorial address 3D and 2D takeoff from BIM.

These tutorials are step-by-step instructions on how to use BIM software to accomplish a variety of tasks. These tutorials are available on the internet at no cost to anyone who would like to use them. These tutorials can be found at the following URL:



<http://cmfac.groups.et.byu.net/miller/cfm411/help/NavisTutorials.php>

The course lecture notes can be found at the following URL:

<http://cmfac.groups.et.byu.net/miller/cfm411/index.php>

## 5. INTERNALIZING THE LEARNING

While the tutorials have helped the students navigate the software, the instructor has found that just because the students have gone through the tutorial, they often don't internalize what they are doing. The instructor has found that the students need to do the tasks three times before they begin to really understand what they are doing and why it needs to be done. The tutorials are step-by-step instructions that the students perform that guide them through the features that the instructor felt were important for the students to be aware of. The tutorials are not a complete overview of all the features of the software, but rather what the students need to know to be able to accomplish a task such as coordination or takeoffs.

The second assignment is a smaller project where the students apply what they have learned from the tutorial to a different small project without the step-by-step instructions. There are often a lot of questions that the students ask on how to do things in the software, but more importantly, they ask why they are doing the tasks.

The third project is larger in scope and fewer questions are asked by the students. During this third project, the students seem to cement in their minds how to accomplish the tasks needed for the project as well gain confidence in their ability to accomplish the task.

## 6. CONCLUSIONS AND FUTURE WORK

While tutorials and assignments have helped the students become more familiar with BIM and many of the tasks that can be accomplished using BIM. The Navisworks software being used in the course seems to have stalled in its development. During the last release cycle only minimal improvements were made to the software. If the products that I'm currently using follow the path of similar products, they are most likely being transitioned to cloud-based products. While there are many advantages of cloud-based products there are also multiple concerns with this approach to software. As a result of this approach by the vendor, I'm reevaluating the software solution that I'm using and reviewing alternate products as well. Concerns that I have with cloud-based solutions are the connection speed and reliability to the particular cloud, and ownership and access of the data. Thinking cynically, once all my data is stored in a particular vendor's cloud, if they chose to triple the usage fee, they could do it because all my projects would cease without the access to the project data. In the words of John Dalberg Acton, "Power tends to corrupt and absolute power corrupts absolutely." Providing a software vendor with all of a company's data with no local storage of the data provides the software vendor with absolute power. This may be tempered by the need for the vendor to keep its customers paying fees, but if it is difficult enough to move project data out of the cloud, the customers may endure a lot more pain before they are willing to move to a different vendor. My view of the workflow is that the data is stored locally, then synced to a cloud solution where it can be shared with the team working on the project. The approach keeps the data local which helps prevent the data from being held hostage; it also eliminates internet speed and connections issues.

This paper describes how the Construction and Facilities Management program at Brigham Young University implemented BIM into the Preconstruction Services course. The tutorials that were developed during this process are made available to other academic institutions that may want to follow a similar path. Hopefully, this sharing of tutorials will assist more students in gaining a deeper understanding of how to use BIM rather than just the theory of BIM.

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# INTEGRATION OF BIM (3D CAD) THROUGHOUT AN INDUSTRIAL CONSTRUCTION EDUCATIONAL TRACK

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## ABSTRACT

This paper describes the ongoing curricular integration of BIM within the LSU construction curriculum, with special focus on the industrial Industry Emphasis Area (IEA) and the integration of BIM-enabled data and graphics within technical and estimating courses not typically considered “BIM” or “graphics” courses. The primary curricular enhancement of this effort is the development of a cohesive, consistent real-world learning framework focusing on a singular industrial facility, allowing faculty and students to better focus on concepts rather than readjusting to widely varying industrial construction plans and specifications. Mastering fundamental concepts within the context of this real-world industrial framework will therefore reduce the time and training employers must expend in preparing graduates to productively contribute in their work environments. Development of a complete project allows faculty flexibility in selecting material for assignments, quizzes, exams, and projects for different semesters, ensuring the integrity of assessment materials.

**Keywords:** 3D CAD, industrial construction, curriculum enhancement

## 1. INTRODUCTION

Building information modeling (BIM) is an intelligent parametric model-based process (Sabongi & Arch, 2009) that grew from the object-based parametric modeling used for designing mechanical systems (Eastman et al., 2011). While BIM is common worldwide (Eastman et al., 2011) and its use is continuing to grow in the AEC industry (Azhar et al., 2010; Pikas et al., 2013) computer-aided design (CAD) has dates back to the mid-1950s, with major development occurring in the 1980s. The simplicity of mechanical systems and limited object libraries needed facilitated the development and use of 3D CAD within the industrial sector. Today, industrial (i.e., plant) 3D CAD is a powerful software platform that facilitates design and construction of industrial facilities with the same benefits as BIM used in the commercial and residential sectors.

Industrial construction relies upon several types of drawings to communicate design information, including process and instrumentation diagrams (P&IDs), equipment drawings, isometric drawings, and orthographic drawings. Each visualization product is used to communicate aspects of the overall facility processes and physical layout in the most efficient manner. Additionally, line lists for piping, equipment lists, and instrumentation lists are indices used to identify and monitor significant aspects of the facility. New facilities and upgrades/maintenance of existing facilities represent significant investments, both

financially and operationally. The complexity of these types of facilities, operator access requirements, and considerations for future maintenance all require significant planning, coordination, and conflict identification during the design and construction phases. Prior to the availability of computer 3D modeling in the 1980s, scaled physical models were often built to help visualize and plan industrial projects.

Design suites are available from major software developers, including Autodesk, Bentley, Intergraph, and others. The capabilities of these software platforms include the ability to design 3D physical models using object catalogs with attributes; manage plant design data, including generation of project indices and isometric and orthographic drawings; perform interference analysis and operational access analysis. 3D CAD provides the same benefits in industrial construction as BIM provides in the commercial sector, including faster and more accurate design, improved coordination with other disciplines through model sharing, rapid generation of material schedules, creation of preliminary models, minimization of rework by early identification of clashes and issues, improved design efficiency, and construction progress monitoring. (Bryde et al., 2013; Shou et al., 2015; Son et al., 2015). In the case study presented in Sullivan (2007), General Motor Plant, Flint delivered 25 percent faster and 15 percent under budget by using building information modeling to enhance team collaboration (Sullivan, 2007). Identical to the need to integrate BIM technology into construction education programs, there is a significant need to expand students' knowledge of industry-level practices in the arena of industrial construction.

In response to this need, The Bert S. Turner Department of Construction Management at Louisiana State University began offering a revised curriculum in 2014-2015 to include Industry Emphasis Area (IEA) or "track" options to allow students to specialize their coursework within their undergraduate degree. To meet the needs of the industrial construction IEA, four junior/senior level courses are in development, the freshman level plan reading course is being revised to now include industrial construction within its emphasis, and the senior capstone course is being redefined to focus on industrial construction for students that select the industrial IEA. To create a robust virtual learning framework for the industrial IEA, LSU has partnered with Fluor Corporation to augment the selected courses with a concise, complete industrial facility model that will be used as a case study throughout the IEA curriculum. The underlying premise is to present learning concepts demonstrated within a consistent plant framework to assist students in learning and application of course concepts. Data generated in each course will be used cumulatively throughout the curriculum, allowing students to focus on course-specific outcomes while maintaining the overall context. This paper describes the industrial facility project model development, and course integration and assessment plans.

## **2. PROJECT DESCRIPTION**

### **2.1 Industry Participation and Data**

LSU has partnered with Fluor Corporation, who has provided information and funding assistance for a prototypical plant facility, including 2D drawings, specifications, and vendor drawings for concrete, structural steel, piping, electrical, and instrumentation scopes of work. Progress meetings and model verification meetings with Fluor have occurred to ensure the 3D model is developed according to typical plant layout and design standards.

### **2.1 3D Plant Model and Drawing Products**

From the details provided by Fluor Corporation, a team of students and faculty at LSU are developing a 3D facility model in Autodesk Plant 3D. Typical drawing products are being produced using Plant 3D to develop a working set of construction drawings. These drawings and the 3D model will be tailored to develop educational materials to systematically integrate the project throughout the industrial IEA and the introductory plan reading course. Figure 1 provides an overview of the 3D model and facility layout (top view). Figure 2 provides plant elevation views from the front and left. Figure 3 provides an example of a piping isometric (iso) drawing including bill of materials. The 2D drawings are typically generated for

construction projects and are important for classroom learning to provide students with experience navigating these types of drawings. Piping iso's are an example of discipline-specific documents needed for construction estimating and scheduling and are one of the key drawing types that requires mastery. Tables 1 and 2 provide excerpts from the (Piping) Line and Equipment Lists, respectively, which are critical for plant inventory, mechanical and electrical scopes, and painting and insulation. The 3D model – in both static and dynamic electronic formats – will be used to help students understand the visual elements shown in the 2D drawings. In addition, models created in Autodesk Plant 3D can be exported to Navisworks for schedule and quantity analyses.

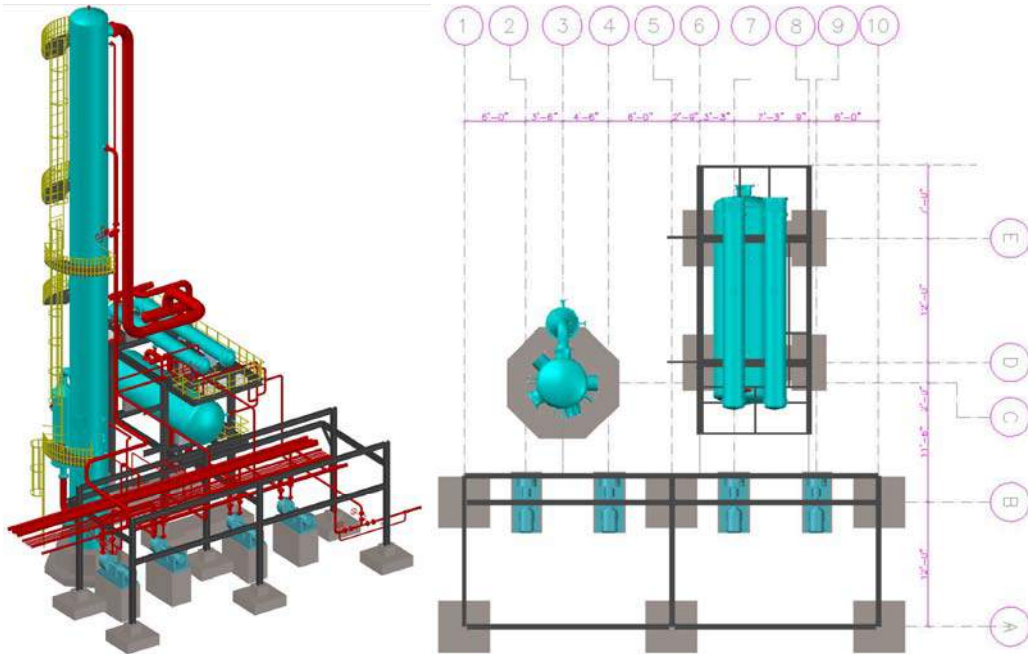


Figure 1: 3D Model and Plant Layout

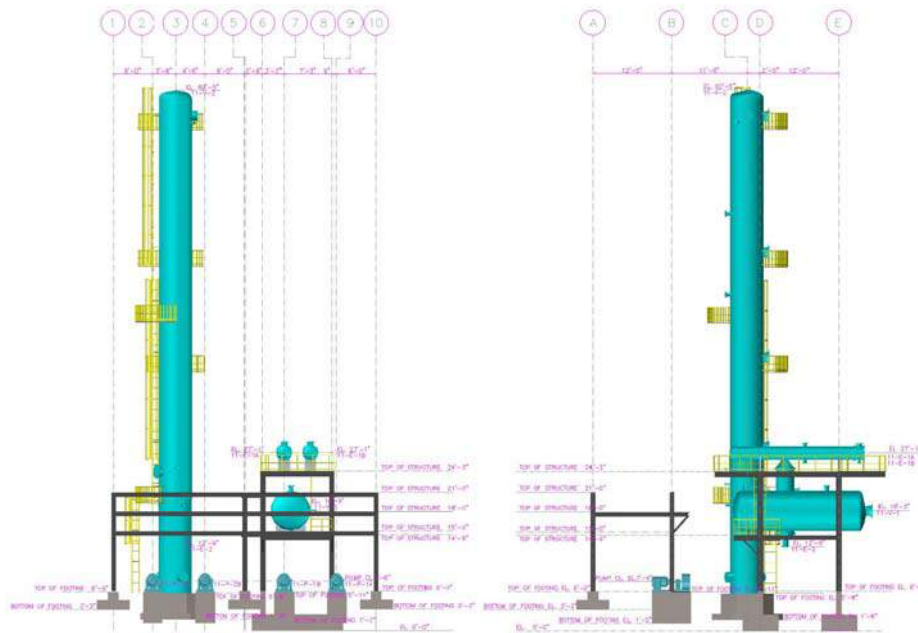


Figure 2: Plant Elevation Views – Front and Left Views

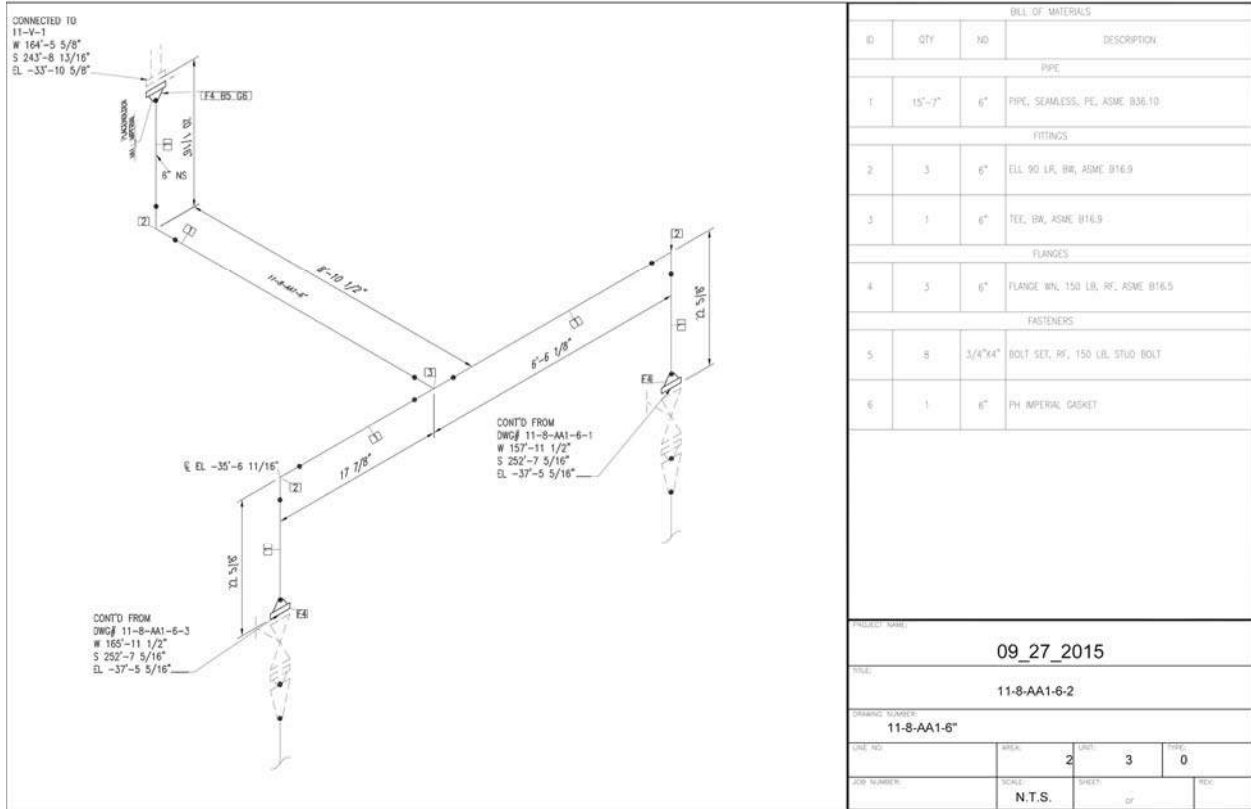


Figure 3: Example Piping Isometric 2D Drawing with Bill of Materials

Table 1: Excerpt from Construction Line List

PROCESS FLOW DIAGRAM	LINE DATA			SERVICE	LIQUID	FROM	TO	DESIGN PRESSURE PSIG	DESIGN TEMPERATURE °F	INSULATION
	NO.	CLASS	SIZE					OPERATION PRESSURE PSIG	OPERATION TEMPERATURE °F	
11-4-011	1	AA1	8"	HC	X	11-V-2	11-P-2A & 2B	125 70	300 250	lh
11-4-011	2	CA1	6"	HC	X	11-P-2A & 2B	LINE 12-5C	325 300	300 250	lh
11-4-011	3	AA1	6"	HC	X	BATTERY LIMIT	11-V-2	125 100	300 100	
11-4-011	4	AA1	10"	HC	X	11-V-2	11-E-2	125 70	300 250	lh

Table 2: Excerpt from Equipment List

EQUIPMENT	DESCRIPTION	TYPE	DESIGN PRESSURE PSIG	TEMPERATURE °F	SIZE	INSULATION
11-V-1	STABILIZER ACCUMULATOR	SHELL & TUBE	125	300	60" I.D.	NONE
11-V-2	STABILIZER COLUMN	SHELL & TUBE	125	300	60" I.D.	NONE
11-E-1A	EXCHANGER	SHELL & TUBE	100	300	24.5" O.D.	NONE
11-E-1B	EXCHANGER	SHELL & TUBE	100	300	24.5" O.D.	NONE
11-E-2	EXCHANGER	SHELL & TUBE	100	300	34" O.D.	NONE

## 2.2 Course Integration Plan and Learning Outcome Flow

Development and refinement of the university construction curriculum is an ongoing process that ideally reflects industry needs, technological advancements, and faculty expertise. For many years, the primary employers of LSU CM graduates have been in the industrial construction sector, although a general curriculum with few electives had been traditionally offered. Beginning in 2012 a new curriculum that included IEA options underwent development through partnership with faculty and local industry to meet the needs of the industrial, commercial, residential, and heavy civil/highway industries. In Fall 2014, these IEA options were made available to students. To meet the needs of the industrial construction IEA, four new junior/senior level courses were identified and have been initially offered, although further development is underway. In addition to the four new courses, the introductory plan reading course was identified to be augmented with components from each IEA and the senior level capstone is being revised to be IEA-specific. Catalog descriptions for these courses are provided in Table 2, along with the plan for model integration within each course.

Table 2: Integration of Industrial 3D modeling into existing CM courses

Course	Course description	Model integration plan
CM 1102 Construction Plan Reading (not IEA- specific)	Principles of graphic communication applied to reading construction plans with emphasis on residential, commercial, industrial, and heavy highway plans.	2D drawings and 3D model will be used to develop visualization exercises and assessments to enhance students' visual literacy. Physical, ABS plastic 3D printed models will be produced to further enhance student learning and facilitate visual fluency between 2D and 3D (electronic and physical) models.
CM 3355 Maintenance and Turnarounds	Principles of industrial maintenance and turnarounds including facility types, process equipment, work order systems, safety, preventive maintenance programs, roles, planning, and facility shutdown concepts.	2D drawings and 3D model will be used to provide a visualization tool to enhance student understanding of the functionality of process equipment and the logistical challenges of turnarounds and routine maintenance activities. Specifications and equipment vendor drawings will be used to enhance knowledge of engineering design criteria and fabrication components.
CM 3356 Industrial Construction Estimating	Principles of estimating including quantity surveys, pricing analysis, and bid package preparation for industrial construction.	Drawings, specifications, and 3D model will be used to create consistent examples and a comprehensive course project to develop industrial construction estimates, including quantification of direct, indirect, and staff/supervision labor hours; construction equipment requirements; material costs; subcontractor needs; and a schedule of work activities. Printed 3D models will facilitate discussion of access issues and site planning.
CM 4357 Industrial Project Controls	Fundamentals of information management required for effective project control on an industrial construction project; data requirements, data collection, and data processing involved in measuring, evaluating, calculating, and reporting job performance from inception of project through closeout.	Data generated from the Industrial Estimating course will be utilized for simulation of project control requirements during construction of the facility, relying extensively on the 3D electronic and printed models for visualization. The 3D printed models will be integrated in a piecewise fashion to physically simulate the construction sequence.
CM 4358 Industrial Electrical Installations	Fundamentals of electrical and instrumentation concepts, systems, plans, and installations relevant to industrial facilities and applications.	Specifications and drawings will be used to facilitate student understanding of electrical and instrumentation installation, and the 3D model will be used to improve student understanding of the interrelationships between electrical and instrumentation (E&I) and mechanical components.
CM 4202 Construction Enterprise (Industrial IEA)	A comprehensive study of construction management as it relates to a single construction enterprise.	The entire senior capstone Construction Enterprise course for the industrial track will be refocused around the drawings, specifications, and 3D model to create an entirely new industrial-focused experience to assess and reinforce the culmination of curriculum concepts.

Figure 4 provides an overview of the data flow between the IEA courses, demonstrating how course outcomes build upon each other and work to produce an integrated industrial IEA centered around a prototypical facility. Although not shown in Figure 4, the introductory Construction Plan Reading (CM 1102) and Industrial/Heavy Civil Materials and Methods (CM 2103) courses provide critical conceptual knowledge and visual literacy skills. The industrial IEA courses begin with CM 3355 Maintenance and Turnarounds, where students gain detailed knowledge of engineering/functionality aspects of process equipment and construction methods needed to address plant maintenance and turnarounds for targeted systems. The 3D model and printed physical models are used extensively in this course to help students isolate specific systems, and this knowledge is translated to enable students to interpret 2D drawings through identification and visualization of individual systems. Using this knowledge of plant systems and logistics, students apply their core curriculum estimating skills to the industrial setting in CM 3356 Industrial Construction Estimating, which focuses on civil, structural, mechanical, and equipment scopes of work. Using the contract-type 2D documents shown in Figures 1-3 and Tables 1-2, students perform quantity takeoffs, evaluate project constructability, plan for equipment needs, and generate field and supervision labor hours and cost estimates. The 3D electronic and physical models will be used to help students conceptualize equipment planning and technology-enabled quantity takeoff will be demonstrated using automated bill of material generation functionality within Plant 3D. This knowledge will then flow to two courses – CM 4357 Industrial Project Controls and CM 4358 Industrial Electrical Installations. In CM 4357, the quantities, budget, and schedule developed in CM 3356 will be used as the numerical framework for scheduling and cost control examples. Project planning developed in CM 3356 will also be used along with project control concepts to learn and demonstrate progress reporting. In CM 4358, the interconnectivity of I&E scopes with the rest of the project (covered in CM 3356) is explored, as I&E scopes are field-routed. With understanding of civil, structural, and mechanical layout, I&E estimates and installation plans will be developed in CM 4358. Acquired student knowledge and generated plant project data from all of the preceding courses culminate in CM 4202 Construction Enterprise, which is the senior capstone course. In this course, all curricular outcomes are integrated in a cumulative project. Data developed in each of the courses will be used by the students to conceptualize and present the prototypical facility throughout the project/construction management life-cycle.

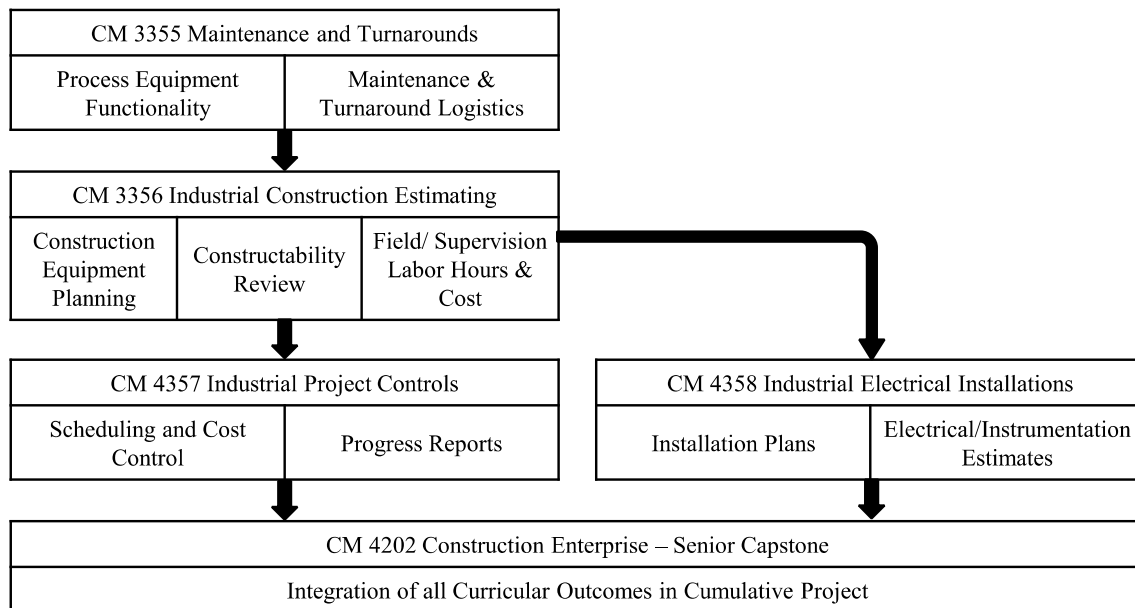


Figure 4: Data Flow Between Courses

### **2.3 Number of Students Impacted**

Based on current enrollments, approximately 150 students per semester (300 students per year) are anticipated in CM 1102, which is a required CM course taught every semester (fall, spring, summer). A minimum of 40 students are anticipated in each section of CM 3355 (fall), 3356 (spring), 4357 (fall), and 4358 (spring). Because CM 4202 will be offered on a more frequent basis, approximately 20 students per section are anticipated to be impacted by the project (fall, spring, summer).

### **2.4 Assessment Plan**

Assessment of the impact of the case study integration will be conducted using four primary measures: 1) faculty feedback of student learning before and after implementation, with data collected through faculty outcomes assessment reports at the end of each semester; 2) student learning outcome performance, quantified through performance on assignments, exams, projects, and the senior exit exam; 3) student feedback, collected informally in class and formally through the senior exit exam and surveys administered to CM graduates by the Construction Industry Advisory Council (CIAC) and 4) CIAC Curriculum and Accreditation Committee feedback of graduate performance.

Faculty provide feedback of student learning at the conclusion of each course utilizing a departmental student learning outcomes (SLO) form, with 20 program-level SLO's covering all aspects of the curriculum. The standardized Student Learning Outcomes (SLO) form also allows quantification of student performance on assignments, exams, projects, and the senior exit exam. In order to compare outcomes before and after implementation of the case study, assessment of the project impact will be accomplished by comparison of pre- and post-implementation SLO data. The percentage increase in pass rates and scores on assignments, exams, projects, and the senior exit exam will be monitored for trends during and after case study implementation. Because of the widespread integration of the case study within the IEA and the expected positive impact on learning outcomes, it is hypothesized that widespread increases in student SLO achievement will be observed, rather than increases in the achievement of specific SLO's, such as visualization ability and technological implementation.

In addition to SLO assessment, student feedback will be collected informally in class and formally through the senior exit exam and surveys administered to CM graduates by the CIAC. Informal collection will consist of qualitative data collection through interviews, class discussions, and course evaluations. The CIAC utilizes a survey instrument to collect data on student perceptions of increased value of BIM integration. The senior exit exam allows for a measure of increased student performance in spatial understanding as it relates to solving construction management problems. Data will be collected of student performance on exit exam questions relevant to spatial understanding both prior to and after implementation of BIM (3D CAD) integration into the curriculum.

The CIAC Curriculum and Accreditation Committee will review the implementation of BIM integration into the current curriculum and provide feedback to the faculty. Graduate performance will be assessed through the utilization of software-based surveys administered annually to measure the employer perception of increased spatial and temporal understanding in graduates from the program.

## **3. CONCLUSIONS AND FUTURE WORK**

This paper presents the curricular integration of BIM (3D CAD) within an industrial construction emphasis area. The overall 3D facility model under development is presented, along with industry-standard visualization products. The model is planned for integration within four junior/senior level courses, the freshman-level plan reading course, and the senior capstone course. Course integration plans are presented and the flow of data between the courses is presented to show the integration within each course and among the IEA courses. An assessment plan and details regarding anticipated student impacts are also presented.

Based on current work, the development of the case study is critical and time consuming, involving many faculty members to facilitate model and course product development. To make this type of project a success, commitment of faculty and coordination among them is important. In addition, to make such an



endeavor applicable to real-world construction, it is necessary to build the model around a complete case study, where students can easily relate abstract spatial and temporal concepts in industrial construction to ideas visualized by models.

In future work, the authors will further investigate factors associated with the technology that significantly contribute to learning.

## ACKNOWLEDGMENTS

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## **BIM CURRICULUM DEVELOPMENT**

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### **ABSTRACT**

Ever since the mid-eighties when CAD (Computer Aided Design) began to revolutionize how we design our buildings, forward thinking people have had a vision of a virtual construction world where we not only design in three dimensions but also schedule and estimate that same project from the information already assembled in the 3D electronic model. The potential benefits to all stakeholders were hard to overestimate. So what is the current progress of this vision and how do we, as college professors, deliver the best preparation for our students who will undoubtedly enter an industry that will continue to exploit the potential of what has come to be known as: BUILDING INFORMATION MODELING (BIM). This paper presents the process of our Undergraduate Construction Management program identifying the importance of BIM education for our majors and the initial steps we have taken in that direction. Richard Faust, PhD student, John Brown University, Siloam Springs, AR

**Key Words:** Building Information Modeling (BIM), Computer Aided Design (CAD), Schedule (4D), Estimate (5D), Sustainability (6D), Facility Management (7D)

### **HISTORY**

John Brown University's Construction Management program consists of 3 full-time faculty and 60 students on average and is ACCE accredited. The first 2D Computer Aided Drafting was introduced in 1987. Then the program progressed to using Graphisoft's ArchiCAD but switched to Autodesk Revit in 2008. BIM technologies were already being used by many of the advisory board member companies and it became apparent that graduates needed as much experience with BIM as possible.

### **INTRODUCTION**

The very first CAD (Computer Aided Design) systems began their development in the U.S. Air Force in the 1950's. They progressed for the next three decades without affecting the construction industry to any great extent until the founding of Autodesk in April of 1982. Autodesk's idea was to create a CAD program for the price of \$1,000 that could run on a personal computer (PC). The following year, 1983, the first versions of AutoCAD were marketed in Germany and France (Bozdoc 2006).

With the application of computer aided design and drafting to the building process, the inevitable move toward including more and more information in our electronic building models was assured. Those who were CAD designers in the 90's remember the regular promise of full 3D design capability in new softwares only to be disappointed by the glitchy limitations and painfully long

screen regeneration times. Just being able to design in full 3D easily, with any speed, was the only goal many architects and designers could imagine. But, as the softwares that made 3D design easier kept developing, so did hardware configurations that could process that information without the long time lags of the 90's and early 2000's. As we realized 3D design ability on simple PC work stations, the idea of attaching even more information to the components in the model did not seem as counterproductive because of continually improving processing speeds.

Visionaries saw the potential and teamed with IT personnel to start adding information that would let us schedule (4D) and estimate (5D) directly from the information we had already created in our 3D models. The idea that the electronic drawings could also give us accurate schedules and estimates was incredible, to say the least. Further additions of Sustainability (6D) and Facility Management (7D) round out the current applications of Building Information Modeling (BIM) by non-profit organizations, private, government and municipal agencies who are all trying to maximize the advantages of BIM in their practices. The chart below fleshes out sub-categories under the 5 main areas of BIM.



“Expect the use of 4D and 5D building information modeling (BIM) technology to flourish in the future’, Turner Construction’s Treighton Mauldin told a group of construction professionals attending a webinar that WPL Publishing held April 17, 2012. He sees 4D, which addresses scheduling, and 5D, which involves estimating, ‘taking off because they bring all of the aspects of a plan, an estimate, a model, and a schedule into one environment that can be easily monitored and managed and communicated to the rest of the team, which is a huge benefit, and it really starts to eliminate errors in communication, miscommunication, and, in the end, makes people more money (Rizer 2012).” These comments are typical of large commercial companies that plan on maximizing BIM in the future.

Before a program creates specific BIM training for their students, they need to answer the following questions;

**Is BIM really here to stay?**

“BIM Adoption Expands from 17% in 2007 to over 70% in 2012, According to New McGraw-Hill Construction Report (Malangone 2012)”.

**Is BIM just happening in the U.S.?**

Building and Construction Authority (BCA); **“Singapore, 1 August 2013** - There has been significant progress in promoting Building Information Modeling (BIM) in Singapore. The adoption rate has gone up from 20% in 2009 to 65% today” (Press Release 2013).

With confirmations like this that the growth rate is fast (about 10% per year) and almost the same in both the U.S. and on the other side of the world, we know our students need to be as familiar as possible with BIM technologies as they enter their careers. We also know we have to be asking the right questions as we set out to create curriculum that meets that goal. The body of this paper will state those questions and the progress JBU has made in implementing what we have discovered and learned so far.

## **What does our client (industry) need?**

When the author first started talking about BIM to his students he made sure they knew what the acronym meant and that it was about clash detection and attaching scheduling/estimating information to the electronic model. This provides information in the planning stage rather than having to wait for the architect to finish the working drawings and then schedule/estimate and look for clashes the architect didn't identify during the design process.

In a job interview in 2008 a JBU graduate was asked what he knew about BIM and he said, “Oh, Building Information Modeling?”, and went on to repeat some of the basic facts accurately. He was offered a job in their newly formed BIM department. That made it abundantly clear that the construction industry was eager for students with Building Information Modeling knowledge.

In a recent survey of our industry advisory board, they said they want our graduates to know about BIM. They usually say BIM is a great tool but they don't quite know how it's done. HR personnel are challenged in how to write job descriptions for these new positions. “To start your formulation of Job descriptions your firm needs to ask and answer, how do you and your management team plan to deploy VDC-BIM on projects? Some firms look at BIM as a drafting activity meant to provide project teams 3D modeling services. Taking this view they would create a BIM department that would likely be staffed with specialized CAD users. Alternatively, other firms focus on integrating 3D technology into each project teams' management skill set. Thus the development of Job descriptions would be different for each management strategy.

The distinction between the specialized CAD manager's approach versus a project management that is specialized in model management requires a unique job description for each position (Cousins 2010).” This quote is from an article written by an HR professional who also did short interviews with BIM managers from 4 respected commercial construction companies. The conclusion is drawn that the better the student's ability in Autodesk Revit, the better they will be able to adapt to whatever system of using the electronic model for BIM in their respective companies.

The action plan for our program was for the instructor to get better at Autodesk's Revit since there are three classes that require the use of Revit in the program. BIM applications will make more sense when people have some level of mastery of Revit. Just as AutoCAD became the industry standard in the 2D drafting world, Revit is already the standard in the 3D/BIM world and will only solidify its position as time goes on.

## **Where does BIM curriculum fit into an undergraduate program?**

The introductory class using Revit (CM 1223 - see below) uses a text written by a designer from Minnesota named Daniel Stine. In it he reviews hand drafting methods and then launches into a preset exercise of drawing the plans for a residence. The class is split in half and the students alternate doing plan reading exercises one lab a week and the Revit chapter assignments on the other. Senior CM students work as Teaching Assistants and lead the plan reading assignments while the instructor focuses on the students doing the Revit lessons. The following is a link to a PDF copy of the syllabus from the spring semester, 2015. It includes a schedule of each lab period: [http://www.jbu.edu/majors/construction\\_management/presentations/](http://www.jbu.edu/majors/construction_management/presentations/) This format is a very good way to get students right into the nuts and bolts of the software (Stine 2015).

The following JBU classes are the ones that directly involve using Autodesk Revit software. They were the initial classes considered for alteration to accommodate dedicated BIM training. CM 1223 starts the process of Revit acquisition and CM 3613 furthers it with a residential project students design themselves (This is something they may legitimately do as professionals).

After consideration, the course that was chosen to be altered was CM 3623 (next page). This is the first JBU course catalog with the new references in the description to BIM design principles and software. These concepts have been incorporated into this class for the past three years but the course description change has only now, in the current year, gotten into the school catalog.

The reality is that, unless JBU grads go on and become licensed architects, they will never legally do the full design of a commercial building and that's what the original course described them doing until this catalog cycle. This has been one of the first steps toward BIM integration into the entire construction management curriculum.

### **CM 1223 Graphic Communication Skills**

**Three hours**

The study and practice of communicating ideas through manual and digital means. Emphases include the development of lettering and sketch abilities, communication through construction documents, an introduction to construction assemblies and an overview of three-dimensional model based design, and construction documentation. Two three-hour laboratory periods per week. An additional fee associated with this course.

### **CM 3613 Architectural Design I**

**Three hours**

The design, development, and presentation of an architectural program for a residence. Introduction to design principles and their influence in the development of a project is addressed. The architect, contractor and owner working relationships are emphasized. Two three-hour laboratory periods per week. An additional fee associated with this course. Prerequisites: CM 1223 and junior standing, or consent of instructor.

## CM 3623 Architectural Design II

Three hours

An introduction to commercial design principles combined with principles of Building Information Modeling (BIM). The course will include an exercise in commercial design presentation and an introduction to BIM software and theory. An additional fee associated with this course. Prerequisites: CM 3613 and junior standing, or consent of instructor. (Course Descriptions 2015)

### What are the standard forms of BIM being used?

Once a program establishes the need for BIM training and dedicates at least part of a semester to it, what should they teach? The educator will find that more curriculum options have surfaced in the last couple of years that make it easier to design a course of study in BIM. In the Master of Engineering Technologies program at Pittsburg State University tutorial exercises are required in two softwares that are emerging as BIM applications in the construction industry. This has great appeal to construction companies that are late adopters of the technology. It also has strong appeal to educators who want to give their students comprehensive BIM exposure along with educating themselves. The JBU class was altered to include: DProfiler and Synchro. The feedback has been very encouraging as several former students have seen these softwares being used by their employers and were glad they were familiar.

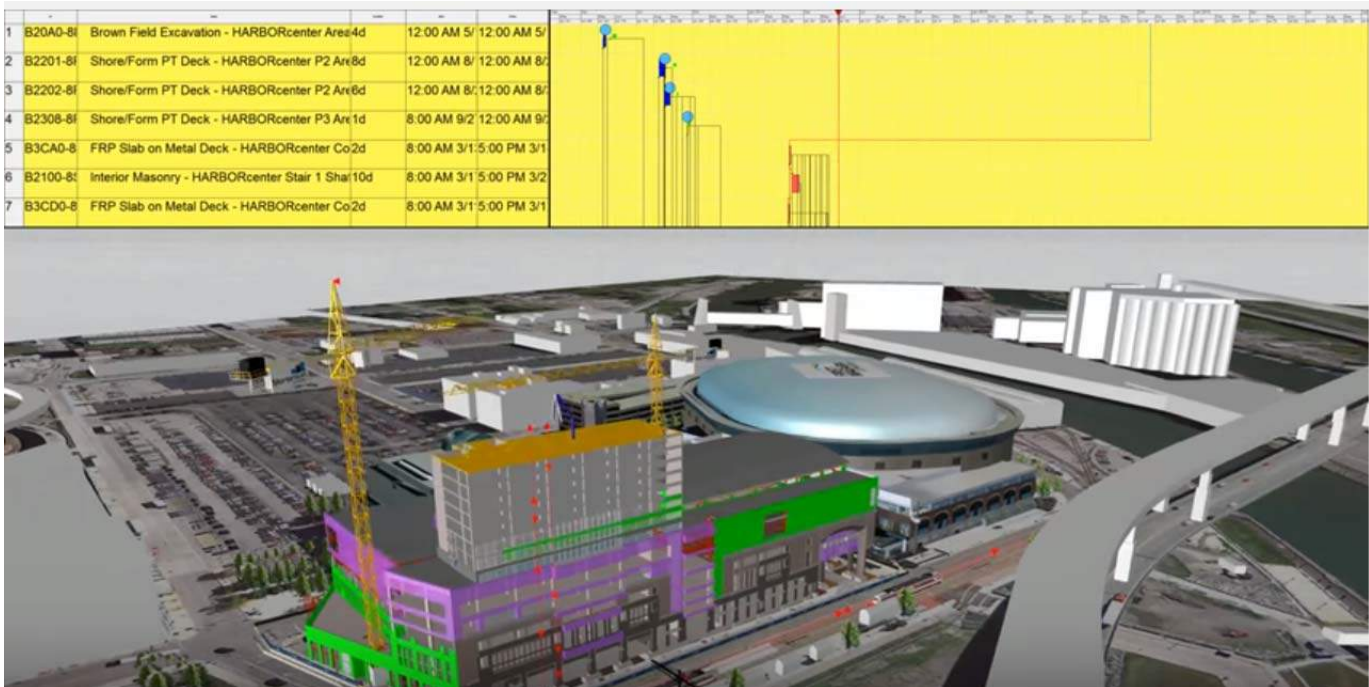
“**DProfiler** is a unique BIM program that integrates 3D macro modeling and cost estimating. With this powerful program you easily build a model of your conceptual design and generate an accurate cost estimate without extra time or effort. An excellent marketing tool, with DProfiler you can give clients an impressive preconstruction package.

DProfiler features: ( DProfiler videos <http://www.beck-technology.com/demos.asp>)

- 3D Modeling with easy importing from CAD programs
- Cost Estimating with integration from Excel, RS Means databases, and Timberline
- Energy Analysis
- Google Earth integration (Beck 2012)”



## DProfiler 3D model scaled on a 2D drawing

**SYNCHRO MODEL WITH INTEGRATED SCHEDULE**

“**Synchro PRO**’s real time visualization capabilities change the way projects are planned- the ability to see into the future, to communicate clearly and to create a shared understanding amongst the entire project delivery team, enables performance on a much higher level. Safety, productivity, quality, reliability and cost competitiveness all increase. As the industry works to close the skills gap, to effectively and successfully utilize new purpose built, digital technology, the Synchro Project Delivery Team is here to support the companies and people who are working hard every day to deliver great projects (Synchro 2016).”

Standardized BIM is trying harder to emerge in places other than the U.S. it seems. “Although the number of project teams using BIM tools increases each year, the transformative potential of these tools remains checked by barriers that impede the information exchange among participants and across different software platforms. Getting the most out of BIM will require an open exchange of information, which in turn requires defining and implementing common protocols and standards. But who wants this arduous task?

In the United Kingdom, the answer is simple: the government. By 2016, all British government building contracts will require “fully collaborative 3D BIM,” according to the country’s 2011 Government Construction Strategy. The NBS National BIM library—yes, such a thing exists—already contains thousands of both generic and proprietary BIM objects. (These objects are virtual building components containing performance parameters and physical attributes that can be placed in digital building models.) Singapore, Finland, and Norway also have national BIM standards, and China has one in the works (Shapiro 2014).” They have also produced a video about the status of BIM in the UK (National BIM Library 2013).

## OTHER RESOURCES HAVE I FOUND TO HELP INTRODUCE BIM

Reid Johnson ([reid.johnson@autodesk.com](mailto:reid.johnson@autodesk.com)) is available to teach mock coordination meetings (via Go-To-Meeting) focusing on clash detection in the CM 3623 course using the autodesk cloud at no charge. There are 6 hours of lab time dedicated to these meetings and it has received great student feedback.

The challenge of grading can be met by allotting an appropriate amount of points for participation and engagement during the actual contact time and some questions on the final that can only be answered by engagement in the original exercise or remedial experience.

## CONCLUSION

First of all, students need to have the highest level of proficiency possible in the 3D software package they will most likely be using in their new jobs. That software should be the current version of Autodesk's Revit.

Because so many companies, especially early adopters, developed their own hybrid systems using softwares like Navisworks, or writing their own, there haven't been many standard protocols for educators to look at to create BIM curriculum. That is changing, however, and several new tools are being offered by Autodesk in specific disciplines like Construction Management: <https://academy.autodesk.com/curriculum/construction-management>. In addition, DProfiler and Synchro tutorials, along with videos and classroom experiences in mock coordination meetings will continue to be some of the best ways to introduce BIM to construction management students.

The author hopes to start a connection with as many other undergraduate professors as possible so the group could go forward developing really effective BIM curriculum together. All universities can prepare students to hit the ground running in this new paradigm called Building Information Modeling.

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# BIM IMPLEMENTATION AT THE BUILDING SYSTEMS COURSE AT THE UNITED ARAB EMIRATES UNIVERSITY.

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## ABSTRACT

As BIM progresses as a necessary tool for the Architectural, Engineering and Construction Management (AEC) programs all over the world, the United Arab Emirates University (UAEU) has a clear path to implement these tools in their Architectural Engineering Curriculum. This paper introduces the roadmap that the Architectural Engineering department at the UAEU is using to introduce BIM.

The paper focuses on the benefits that we found at the Building Systems Course. We compared the students' performance after the first semester with a Project Base Learning (PBL) methodology using Revit with the traditional course.

This paper will provide data about how BIM will improve the construction drawing's quality and increase the speed of the students. It will change the whole learning process from simply memorizing solutions to analyzing and testing in order to select the best construction system from a database. It will also help to solve the integration problem that schools are facing by teaching each system in separate courses and it will change the concept from only drawing to actually building projects.

**Keywords:** BIM, Architectural, Engineering, Construction Management, Construction, Curriculum, Building systems, AEC.

## 1. INTRODUCTION

Today the Architectural, Engineering & Construction Management (AEC) industry is looking forward to hiring new professionals who are able to move totally into Building Information Modeling/Management (BIM) (Vázquez, )

. AEC Programs, face a turning point, "25 years ago, AutoCAD pushed designers into a new era; BIM represents a new generation of virtual model already widely accepted it by in the industry" (United Nation Human Settlements Programme (UN-HABITAT), 2008).

The implementation of BIM in the AEC curriculum is a reality all over the world as scholarship describes it. In the US there are a great number of schools currently using BIM for teaching architecture and civil engineering (Rey Merino, 2012). There are Schools all over the world introducing BIM in their AEC curriculum we can introduce several samples as (Bedoya, 2005a) in Spain, (Naciones Unidas, 2012) in Indonesia and this article in United Arab Emirates.

The Architectural Department of the UAEU decided to move from a traditional Architectural program into an Architectural Engineering one. As part of these decision the Architectural Design process is moving towards an Engineering Design process focused on a cyclic process which applies solutions, feedback and remodeling based on engineering data. To implement this process, it was suggested from the ABET advisors to implement BIM technologies.

The Architectural Engineering Department at the United Arab Emirates University (UAEU), decided to introduce BIM in the curriculum starting in fall 2014. To make this possible the faculty was trained by an Autodesk Official Training Center in Revit and Naviswork 2015 during the summer of the 2014.

The proposed roadmap included an eight week BIM workshop for all the students interested during the fall semester 2014; the introduction of Building Integrated Modeling concepts (BIM) in the first course of construction "Building Systems (BS)" during the Spring 2014 and the gradual

implementation of BIM in the Construction and Design courses of the Architectural Engineering Curriculum.

This paper explains the contributions of BIM to the BS course. This course uses a mixed method that combines traditional lectures with a Project Based Learning (PBL) experience enhanced by BIM.

## 2. BUILDING SYSTEMS COURSE

Building Systems is the first course where the students will be introduced to the Building Construction Systems at the UAEU. This course will provide the students with a solid base in building construction principles, concepts, systems and criteria.

The course aims to make students understand the main construction materials and methods widely applied in the building construction industry. The students are introduced to the applicable building codes and standards that they will use during the design courses. The course covers: Building materials, their properties, and construction processes; Construction technology, systems, methods and techniques, emphasizing the local applications and practice; construction drawing standard; structural systems; construction methods; and building components.

### 2.1 Course Objectives

The course objectives are to understand basic building construction terminology; building standards, and building codes; to enhance knowledge of building systems and materials, including structural systems, wall systems, floor and roof systems; to understand the different building components both technically and structurally; to enable students to undertake professional drafting skills and principles of working drawing process.

### 2.2 Learning Method

The learning methodology of this course changed in the spring 2015 semester from a traditional approach of lectures and assignments to a mixed method approach of lectures and project based learning sessions. In the traditional approach the student has to reproduce the content of the lectures to understand and memorize the topics. In PBL based on BIM the student builds and develops a 3D model of a building, analyzing, selecting and applying different construction systems.

During this project they will modify the type of structure, allocate the stair, add different components, discover issues by themselves, research for alternatives, apply different solutions, and mainly they will learn how to search, think, select with proper criteria and apply alternative solutions to solve the problems.

### 2.3 Course Outline

Table 1: Course outline Lectures and Assignments Fall 2014/Spring 2014

Lectures		Lab Sessions		
Week	Topic/Subject	Course with out BIM	Week	BIM Project based course
1	Orientation & Course Overview		1	
2	Understanding Buildings & Load Distribution, Construction Terminology, Standards, and Codes	EX01 Basic Structural System	2	EX01 Basic Skills, Plan Section and elevation, drawn by Hand and AutoCAD
3	Buildings Materials & Principles of Working Drawing Process		3	
4	Short Span Structural Systems: Bearing Wall System	EX02 Floor and Roof Systems Application of Masonry walls and Stud Partitions	4	
5	Short Span Structural Systems: Skelton System		5	EX02 Structure systems. Foundation, columns, retaining walls, one way and two way slabs.
6	Foundation Systems	EX03 Foundation Systems	6	EX03 External walls, flooring, add cantilever to the structure.
7	Floor Systems		7	
8	Mid-Term Exam			
9	Spring Break March 29th - April 9th			
10				

11	Roof Systems	EX04 Wall Systems	11	EX04 Structure modification. Metal decking, open web joist. False ceiling.	PROJECT
12	Wall Systems	Presentation I	12		
13	Openings and Wall Components	EXOS Long Span Structure	13	EX05 interior partitions, wood and metal studs.	
14	Moisture and Thermal Protection		14	EX06 Add to the model Stairs. Reseach stair detailing and conections.	
15	Long-span Structural Systems	Presentation II	15		
16	Vertical Circulation	EX06 Vertical Circulation Application of staircase design and structure	16	EX07. Add doors, windows and create schedules and quantities. Research windows and doors details.	
17	Concrete Stair Cases		17	EX08 Create the site plan, print in pdf and A3 paper all the architectural and structural plans.	
18			18		
19	Final Exam				

## 2.4 Course Assesment.

### 2.4.1 Student Performance Assessment & Grading Criteria:

Throughout this course, student will be gaining knowledge and competencies that will be evaluated using different assessment techniques. This course allocates 40% of the final grade to the students' performance in the lab sessions where we use a PBL-Revit methodology. The other 60% is allocated for exams the class participation. The following grading percentages will be applied: Assignments and presentations: 40%; Class Participation: 10%; Mid-Term Exam: 20%; Final Exam: 30%.

### 2.4.2 The following are the main assignment grading criteria:

The assignments are graded using the following criteria: the understanding of the construction problem; the design of a solution based on the literature review, case studies and problem analysis; the application of criteria to select the appropriate construction systems; the integration of both these systems and its components to the project; the proper integration and application of the Building Standards and Building Codes; the pre-calculus of structural elements; and finally the capacity to produce quality and well defined Building Construction Drawings.

## 3. REMARKABLE ACOMPLISHMENTS

The implementation of BIM to develop a project based learning environment during the lab sessions of the BS course at the UAEU has resulted in very useful experience where the students learn, discover and understand the construction process and its elements by themselves. The professor takes the role of an advisor, who guides and helps the students in the learning process. The students change its role from a passive to an active learner. The 3D building methodology used during the lab sessions helps the students to understand the concepts quicker and better.

### 3.1 Research assessment

These statements are based on the comparison of the performance of the students during the fall 2014 and the spring 2015 semester, using the graded samples that are stored in the Course Files at the Architectural Engineering department, and the e-files at the University Curriculum Directory of the United Arab Emirates University.

To have reasonable, stable and fitted criteria to evaluate the performance of the students, we have used the course assessment elements that are defined in the syllabus and stated in this paper in chapter 2.4 Course Assessment.

### 3.2 BIM requisites.

Before we can introduce BIM, the students need to learn several concepts. They need to understand the different types of projections, their relations and the process to create them. The students need to be able to draw a plan, a section and an elevation by hand and AutoCAD. They also need to learn the relations between each projection, and how to represent them properly. They need to be introduce to

the standard criteria of the drawings like black thick line for elements which are cut, dashed lines for hidden elements, dash dot lines for axis, etc.

### 3.3 BIM improve the construction drawings quality and speed.

The students need a proper background in drawing skills to understand the plans done by the program from the 3D model, and also to determine their level of detail, the type of connections, and correct modify the ones that do not meet their design. After this step they will learn, all the construction drawings that should be delivered to define a project. BIM helps with these by organizing the drawings by categories and sub-categories. We can create the whole set of plans from the beginning, and they will be developed further on.

As scholarship describes it “the model's output would produce all the documentation that the team members would otherwise have to create in isolation and duplication” (Baeza, 2006), BIM integration of the whole project, has a huge effect in the Learning processes.

BIM represented in the BS course by Revit is a very powerful tool to develop the construction drawings. The students spend less time drawing the plans, sections and elevations. With the extra time we can guide them through a project where they apply all the concepts from the lectures. They can also use this extra time to understand the building systems concepts and develop other skills related to the construction detailing, problem solving and design process.

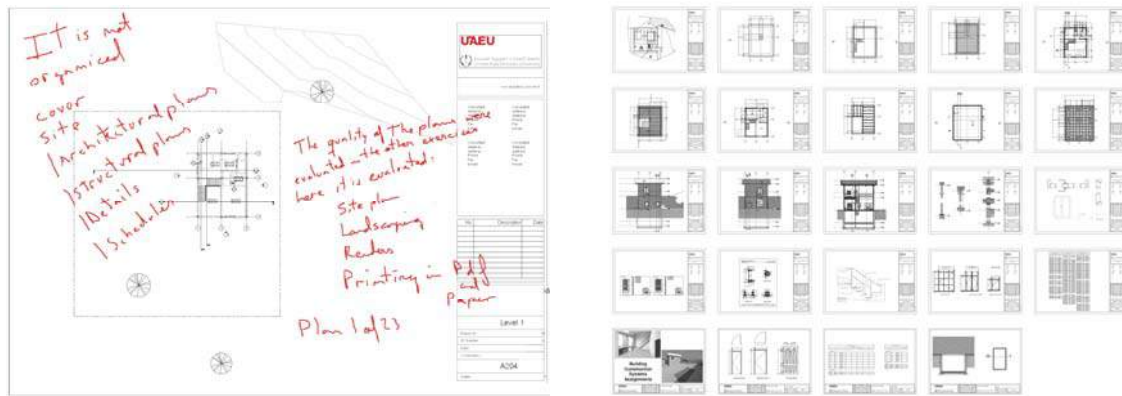


Figure 1 & 2: Student BS Spring14 submission

### 3.4 Build instead of Drawing

The project based learning environment, that we created in the lab sessions, simulated a construction building site process while, introducing design changes to develop the project. The students built their project in the same order that they would have done in a real construction site, but with the opportunity of modifying and trying alternatives.

The students begin creating the columns, retaining walls and foundations. Then they create the main beams, the beam systems (one way and two way) and the concrete slabs. The student have to deal with different kind of structures; modify the structure type during the project from concrete to steel; add a cantilever to the slab analyzing the proper direction of the beams; and reorganize the beam systems to place the stair.

The process of creating and modifying the building step by step, enables the students to understand the building by themselves. They assimilate the function of each element, the proportion and order.

Creating a cantilever and allocating the stairs are small exercises that make them realize the importance and function of each element of the structure.

The students develop step by step the whole building while they study or research each building system. This learning process creates an interactive environment where the students build what they just saw in the lectures or researched by themselves. This process check their understanding and knowledge creating a very solid base

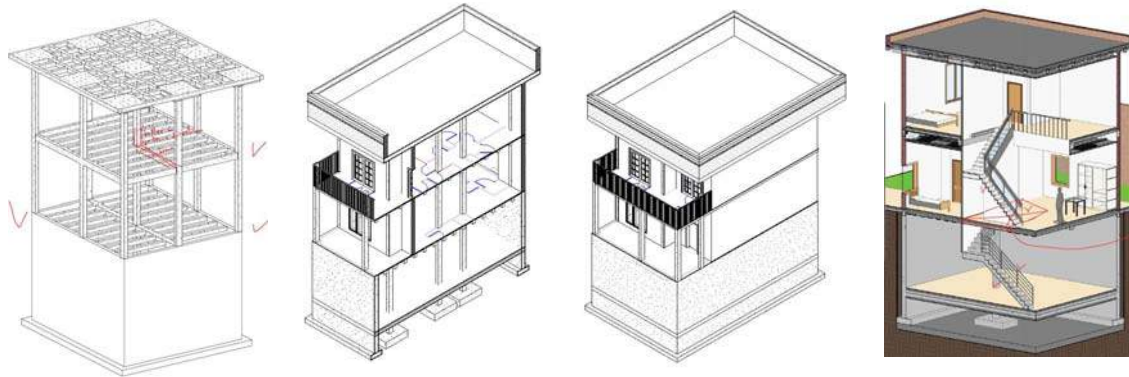
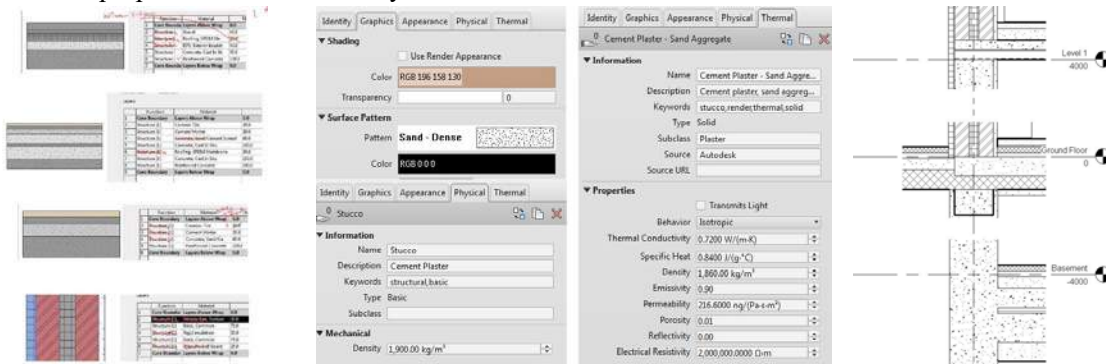


Figure 3,4,5: 3D views of building during different exercises (Students BS Spring14)

### 3.5 Building components BIM academic approach.

The approach to the building components using BIM is totally different. The students have a big database. This give us the opportunity to explain the function of each layer instead of the layers of the component. The first assignment will be to analyze the needs of a building component and select two different alternatives and explain to the class the reasons for selecting those ones; these will create a debate about the alternatives chosen by the students and their reasons. As a second assignment they have to look for the physical properties of specific materials that we selected for create a new alternative that is not in their database.

The students need to understand the hierarchy of the different elements, and the layers inside of them. It is amazing that the issues that Revit has to create proper joints between different construction elements is a powerful tool for the students to learn. As a third exercise they have to point out the function of each material at the encounter of a wall and a floor system. After knowing the functions, they have to organize the layers manually. Again we can discuss with the students the different solutions proposed and their viability.



Figures 6,7,8: created elements, joints between different elements (Students BS Spring14)

### 3.6 Multiple approach

The BIM model contents 2D, 3D and properties like dimensions, cost, areas, U value, CO<sub>2</sub> values, etc. The BIM parametric design, emphasize several factors.

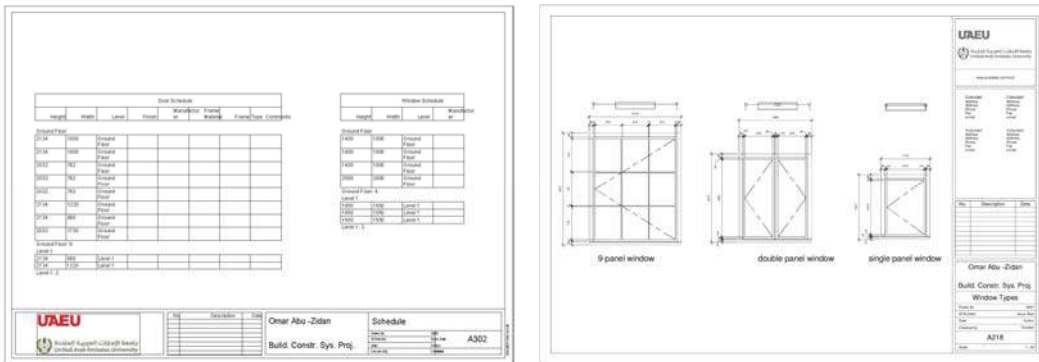
First as we build instead of draw, when we need to modify an element we just have to change its type. This is not as quick as it seems because we have to check and remodel the joints between the new elements and the old ones to be the way we want. This make the students review and rethink the details each time we change an element. This is a good opportunity for the students to review their work and create critical thinking.

Second the parametric information of the project is updated in real time. This gives us the opportunity to have updated quantities, schedules, take off materials and key legends for the different design options, and construction stages.

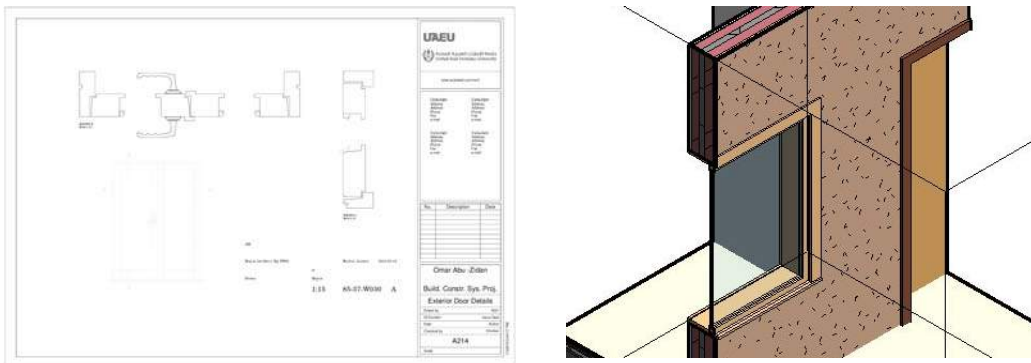
(Bedoya, 2005b) stated in 2008 that “BIM’s multi-dimensional approach allow us to see how the pieces of their project fit together in real time”

Third the use a multi dimension approach for academic purposes give us the opportunity to make more accurate and data-based decisions for our projects allowing a very quick and interactive lecture and analysis using 2D, 3D, quantities and schedules where we can compare the properties.

As a sample for the opening lecture, we use the 2D approach to explain the doors and windows components. 3D approach for the students research products and analyze how they will adapt the product or their walls to make them a proper fit, create schedules and quantities to compare the properties, and cost of the different types of windows.



Figures 9,10: Windows assignments (Students BS Spring14)



Figures 11,12: Windows assignments (Students BS Spring14)

### 3.7 Remodeling, Redesign and Redetailing, but keeping the drawings updated.

BIM simplifies the construction drawing and keep them updated. We have to make sure that all the joints are properly done as it is already stated but they are updated. BIM lets the students see the changes in real time in 2D and 3D. This make this tool their perfect partner to learn, try, investigate and rethink the spaces and details of their projects.

During the course the stair case lead us into the first developing element of their project. As a project based learning course, the students have to analyze their project and find the most appropriate place for the stairs. After this location is defined they will have to analyze and modify their structure to make it suitable with the hole they want to create in the slab. This will make the students realize the consequences of each decision. They will also need to take care of the ceilings, walls and the space under the stairs.

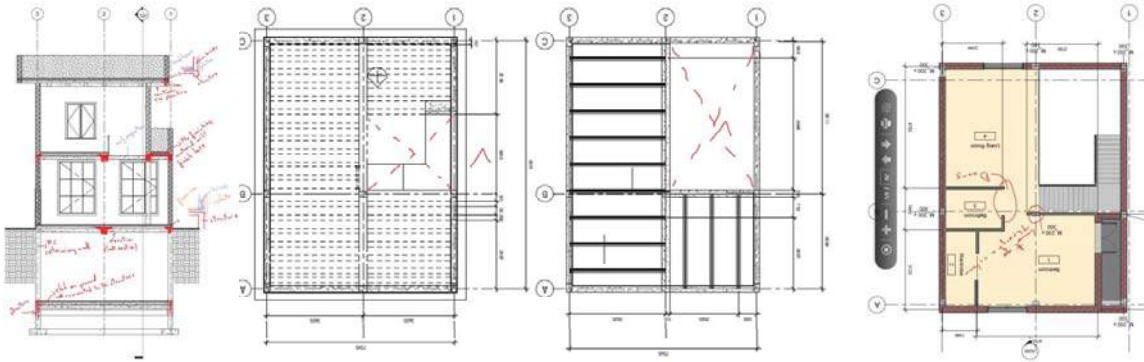


Figure13, 14 & 15: Section development, Structural plan alternatives, Final plan(Student BS Spring14)

#### 4. CONCLUSIONS

Even though the first perception was that students will apply more effort in a 2D environment and they will learn more because of this. The results of applying a BIM 3D technology like Revit in the BS course reveal several factors which tilt the balance in favor of the BIM.

A better and quicker understanding of the course content by the students. due to the 3D model that they build instead of draw. This will also help the students to understand the relation between the elements by themselves. Each time a student create two different elements that intersect, they have to move from the plan to the section to adjust the type of connection and the level of each material. These will force them to make decisions which lead them to develop knowledge and critical thinking.

BIM 3D technologies reduce the time invested in drawing, time that is very useful. We can develop father each chapter, place new chapters, or let them think out of the box pushing the students towards research, analytical and critical thinking abilities. The students spend less time, to draw and modify each plan, section and elevation while but to thinking about alternatives and solutions for each issue and connection.

BIM can be used to implement a whole set of working drawings, that they will develop on their specific courses. This will help the students to create an organized base to build their knowledge in an integrated manner.

BIM is the perfect way to introduce a Project based learning environment, which gives us a totally different learning environment. The students are not taught the solution, but the principles that lead them to solve problems by themselves with the supervision of their professor. The change is not based on BIM but it helps. The professor changes his role during the lab sessions to become an advisor.

The project based learning, enhanced by BIM Technology creates an environment where they can develop, and integrate the knowledge of all their AEC courses. Using the knowledge acquired in this course as a base, the students will have during their next courses the opportunity to integrate their MEP, HVAC, Structures, Sustainability, Scheduling, Quantity survey, Management and Maintenance into their project. This will lead them to understand the whole process as one, and the relations that each of them has into their designs and construction projects. This Makes a gigantic difference on the learning process and their understanding of the AEC industry.

To conclude BIM gives the students an enhanced motivation due to the real time visualization of their projects. The students have the opportunity to have 3D sections, details and images of their projects. That encourages them to increase the effort and time dedicated to the project.





Figure 16, 17, 18: Section development, Structural plan alternatives, Final plan (Student BS Spring 14)

## 5. FUTURE WORK

During the fall 2015 semester we have implemented BIM into the Intermediate Design Studio (IDS), Building Components (BC), and Modeling and Simulation (S&M). BIM is going to be implemented in the Advanced Building Construction (ADC).

We are actually studying the implementation of BIM in the Architectural Engineering (AE) curriculum at the United Arab Emirates University (UAEU). We will present this study at the 18th International Conference on Human-Computer Interaction, at the session 'Knowledge Society for all. New trends in Education' in July in Toronto, Canada.

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# THE DEVELOPMENT OF A BIM-ENABLED CURRICULUM: PLANNING FRESHMAN YEAR

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## ABSTRACT

In order to address the shortage of qualified personnel, construction companies across the country are looking to academia to produce entry-level hires with an undergraduate or associates degree in construction that are equipped with the necessary knowledge and skills to assimilate quickly into a building information modeling (BIM) environment. Similar to the situation throughout industry, most college and university construction programs, aside from developing introductory BIM pedagogy as an elective or at a graduate level, fail to create learning continuity in an attempt to fully understanding the collaborative benefits of the BIM process. Through a consideration to learning theory, a constructionism approach has been adopted for the development of a BIM-enabled undergraduate Construction Management (CM) program. Instead of teaching BIM inside an existing CM degree plan, this research is in the initial stages of developing a pedagogy that would teach construction management inside a BIM-enabled curriculum. By integrating the use of building information models (BIMs), existing course content is delivered through the BIMs, tapping into the rich visual nature of the 3D environment. Beginning with the Freshman CM courses, followed by the eventual development of subsequent program courses, BIM becomes a continually evolving part of the pedagogy, creating a foundation that contributes to the student's problem-based learning of the whole BIM process. As a result, preparing the eventual graduates not only for the BIM environment, but teaching them the benefits of interdisciplinary collaboration.

**Keywords:** Building Information Modeling; BIM Education; Curriculum Development; Undergraduate Education

## 1. INTRODUCTION

It is widely accepted across our industry that building information modeling (BIM) and the associated technologies represent an opportunity to improve all aspects of the business of construction. As construction companies adopt and implement the latest virtual design and construction (VDC) processes including BIM, many are realizing why this 'innovative way of doing things' is referred to as disruptive. Most of what was considered to be standard operating procedures or 'business as usual' is now a fragmented group of disparate stakeholders overseen by a disproportionately small number of technologically overwhelmed and ill-equipped individuals. And the few true industry experts that do exist are spending the vast majority of their time trying to keep up with latest evolution in software. In order to address the shortage of qualified personnel, companies across the industry are looking to academia to produce entry-level hires with an undergraduate or associates degree in construction that are equipped with the necessary knowledge and skills to assimilate quickly into this data-rich environment. Most research on the subject indicates that the vast majority of institutions are still watching from the sidelines as a small group of progressive schools are attempting to address these issues through

pedagogical research, case studies and industry partnership. Unfortunately, like most of the companies throughout the industry, academia is struggling with the dynamic nature of the BIM/VDC technologies and an unfamiliar environment of collaboration. Already existing requirements for graduation, the absence of room in the curriculum for additional elective courses, and a lack of reference materials and establish curricula are all obstacles to the inclusion of BIM in undergraduate construction management programs (Sabongi 2009). In addition, there is the issue of how to equip the existing faculty with the necessary skills to teach this technologically enhanced subject. Currently, most BIM courses offered at an undergraduate level are electives or post-graduate offerings. And due to the additional time and expense this may not be an option for most. In order to resolve these issues while meeting the criteria of the accreditation bodies, academia must rethink its pedagogical approach by incorporating BIM into an undergraduate curriculum.

The pedagogy behind BIM education at an undergraduate level must be reevaluated with the mindset that BIM is still a developing process. It is a process that cannot be fully designed in advance of us; rather it must be developed through use (Fisher & Hermann, 2011). Instead of teaching BIM as an independent course subject or as an individual topic in a construction curriculum, academia should consider teaching construction inside of a BIM-enabled curriculum. This approach to teaching BIM is a socio-technical process that facilitates both the learning of construction and the benefits of the many applications as they are applied to the built environment. The BIM-enabled curriculum will continue to utilize the existing course material and follow the same individual class syllabi while maintaining the current accreditation requirements. This paper prescriptively discusses the development, from a constructionist and problem-based view, of a plan to use BIM as a platform to teach the three freshman year introductory construction courses of an accredited construction management curriculum starting in the fall of 2016.

## **2. CURRENT UNDERGRADUATE BIM PEDAGOGY**

To understand the current state of undergraduate BIM education, a survey was conducted to find all of the stand-alone BIM courses, with available course syllabi, that are currently being offered by the undergraduate programs of the member institutions of the Associated Schools of Construction (ASC). Of the 138 schools listed on the ASC website, 62 institutions used the words BIM or VDC in the course title and only 41 current course syllabi were found. 37 of the 41 BIM/VDC courses are available only as an electives. This limits the exposure to BIM as an integrated part of a curriculum. The most popular approach to integrating BIM into a curriculum has been through computer graphics classes, by replacing the Department's existing CAD class with a BIM class at the freshman level. The course objectives are to introduce students to the techniques and capabilities of a specific modelling program, and to arm them with basic BIM modelling skills (Clevenger et al., 2010). BIM is about communicating in a construction environment using a specific language based on a particular knowledge set. Users need to have a clear understanding of building systems and construction methods. With these requirements, limiting the BIM education to only one class in one domain leads to teaching BIM tools without providing any exposure to collaborative aspects (Zhao et al. 2015). The collaborative aspects in this case could be considered the communication part of the process. And without a base knowledge in construction, BIM becomes just a new technology. According to Lee and Hollar (2013), becoming skilled in using BIM technology cannot be gained through one or two intensive courses alone. In most cases, those courses fall short of the expectation of BIM fluency. Moreover, BIM training within a CEM curriculum usually focuses on usage of the technical software tool, not on the VDC processes inherent with BIM implementation. CEM programs need to develop and implement best practices in teaching BIM and VDC to students, thereby fostering further industry innovation as graduates enter the workforce. Some programs are currently making an attempt to integrate BIM content into existing courses as lecture notes or even as single to multi-lecture modules. However, it has been noted that without the BIM technology component delivered in conjunction with theoretical BIM, traditional lecture classes fail to develop an understanding for the full BIM process. BIM can also be used as a learning tool that can aid team members in familiarizing

themselves with many aspects of a construction task. Therefore, the integration of technology (such as BIM) and team collaboration becomes more critical for construction education (Zhao et al. 2015). It is important that both academia and industry share in the development of BIM education, bringing together the current collective body of knowledge of academic research with that of industry understanding and practice in order to provide a holistic picture of Building Information Modelling within the industry (Isikdag and Underwood 2010). Given the current state of undergraduate BIM education, there exists a need for a sustainable method of delivering BIM knowledge that builds upon the traditional construction topics.

### **3. FRESHMAN YEAR FALL 2016**

The following is an outline of the development of a BIM-enabled construction management curriculum. BIM topics and technology, as it aids in the delivery of the individual course material, will be used to facilitate existing course content. This outline is a work-in-progress by the author with help of department faculty and industry professionals.

#### **3.1 The Courses**

##### **Graphics I**

Provide the 1<sup>st</sup> year CM students with an opportunity to explore the 3-dimensional environment of the Building Information Models (BIMs) in Graphics I. This lab-based course introduces students to graphic communication and visualization of constructed facilities. As part of the schedule of topics during the 2<sup>nd</sup> half of the semester, the students are given opportunities to explore and manipulate the visually rich environment of the BIMs. Topics like Basic Revit, Views, Dimensioning and Annotating are addressed using the 2D side of Revit. Where this class exceeds its predecessor is during the topics of Interpreting Architectural, Structural and MEP drawings, and As-Built Drawings. This class has traditionally relied on Autodesk's AutoCAD. As part of this program initiative, AutoCAD will be phased out as part of a multi-year plan to completely replace it with Autodesk's Revit. The specific BIM terminology and its integration into the weekly lector topics are developed by the individual course instructor(s) and the BIM Content Facilitator.

##### **Construction Management I**

Introduce the freshman construction management (CM) students to BIM terminology in Construction Management I. This lecture-based course is designed to provide the first introduction to the principles of management, the construction industry, roles and responsibilities and an overview of common management tools. The specific BIM terminology and its integration into the weekly lector topics are developed by the individual course instructor(s) and the BIM Content Facilitator.

##### **Construction Methods & Materials**

BIMs are used to facilitate the learning objectives of Construction Methods & Materials. In this lecture-based course that introduces the new CM students to basic building materials and systems, the virtual interactive environment of the BIMs replaces still pictures and static diagrams. The model will be used by the instructor as a visual tool to teach course subject matter and basic BIM process concepts, as they apply to communication between stakeholders. The specific BIM terminology and its integration into the weekly lecture topics will be developed by the individual course instructor(s) and the BIM Content Facilitator.

First Year	
First Semester	Second Semester
FALL	SPRING
CNST 1301 3 <b>Construction Management I</b> Pr: None	
CNST 1303 3 <b>Graphics-I</b> Pr: None	CNST 1301 3 <b>Conc. Materials Methods</b> Pr: Credit for or concurrent enrollment in CNST1301 & 1303 or 1315
CNST 1315 3 <b>Proj. Drawings Graphics</b> Pr: None	CNST 1325 3 <b>Process &amp; Industrial Const.</b> Pr: Credit for or concurrent enrollment in CNST1301 & 1303 or 1315

Figure 1: First Year Construction Management Courses

### 3.2 Tools and Skills

#### The Model

The model, a Revit model, should be a multi-story building similar in construction to the buildings on campus. If possible, for the purpose of future research in the area of Facility Management, an actual model of one of the buildings on campus would give students an opportunity to explore a viable finished facility. It should be composed of an architectural model, a structural model, and a MEP model. It will be given to the students as a supplementary learning tool which will be used in each of the courses as described above. As a visual tool, the individual course instructors will utilize the model to help teach existing course material. Students will be encouraged to explore the models on their own time. Computer labs with applicable software programs will be made available. If possible, a dedicated lab assistant/grad student with a high level of BIM technology proficiency will be hired as a resource for interested students and faculty.

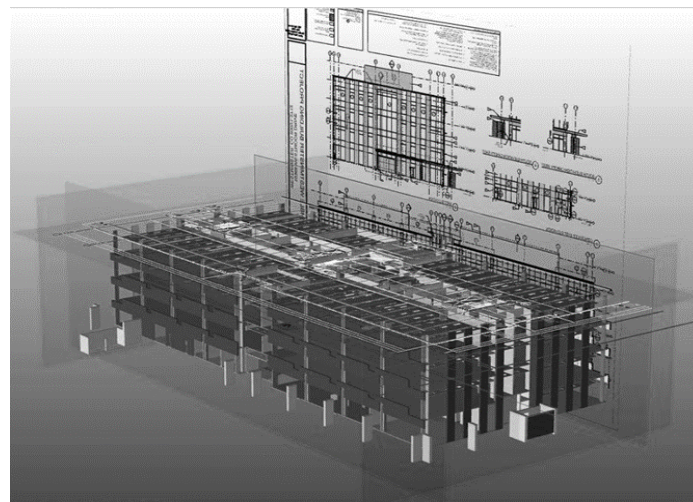


Figure 2: The Model as a Visual Tool

## Instructor's Additional Skills/Training

Prior to the start of each semester, a 4-hour class covering basic Revit and Navis user interface tools will be offered to faculty, staff, and interested students. Freshman-year course instructors will only be required to manipulate a model as a visual tool for instruction of course content. Exception: Graphics I instructors will be required to learn annotation, dimensioning, and drawing skills in Revit as they apply to the course material. The 2D side of Revit is very similar to AutoCAD and should not be difficult to learn with a little practice. No other additional skills will be required for the 1<sup>st</sup> Year course instructors.

### 3.3 Future Plans

#### Planning for the 2<sup>nd</sup> Year CM Courses and Improving the 1<sup>st</sup> Year

As the Implementation of the 1<sup>st</sup> Year begins, development of the 2<sup>nd</sup> Year courses will begin in weekly meetings with individual instructors and the BIM Content Facilitator.

#### Creating Interdisciplinary Collaboration Opportunities in the 3<sup>rd</sup> and 4<sup>th</sup> Year

Initiate conversations with Architecture and Engineering faculty. Enlist interested members to foster interdisciplinary conversation and collaboration.

Start a student-run organization that meets once a month to listen to industry professionals discuss, compare or debate BIM and the Built Environment. Once organized, form committee to evaluate other interdisciplinary opportunities.

#### Research

The research aspect of this initiative will not until until the first graduates of the BIM-enabled curriculum (May2020) decide to attend graduate school and continue developing BIM alongside industry. Explore possible opportunities for senior students.

Create Capstone courses around BIM-enabled processes such as “Prefabrication and Modularization”, “Facility Management”, etc.

#### Measuring Objectives and Learning Outcomes

- Enlist graduate students to begin student survey process.
- Develop Student Learning Outcomes (SLO) with the help of industry and curriculum development.
- Collaborate with instructors to ensure assessments are including course-applicable BIM subject matter.

## 4. DISCUSSION

Construction programs need to begin looking at undergraduate BIM education as a means to improve the delivery of an already existing body of knowledge. The most effective approach would be to immerse the construction curriculum into a BIM-enabled environment that not only improves learning through the visual nature of the technology, but also facilitates communication and collaboration.

Future research will be developed as this concept is implemented in the Fall of 2016. With the help and support of faculty and industry professionals like yourselves, this author will continue to develop the subject matter of this research for future publication.

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# FORMWORK MATERIAL EFFICIENCY USING BIM AND CASCADING MODEL

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## ABSTRACT

The purpose of this research is to increase the reusability of concrete formwork material, optimize the usage and hence reduce the expenditure on formwork using Building Information Modeling application along with a novel cascading model.

The objective is to determine the minimum number of any formwork component required, which can be reused through a project in different phases and the schedule of the usage of components. The proposed methodology utilizes a Cascading model based on the principle of Placement Analysis Flow Diagram (Hurd 2005) using mathematical logic for the availability of components.

The model takes in two sets of inputs. The first set is a feature matrix containing unique identification number, quantity, dimension, and name for each formwork component extracted from the quantity take off reports generated by BIM applications. The second set is project's scheduling information that is obtained from the user and that contains the anticipated start and end date of each phase, the time interval required for each form to stay on concrete before stripping, the number of times a particular form can be reused. The model then calculates the minimum number of a specific type of component required for the entire project, the number of times each component can be reused, and the schedule that the particular component follows. The result generated by the model can be used by contractors to order the formwork components and develop formwork schedule. The paper ends by describing an example that illustrates how the cascading model operation generates the formwork quantity using the quantity take off reports from the concrete pouring phases from a construction project for Proton Therapy Center for Cincinnati Children Medical Center, Liberty Campus, Cincinnati Ohio.

**Keywords:** BIM, Formwork, Pre-construction.

## 1. INTRODUCTION

Formwork can be defined as the temporary structure that supports its own weight as well as the weight of the concrete poured and any other live construction loads such as hardware, material, equipment or labor until the concrete gains sufficient strength to bear its own load. Until then formwork remains as the main support system for concrete(Hanna 1998).



Because each structure is a unique, the formwork must be designed and fabricated as per the specific requirements of each job. The level of effort required to produce a good formwork system is as important as the level of effort required to produce the right combination of steel and concrete for the structure. Formwork for concrete structures has a significant impact on the cost, time, and quality of the completed project. Also, for most of the structures the cost and time invested in making, erecting and removing formwork is more than the time and cost to place the concrete or reinforcing steel (Oberlender and Peurifoy 2010). Economic efficiency in formwork design can only be achieved through constructability studies that use construction knowledge, experience in planning, engineering, procurement and field operations to achieve overall project objective (O'Connor et al. 1987).

For some structures, prioritizing the formwork design can reduce the total frame costs by as much as 25% (Oberlender and Peurifoy 2010). Planning for maximum reuse of forms within the basic limitations of safety and quality of construction is one of the most important factors that lead to an economical construction project (Hurd 2005). Although the planning process for formwork reuse varies greatly depending on the type of the construction job, it is highly recommended to plan for the maximum reuse but with great caution. In other words, maximum return on forms investment is achieved by ordering a minimum number of formwork components, which can be reused as many times as possible throughout the construction job. For the smooth working of any construction schedule it is required to study and develop a work flow of the construction phases and determine feasible number of reuses so as to maximize efficiency and minimize over-all cost.

## 2. METHODOLOGY

To determine the formwork material quantity, reuse schedule and minimum number of the components required for smooth working schedule of a construction project, the following step-by-step approach has been adopted.

### 2.1 Dividing the construction job into different pours/phases-

The sequence of the overall construction must be planned practically considering all the limiting aspects of each phase of the sequence including the availability of mixing concrete and placing equipment, availability of labor, similar construction patterns, limitations due to construction joints, weather conditions etc. Different alternatives are examined so that over-all costs are compared including initial form costs, stripping and erecting costs, maintenance of forms between reuses, to arrive at the sequence and phase schedule which permits maximum reuse and which has lowest over-all investment in forms within the limitations of safety and quality of construction. The size and schedule of a concrete pour/phase are decided on the basis of different factors, which may affect the schedule. A superintendent engineer and project manager calculates the sizes taking into consideration the availability of concrete at the jobsite for example, if the job site is located in a locality where other construction jobs are also being executed, it will be difficult to procure large amount of concrete for big pours which will ultimately result in small pours of concrete and will subsequently increase the number of phases. It also depends on the amount of formwork to be dedicated to each pour, if a large amount of formwork is dedicated to a huge pour then the formwork cannot be taken off until the concrete sets and hence either the construction schedule has to be slow or large amount of formwork has to be ordered, which either way will increase the budget of construction.

## **2.2 Detailing different concrete pours for maximum formwork reuse-**

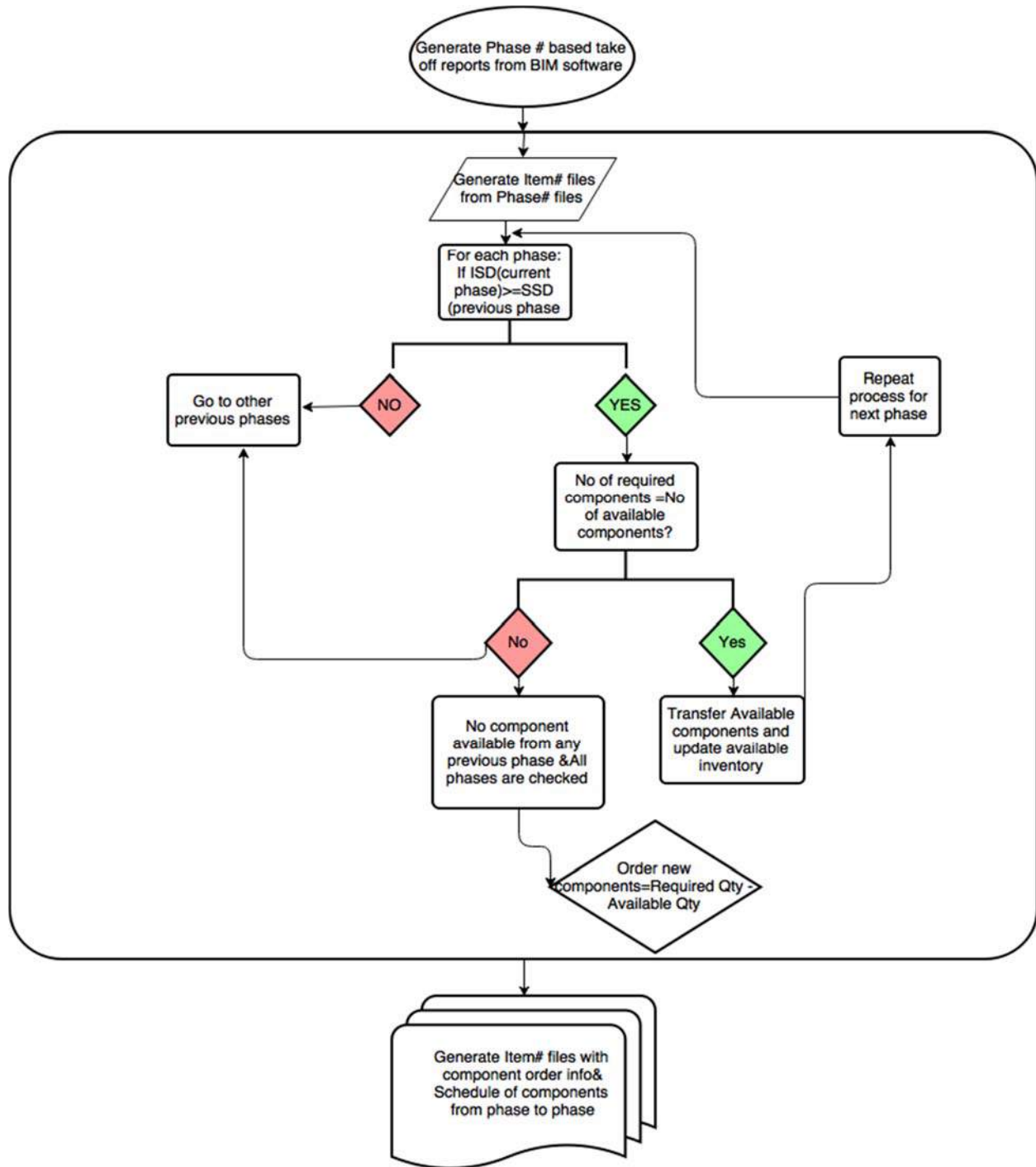
It is easier to detail a typical high rise building where most of the floors follow the same layout as the previous floors and the reuse of the formwork is accomplished without much difficulties (Huang et al. 2004). Whereas, in the construction of a complex building where the phases are dissimilar to each other, it is the responsibility of the detailer to detail the formwork keeping in mind maximum reuse. For example: If a detailer starts to detail formwork on concrete from phase 1 and used maximum 8ft panels, he has to keep in mind that he has to use those 8 ft. panels in future phases as well; and if he needs to detail a 12ft wall for phase 4, the wise decision would be to use a 4ft. panel along with the reused 8ft panels from the phase 1 instead of ordering new 12 ft. panels.

## **2.3 Generating quantity take off reports-**

Building Information Modeling (BIM) facilitates the development of a knowledge repository and provides a framework to develop data rich product models. It serves as an excellent data management tool. Creation of parameters and their association with information can integrate the information with 3D model (Meadati et al. 2011). The data required for this research was taken from a BIM model developed for Proton Therapy Center for Cincinnati Children Medical Center, Liberty Campus, Ohio. Each phase has formwork components designed in Tekla3D, which are detailed around the concrete structure and each component has been assigned different attributes as per design specifications for unique identification. The number of attributes can be increased or decreased depending on the user's requirements. While generating the takeoff reports, the unique identity of each component, the number of times a component has been used in a particular phase, the name of phase and the date of installing and stripping formwork is generated and exported into an excel file. Similarly, excel files for each phase was exported out of Tekla3D and stored on the user's hard drive to be used for the Cascading tool in the next step.

## **2.4. Running the Cascading tool-**

The tool is based on a Cascading algorithm as shown in Figure 1. This algorithm runs in a loop incorporating every possible component that could be reused in the following phases throughout the construction schedule. The algorithm starts with the scheduling information of any phase - installation start and end dates, stripping start and end dates, takeoff quantity reports and then it searches for any components from the previous phases that are available to be used in the current phase. It keeps a track of the available components to be used in the phases that follow by creating a virtual inventory which updates each time a component is being used or being available from previous phases depending on the formwork installation and stripping dates. It also takes into consideration the number of days between stripping date of each phase and the formwork installation date of next phase, so as to align the phases as close as possible so that the formwork can be stripped off a phase and taken to next phase for maintenance and installation, thus saving the crane working hours and avoiding the need for formwork storage and double handling which would be necessary if the installation date of the next phase is not aligned closely with the stripping date of the previous phase. The algorithm generates the total number of formwork components needed for the smooth operation of the construction schedule and also the detailed schedule of each component for all phases.



### CASCADING PROCESS

Figure1. Cascading Process Flow Chart. **Note:** ISD - Installation Start Date, SSD – Striping Start Date

The tool was developed and runs in MATLAB. Upon starting the tool the user is prompted to select the folder where the takeoff reports are stored on the hard drive. After selecting the folder, the tool processes all the files and once the processing is completed, the user is again prompted to select the destination folder where the cascading reports will be stored. The cascading reports

contain information regarding the minimum number of components required to order as well as the detailed schedule for each component.

### 3. RESULTS:

#### 3.1 Savings in Material:

The tool was run on the data acquired from the Proton Therapy Center for Cincinnati Children Medical Center, Liberty Campus, Ohio from the concrete subcontractor of the project Baker Concrete Construction Inc. Take-off reports were generated from the project’s 3D model and processed by the Cascading tool. The generated reports were exported as .csv files and stored in the folder, which was selected by the user. Figure.2 shows a sample file for a particular item type that was generated using the cascading tool.

	A	B	C	D	E	F	G	H	I
1	<i>Phase</i>	<i>Desc</i>	<i>Qty.</i>	<i>ISD</i>	<i>IED</i>	<i>SSD</i>	<i>SED</i>	<i>Order_Info</i>	<i>Scheduling_Info</i>
2	FW-GP-0325	12x8 Panel	17	28-Apr-14	1-May-14	6-May-14	8-May-14	17	
3	FW-GP-0625	12x8 Panel	23	1-May-14	2-May-14	13-May-14	14-May-14	23	
4	FW-GP-0425	12x8 Panel	14	7-May-14	13-May-14	19-May-14	19-May-14	0	(Phase FW-GP-0325 to Phase FW-GP-0425 - 14)
5	FW-GP-0525	12x8 Panel	15	16-May-14	22-May-14	30-May-14	2-Jun-14	0	(Phase FW-GP-0625 to Phase FW-GP-0525 - 15)
6	FW-GP-0825	12x8 Panel	17	23-May-14	2-Jun-14	6-Jun-14	9-Jun-14	0	(Phase FW-GP-0625 to Phase FW-GP-0825 - 3)
7									(Phase FW-GP-0425 to Phase FW-GP-0825 - 14)
8	FW-L1-6	12x8 Panel	22	21-Jul-14	23-Jul-14	28-Jul-14	30-Jul-14	0	(Phase FW-GP-0525 to Phase FW-L1-6 - 5)
9									(Phase FW-GP-0825 to Phase FW-L1-6 - 17)
10	FW-L1-11	12x8 Panel	2	28-Jul-14	31-Jul-14	5-Aug-14	6-Aug-14	0	(Phase FW-L1-6 to Phase FW-L1-11 - 2)
11	FW-L1-7	12x8 Panel	18	29-Jul-14	31-Jul-14	11-Aug-14	12-Aug-14	0	(Phase FW-L1-6 to Phase FW-L1-7 - 18)
12	FW-L1-12	12x8 Panel	10	31-Jul-14	7-Aug-14	15-Aug-14	18-Aug-14	0	(Phase FW-GP-0525 to Phase FW-L1-12 - 8)
13									(Phase FW-L1-6 to Phase FW-L1-12 - 2)
14	FW-L1-8	12x8 Panel	22	5-Aug-14	13-Aug-14	27-Aug-14	29-Aug-14	10	(Phase FW-GP-0325 to Phase FW-L1-8 - 3)
15									(Phase FW-GP-0625 to Phase FW-L1-8 - 5)
16									(Phase FW-L1-11 to Phase FW-L1-8 - 2)
17	FW-L1-4	12x8 Panel	22	11-Aug-14	19-Aug-14	21-Aug-14	22-Aug-14	4	(Phase FW-L1-7 to Phase FW-L1-4 - 18)
18	FW-L1-3	12x8 Panel	13	21-Aug-14	29-Aug-14	2-Sep-14	3-Sep-14	0	(Phase FW-L1-4 to Phase FW-L1-3 - 13)
19	FW-L1-9	12x8 Panel	2	25-Aug-14	28-Aug-14	1-Sep-14	2-Sep-14	0	(Phase FW-L1-4 to Phase FW-L1-9 - 2)
20	FW-L1-10	12x8 Panel	13	28-Aug-14	9-Sep-14	15-Sep-14	16-Sep-14	0	(Phase FW-L1-8 to Phase FW-L1-10 - 6)
21									(Phase FW-L1-4 to Phase FW-L1-10 - 7)
22	FW-L1-13	12x8 Panel	20	8-Sep-14	10-Sep-14	15-Sep-14	16-Sep-14	0	(Phase FW-L1-8 to Phase FW-L1-13 - 5)
23									(Phase FW-L1-3 to Phase FW-L1-13 - 13)
24									(Phase FW-L1-9 to Phase FW-L1-13 - 2)
25	FW-L2-6	12x8 Panel	20	3-Oct-14	9-Oct-14	10-Oct-14	13-Oct-14	0	(Phase FW-L1-13 to Phase FW-L2-6 - 20)
26	FW-L2-12	12x8 Panel	36	24-Oct-14	31-Oct-14	4-Nov-14	5-Nov-14	0	(Phase FW-L1-8 to Phase FW-L2-12 - 3)
27									(Phase FW-L1-10 to Phase FW-L2-12 - 13)
28									(Phase FW-L2-6 to Phase FW-L2-12 - 20)
29	FW-L2-13	12x8 Panel	50	5-Nov-14	14-Nov-14	14-Nov-14	14-Nov-14	0	(Phase FW-L1-12 to Phase FW-L2-13 - 6)
30									(Phase FW-L1-8 to Phase FW-L2-13 - 8)
31									(Phase FW-L2-12 to Phase FW-L2-13 - 36)
32	FW-R-2	12x8 Panel	2	5-Nov-14	13-Nov-14	28-Nov-14	1-Dec-14	0	(Phase FW-L1-12 to Phase FW-R-2 - 2)
33	FW-L2-8	12x8 Panel	14	17-Nov-14	21-Nov-14	25-Nov-14	26-Nov-14	0	(Phase FW-L2-13 to Phase FW-L2-8 - 14)

Figure.2 Note: ISD - Installation Start Date, SSD - Stripping Start Date, IED - Installation End Date, SED -

Stripping End Date, Order Info – Number of items required, Scheduling Info – Phase to phase item reuse information.

As shown in Figure 3, a preliminary cost analysis on 32 out of 82 items was performed on the data that was predicted from the tool and the data available from the actual vendor orders that were given out for the project. The predicted and actual orders were compared based on list prices of the components, and potential savings of 13.80% was calculated from the formwork material cost.

1	Item Num	Description	List Price	Required_Predicted	Price Predicted	Actual_Order	Price_Actual
2	23-300-05	12'x8' Panel	\$7,775.10	54	\$419,855.56	57	\$443,180.87
3	23-300-60	12x2 Panel	\$2,228.27	28	\$62,391.56	30	\$66,848.10
4	23-300-70	12x1.5 Panel	\$1,854.74	6	\$11,128.43	8	\$14,837.90
5	23-300-80	12x1 Panel	\$1,578.20	10	\$15,781.98	10	\$15,781.98
6	23-302-60	8x2 Panel	\$1,756.26	23	\$40,393.98	25	\$43,906.50
7	23-306-00	Outside Corner 12ft	\$1,018.08	35	\$35,632.73	35	\$35,632.73
8	23-306-10	OC 8ft	\$743.33	5	\$3,716.63	6	\$4,459.95
9	23-306-50	Inside Corner 12ft	\$2,703.80	21	\$56,779.80	16	\$43,260.80
10	23-307-50	Art. IC 12ft	\$4,185.12	9	\$37,666.04	12	\$50,221.38
11	23-311-10	I-Scaffolding Adapte	\$555.60	104	\$57,782.40	194	\$107,786.40
12	29-106-50	Scaff. Bracket	\$315.36	90	\$28,382.40	183	\$57,710.88
13	29-400-71	M-Assembly Lock	\$71.48	516	\$36,883.68	1342	\$95,926.16
14	29-400-90	Uni Assembly Lock 28	\$113.48	309	\$35,065.32	155	\$17,589.40
15	29-401-10	Flange Screw 18	\$36.24	227	\$8,226.48	618	\$22,396.32
16	29-804-85	Prop Connector	\$39.92	15	\$598.80	40	\$1,596.80
17	80182	Quick Bolt 3/4 x 4	\$4.40	43	\$189.20	180	\$792.00
18	81106	HDPB 3-5	\$206.00	13	\$2,678.00	20	\$4,120.00
19	83109	HDPB 10-15	\$558.88	27	\$15,089.76	31	\$17,325.28
20	23-300-20	12x4 Panel	\$3,747.10	21	\$78,689.00	24	\$89,930.28
21	23-311-00	I-Column Clamp	\$237.48	9	\$2,137.32	27	\$6,411.96
22	23-300-40	12x3 Panel	\$3,502.40	24	\$84,057.60	24	\$84,057.60
23	23-302-30	8x3.5 Panel	\$2,837.84	9	\$25,540.52	4	\$11,351.34
24	23-304-30	4x3.5 Panel	\$1,620.16	1	\$1,620.16	1	\$1,620.16
25	23-304-40	4x3 Panel	\$1,583.97	1	\$1,583.97	1	\$1,583.97
26	23-304-50	4x2.5 Panel	\$1,253.86	1	\$1,253.86	1	\$1,253.86
27	23-304-70	4x1.5 Panel	\$902.03	1	\$902.03	1	\$902.03
28	23-306-60	Inside Corner 8ft	\$2,000.30	2	\$4,000.59	12	\$24,003.54
29	23-309-10	Inside Strip Corner	\$1,879.52	6	\$11,277.09	8	\$15,036.12
30	23-300-50	12x2.5 Panel	\$2,664.09	16	\$42,625.44	15	\$39,961.35
31	23-300-30	12x3.5 Panel	\$3,642.84	12	\$43,714.12	15	\$54,642.65
32	23-307-00	Art. OC 12ft	\$2,686.53	16	\$42,984.48	8	\$21,492.24
33				Total	\$1,208,628.91		\$1,395,620.56
34				Nominal wastage-3%	\$36,258.87		\$41,868.62
35				Grand Total	\$1,244,887.78		\$1,437,489.17
36				Savings	\$192,601.39		
37				Percentage Savings	13.80041247		

Figure 3. Cost Analysis Report based on the list prices of the formwork components.

### 3.2 Saving in Man Hours:

The number of man-hours dedicated to complete a job adds to the overall budget of the job. Due to the lack of real time data and based on the time taken by the author to manually complete this process, it is assumed that to process the information of all the phases for one component and calculating a cascading schedule with the minimum number of components requires

approximately 2 hours for a formwork engineer after the takeoff reports are generated and initial pour schedule is prepared. The 2014 median pay of a Civil Engineer is \$39.45 per hour (“Civil Engineers” n.d.) according to the Bureau of Labor Statistics, U.S. Department of Labor. For this project, 82 different types of components were used, therefore the man-hours required would be

$$\text{Man Hours} = \text{No of different Items} \times \text{per hour pay} \times \text{Hours spend on each item type}$$

$$= 82 \times 39.45 \times 2 = 6469.8 \text{ USD}$$

Whereas this tool requires 1 minute (on a normal computer system with 4GB RAM) to process the data and calculate the desired result. The number of man hours saved by this tool can be used in some other aspect of construction, which needs immediate attention of engineers.

#### 4. IMPLEMENTATION IN THE ACADEMIC ENVIRONMENT

A Project Based Learning (PBL) pedagogical approach is suggested for introducing the topic to engineering students in their senior year. Typically, civil engineering students are taught project management skills during their final year of study. Therefore, it is expected that this project will help students learn through hands-on experience. Although this topic has significant disciplinary relevance for students that study civil engineering, however, this is not the primary objective of the learning experience. The anticipated primary learning outcome of the project would be to allow students to describe the problem statement, analyze data, develop novel and creative frameworks for efficient formwork management and design according to realistic factors encountered in engineering projects. Secondary learning outcomes include reinforcement of previously obtained theoretical knowledge, development of personal skills such as creativity, problem solving, engineering reasoning and interpersonal skills such as teamwork, communication and leadership. Finally, in order to gain insight into metacognitive learning outcomes it is also suggested that a questionnaire be developed for students to reflect on their misconceptions prior to the start of the project, how they resolved the misconceptions, what they have learned and how it can be generalized to other real life engineering projects.

#### 5. CONCLUSIONS AND FUTURE WORK

The advancement in BIM technology opens up the scope of significant progress in computer-based automation in the construction industry, which can be executed to tackle labor intensive and fallible practices. Carefully planned and automated process can improve the productivity as well as results in a cost effective approach to construction. The aim behind the development of the Cascading tool was to maximize reusability of formwork materials, minimize man-hours needed for formwork planning and reduce the cost of construction projects. The developed tool can be used in any type of construction projects irrespective of their differences. Thus, the application of this tool makes way for using BIM technologies along with computer automation to overcome real time problems of the construction industry.

#### 5. ACKNOWLEDGMENTS

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# **BENEFITS OF INTER-INSTITUTIONAL COLLABORATION IN THE DELIVERY OF BIM EDUCATION IN IRELAND: REFLECTIONS OF AN IRISH MASTERS PROGRAM**

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## **ABSTRACT**

The Architectural, Engineering and Construction (AEC) industry clearly needs graduates with knowledge, skills and competences in Building Information Modelling (BIM) that complement those other key skills and competences of communication and collaboration. Higher Educational Institutes (HEIs) clearly have a major role to play in this transition. They have the opportunity and will seed the next generation of professionals who understand BIM as a technology that supports collaborative working. However, there are barriers to change built into our Universities and Colleges, not least of which is the entrenchment of the traditional discipline focused programs. In an utopian world HEIs should be microcosms of the way one desires the industry to operate in the future. High levels of integration included inter-disciplinary working designed into course content and project work that integrates rather than isolates professional roles in a virtual environment. This integration should transcend beyond the HEIs and lead to the ultimate collaborative goal of inter-institutional collaboration and the sharing of knowledge.

This paper describes the global reach of BIM and how global HEIs are culturally challenged in delivering integrated programs. In addition the paper contextualizes BIM in Ireland, the response of Irish HEIs and a particular an Irish Masters level program that brings together those future looking professionals in the industry eager to shape and contribute to this fast changing sector. What is described is the rationale for conducting and delivering an international Masters program that provides the setting for both academics and practitioners across different international jurisdictions to come together to share their knowledge with participants. This virtual learning environment integrates resources (courses of study, learning management system, virtual classroom learning) from candidates around the globe to share their knowledge and learn. Whilst international collaboration is evident, a major barrier is the lack of more local collaboration. Reflections and evaluation of those directly associated with BIM programs in Ireland are presented together with attitudes towards greater HEI collaboration on BIM program content.

The principal research question focuses on how Irelands HEIs are responded to the growing demand for BIM education and their perceptions on the potential of HEI collaboration in the sharing of BIM leaning expertise and content. It is evident from the data collated in this paper that there is a real appetite to share online content. In particular, the experiences of one Irish Master's program are presented with the paper concluding with a range of benefits of effective inter-institutional collaboration that will enhance the quality and economic viability of locally provided BIM programs in Ireland. To foster an environment, where BIM or collaborative thinking is a practical goal, is essential.

**Keywords:** BIM, collaborative working, e-learning



## **1. INTRODUCTION**

Education is about providing the support and direction to people on how to think, how to question and how to reflect on what they see and hear. They need to be educated to partake fully in the society in which they live, not merely trained to perform a set of limited or limiting tasks. Palmer (2007) spoke of educating ‘new’ professionals and reflects that if Higher Education (HE) is to serve a human purpose it is not sufficient to acknowledge what is known but more importantly to take responsibility for this knowledge. As educators in HE there is a need to educate people to have ethical autonomy and have the courage to act upon it, people who possess the knowledge, skill and the highest values of their professions.

Making predictions about the future direction of the education of construction professionals, not least for the reason of the constraints of our life’s journey, is fraught with difficulty. Since neither the construction industry nor HE exist in isolation, there is a necessity to come to terms with and understand the present and future contexts before going on to discuss the possibilities. Graduates in the future will need to be highly technical, adaptable, good communicators and lifelong learners (Hunt, 2011). Active learning approaches create the opportunity to develop those skills, competences and understanding. Future construction professionals must challenge the conventional ways of the past in ways that use their creative and innovative capacities in the delivery of knowledge. It is imperative that individual HEIs do not see themselves as islands of knowledge but reach out to other providers to share this knowledge creating a more open cultural exchange of learning.

The particular focus of this paper is BIM and the rapid digital transformation that is taking place in the AEC sector both internationally and in Ireland. It will be seen how the Irish HEI sector have responded to BIM and its relevance in the education of future professionals. Whilst this response is admirable, it is occurring in a parochial context with the absence of cross-institutional collaboration and the absence of a national vision for the digital transformation of the AEC sector in Ireland.

## **2. GLOBAL IMPORTANCE OF BIM IN BUILT ENVIRONMENT EDUCATION**

### **2.1 Global Reach of BIM**

BIM implementation has gained considerable momentum over the past few years with North America, the United Kingdom and Scandinavia leading the way. Coupled with the driver of coordinated government support and leadership, the importance and relevance of BIM education and training globally is growing rapidly (Smith, 2014).

BIM usage is accelerating across the world with building clients and government entities increasingly becoming a driving force for the adoption of BIM by mandating its use on their projects (McGraw Hill, 2014). A major development in January 2014 by the European Parliament seeks to modernize European public procurement rules by recommending the use of electronic tools like BIM (Autodesk, 2014). It is clear that within the AEC industry, particularly within the UK, that BIM adoption is growing rapidly (NBS, 2015) given the influence of the imminent 2016 BIM mandate.

### **2.2 Cultural Change Needed in Higher Educational Institutions**

Cultural change is a significant challenge for the built environment domain. Changing the mind set of senior and more middle ranking staff is the biggest obstacle. However, the growing momentum of BIM implementation in many countries around the world, and particularly where governments and major clients are mandating BIM is effectively forcing HEIs to respond to provide BIM programs.

Collaboration is the top ranking driver for implementing BIM (Eadie et al. 2013). However, there is a perception that HEIs in general are not adapting to this collaborative challenge within their program design and module content. This view is supported by the findings of a study examining BIM integration into the curricula in the USA and elsewhere (Barison and Santos 2010). Collaboration can be hindered also by the hierarchical structure within HEIs. Individual AEC courses are often located in

different schools or faculties, different locations, making collaboration more challenging due to logistical and timetabling issues (Comiskey et al. 2015).

It is vitally important for HEIs to support the increased adoption of BIM by introducing BIM into curricula to support industry and supply graduates with the required knowledge and skills (McDonnell and West 2015). The HEIs and industry professionals expect a steady growth in demand for BIM competent professionals (Azhar et al. 2008 and Wu and Issa, 2013). Many companies are on different points on the continuum of introducing BIM practices where many are gaining momentum in the field giving reason for only hiring experienced and seasoned professionals in BIM. The difficulty arises in hiring experienced staff and so HEIs need to grasp the nettle and embed more diverse and applicable learning opportunities. Once BIM is established fully within companies in the near future, there will be a greater need for new graduates with appropriate skills.

### **2.3 Global Demand for BIM Education**

BIM presents enormous opportunities and challenges for the AEC industry. BIM is evolving at a rapid pace causing the roles of professionals to become more automated, which is in turn demanding more sophisticated services that incorporate 3D, 4D time, 5D cost modelling and 6D facilities management (Smith 2014).

BIM education and training are essential if the industry is to respond to rapid use of the technology. BIM education is required at a tertiary level, so that graduates entering the industry have the necessary BIM knowledge and capabilities. Integration of BIM concepts, principles and processes are essential within the curriculum to ensure graduates are ready to meet the challenges that will face in industry (Comiskey et al. 2015).

Natspec (2015) undertook a significant international study of tertiary BIM education and found that current BIM education tends to focus on the use of particular BIM software, whilst there is a pressing need for education in open BIM concepts, BIM management and working in collaborative BIM environments. Natspec reported that BIM education is currently at different levels of implementation across the world. Tertiary education institutions are either already providing, or gearing themselves up to provide BIM education on both undergraduate and postgraduate programs internationally. Some countries, such as the UK, appear to be leading the way in terms of the number of postgraduate BIM courses at universities.

The move towards BIM capability requires firms to re-engineer their business practices. Software and technology typically requires substantial up-front investment, where the greatest cost lies in staff training and development. It is proving difficult for some small businesses to see the longer term benefits of this investment, particularly when competition is high and profit levels are low. Many firms have limited financial resources to invest in expensive software packages, training and education programs (Smith, 2014).

### **2.4 Program Content**

There is a debate as to whether institutions should focus on teaching specific BIM software or solely focus on developing the student's knowledge on BIM theory and processes. An over-reliance on teaching BIM software packages, can lead to a reduction in the time needed in programs to cover collaboration with other disciplines (Underwood and Ayoade 2015). Underwood and Ayoade outline an ideal delivery format of BIM and associated collaborative working practices, where a number of possible approaches could be considered such as; collaboration between disciplines within the same institution, collaboration between disciplines in other institutions (including international collaboration), collaboration with industry professionals to simulate real life projects or a combination of the aforementioned.

BIM education needs to cover the whole of the industry. An important focus needs to be placed on project clients (both public and private sector), as they ultimately have the most influence on BIM implementation on their projects. This education needs to cover BIM awareness in the first instance and then the business benefits and return on investment, the development of technical skills and knowledge and a working understanding of BIM as a collaborative working tool (buildingSMART 2012). The challenge is to achieve recognition of the effective learning outcomes that could emanate from international BIM

programs, whilst also recognizing the important role that local industry can play in this educational experience.

In the UK the BIM Academic Forum (BAF) assessed the current position and associated challenges along with perspectives of BIM education in the UK HEIs through surveys targeted at BIM-related academic networks (BAF 2015). Findings from the BAF indicated a nuanced appraisal of BIM readiness in UK HEIs.

### **3. METHODOLOGY**

For the purpose of this paper, a quantitative methodology is utilized. The principal research question considers how Ireland's HEIs are responding to the growing demand for BIM education and their perceptions on the potential of HEI collaboration in the sharing of BIM learning expertise and content. The exploratory study sought to identify what post-graduate programs in the built environment in Ireland are currently providing as formal educational accredited learning in the area of BIM. The authors set about identifying HEIs and contacts therein who were championing BIM in various HEIs located both in the south and north of Ireland. The study was conducted utilizing a short survey administered through an internet-based survey tool. The survey was designed with brevity in mind but also with the aim of capturing the details of contacts within HEIs in Ireland, which provided a platform for potential further engagement in respect to driving increased collaboration within the Irish HEI sector in BIM education. A total of seventeen responses were received from a total sample pool of twenty four HEIs. A great deal of momentum and good will was created following the Construction IT Alliance (CitA) BIM Gathering International conference that took place in November 2015, where a number of contributing authors had an opportunity to both review these papers and present their work.

### **4. BIM EDUCATION IN IRELAND**

#### **4.1 Ireland's National BIM Program**

In the fall of 2015 Enterprise Ireland (EI) commissioned CitA to collate data that will be targeted to accelerate the Irish construction sector's transition in the use of Level 2 BIM. The research project known as the BIM Innovation Capability Programme (BICP) commenced in early January 2016 and will be carried out over a period of two years. Coinciding with the BICP is the important task of establishing a National BIM Steering Committee (NBSC) for Ireland, which is anticipated to be in place at the end of March 2016. The key function of the NBSC will be to develop a National BIM Roadmap to optimize and support the successful implementation of BIM Level 2 in Ireland. It is intended that this BIM Roadmap and the key tasks of the NBSC will be informed by data collected by the BICP research team on BIM adoption in other countries, assessing BIM maturity in Ireland, capturing exemplar Irish BIM case studies and consulting widely with both industry and academia over the two year period of the project.

A key ingredient in devising this BIM roadmap will be the outputs of the engagement process with HEIs in Ireland, both in the south and the north of the country. The NBSC intends to devise a strategy that is appropriate for the Irish marketplace and is aligned with the ambitions of the Irish Government.

It will be important that in parallel with the formation of the NBSC, and the important work of the UK BIM Task Group and more recently the Scottish Government (Scottish Futures Trust 2015) BIM implementation will be closely scrutinized. An additional key enabler will be the necessity for any roadmap to be supported by the Construction Industry Council (CIC) of Ireland and its constituent representative members. The CitA Smarter Cooperative Building Series 2016 will be a key stimulant in achieving this support. The purpose of this series is to foster a cooperative approach among the CIC constituent groupings, which will see representative industry parties coming together voluntarily to showcase Irish BIM capability throughout 2016. HEIs are playing a significant role in upskilling the industry currently and during the implementation phase of the Irish BIM roadmap.

## 4.2 BIM in Ireland

The first Irish National BIM Survey was carried out by EI and CitA in October 2015. A sample size of the top one hundred most influential leaders in the Irish AEC were selected with the co-operation of the Association of Consulting Engineers of Ireland (ACEI), Construction Industry Federation (CIF), Society of Chartered Surveyors in Ireland (SCSI), Engineers Ireland and the Royal Institute of Architects in Ireland (RIAI). The results revealed that 67% of the industry sample possessed confidence in their skills and knowledge to deliver BIM. Only 6% reported no confidence with the remaining 27% reporting a general knowledge of BIM and a gradual improvement in BIM skills. 75% of the sample reported an increase in demand for BIM in Ireland mainly due to the influence of the 2016 BIM mandate in the UK.

The results of this survey were announced by the CIC of Ireland at the hosting of the launch event for Digital Construction Week (DCW) in the Irish Embassy to Great Britain in London in late October 2015. At the DCW an Irish BIM Pavilion was located where many of the leading Irish AEC businesses operating in the UK showcased their BIM projects.

## 4.3 BIM in Ireland HEI Survey 2016

It will be seen that Ireland's HEIs have responded rapidly to a demand by industry for BIM related training despite the absence of national BIM mandate, such as is evident in the UK. Figure 1 provides an overview of the HEI landscape on the island of Ireland. Ireland is divided into the Republic of Ireland and Northern Ireland, which forms part of the UK home nations alongside England, Wales and Scotland. Northern Ireland has two main universities, six regional colleges and a number of private colleges, all of which run Engineering and Built Environment (E&BE) programs. In the south the E&BE programs are mainly served by five National Universities, eleven Institutes of Technology (IoTs) and a number of other community and private colleges.

In order to gauge the extent of BIM education presently throughout Ireland, a short online survey was sent to twenty four HEIs. A total of seventeen responses were received, which included three responses from the University of Ulster and individual responses from contacts in fifteen other HEIs in Ireland. Respondents were specifically asked to provide data on:

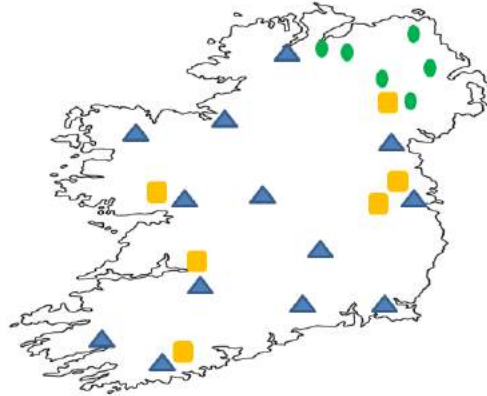
1. BIM Programs on offer, including title, mode of delivery and level.
2. Extent of BIM embedded into programs.
3. Sharing of BIM modules or content with other institutions.
4. Future plans in respect to BIM program development.
5. Future direction of BIM education in Ireland.

Whilst it is acknowledged that the sample size is small, the data collated provides an accurate landscape of current BIM HEI offerings in Ireland.

### 4.3.1 BIM and BIM related Programs in Ireland

A range of BIM and BIM related programs were identified by the respondents. 50% of those surveyed indicated that they had developed specific BIM programs in recent years. A sample of program titles, modes of delivery and levels reported by these HEIs are listed in Table 1. Two of the programs listed in Table 1 did not form part of the data collated in the survey responses but were commonly known by the authors.

It can be seen that there are a range of programs on offer, ranging from short Continuing Professional Development (CPD) part-time programs to full-time Masters level programs and a variety of hybrid programs in between. What was particularly noticeable was the relative few e-learning programs current on offer in Ireland.



Republic of Ireland HEIs		Northern Ireland HEIs	
■	Trinity College Dublin (TCD)	■	Ulster University (UU)
	University College Dublin (UCD)		Queens University Belfast (QUB)
	National University Ireland Galway (NUIG)		Belfast Metropolitan College (BMC)
	University College Cork (UCC)		North West Regional College (NWRC)
	University of Limerick (UL)		■
▲	Dublin Institute of Technology (DIT)	●	Northern Regional College (NRC)
	Waterford Institute of Technology (WIT)	●	South Eastern Regional College (SERC)
	Cork Institute of Technology (CIT)	●	South West College (SWC)
	Institute of Technology Carlow (ITC)	●	Southern Regional College (SRC)
	Institute of technology Tralee (ITT)		
	Dundalk Institute of Technology (DKIT)		
	Letterkenny Institute of Technology (LKIT)		
	Galway-Mayo Institute of technology (GMIT)		
	Limerick Institute of Technology (LIT)		
	Institute of Technology Sligo (ITS)		
	Athlone Institute of Technology (AIT)		

Figure 1. HEIs in Ireland Delivering AEC Programs

Table 1. BIM Programs in Ireland

HEI	Program Title	Mode of Delivery
GMIT	Diploma in BIM	Part-time
DIT	Applied BIM & Management	Part-time
DIT	Construction Informatics (IT)	Part-time (online)
WIT	Architectural & BIM Technology	Part-time
CIT	Certificate in BIM	Part-time
ITT	Certificate in BIM	Part-time
LKIT	Certificate in BIM (Revit)	Part-time (online support)
UU	Postgraduate CPD in BIM	Part-time
QUB	BIM Project Management	Full-time & Part-time
UCC	ITC in A/EC	Full-time & Part-time
SWC	NOCN Level 4 BIM Revit	Part-time

### 4.3.2 Embedding BIM in Program Offerings

All of the respondents reported that they were making good progress in embedding BIM into both their undergraduate and postgraduate AEC programs but none reported full integration. The following is a sample of responses providing a range of strategies adopted by HEIs in seeking to embed BIM in to program offerings.

*BIM is taught through project based learning and lectures in modules in 3rd, 4th and 5th year of our integrated Masters degree and on our MSc in Civil Engineering course.*

*BIM is embedded in a specific first year module on the BSc(Hons) Quantity Surveying & Commercial Management program. It is also embedded in construction measurement, construction economics and commercial management modules. At MSc level there is a specific module offered as part of the MSc and as a standalone CPD module. BIM is also embedded in other undergraduate programs such as Construction Engineering & Management, Building Surveying, Civil Engineering and Architectural Technology & Management.*

*All building-related courses now include 3-D modelling along with drawing and CAD outcomes. Information exchange points are increasingly taking BIM collaboration principles and techniques into account. Component design and integration is being done with new software tools. Lecturing staff are working feverishly to up-skill in the area.*

*BIM related content has been added within modules on the Architectural Technology and Management program. A basic overview is provided in Year 1, Year 2 students have undertaken a project in collaboration with QS and Civil Engineering students at Ulster and students at Penn State University, and Final year students study a BIM module which focuses on both theory and practice.*

*BSc (Hons) Architectural Technology has a set of 6 fully integrated critically aligned BIM modules in the course.*

It was evident that all seventeen HEIs have responded to the demand for BIM and incorporated these changes into both their undergraduate and post graduate program. It is also evident that many of the IoTs in the south, in particular, have developed industry ready part-time CPD type programs to address the BIM skills deficiency in the market at the present time. In many instances these programs gain state support from schemes like Springboard and Skillnets to both encourage the AEC sector to upskill in BIM but also to support unemployed persons in the sector.

### **4.3.3 Sharing of BIM Learning**

The question of sharing was a challenge for most respondents, with many of them reporting that they were only starting out on their BIM journey and the concept of sharing was not something that they were focusing on presently. 70% of the respondents reported that they did not share module or online content with other HEIs either in Ireland or overseas. The following is a sample of responses providing a range of approaches taken by HEIs in sharing BIM learning.

*A pilot project was undertaken with students from Penn State University.*

*We collaborate with Universities in UK & Denmark annually on a weeklong inter-disciplinary BIM Workshop that is assessed and forms part of each institute's programs. This is a tri-institute workshop that rotates to each campus in turn.*

When asked whether sharing modules or online content would be looked at favorably only 25% of the sample were in agreement. Feedback from the respondents suggested a number of impediments in respect to cross-institutional collaboration.

1. HEIs were focusing on embedding BIM in-house first.
2. Difficulty in resourcing this type of initiative re: staffing, logistics and scheduling.
3. Data sharing and privacy.

A number of very positive observations were forthcoming from a number of respondents in respect to the vision of content sharing among HEIs.

1. It would allow access to expertise in different areas which all HESs do not possess.
2. This would encourage innovation and academic enterprise coupled with research.
3. This could reduce the overall cost of delivering our programs and expose our students to a wider global pool of knowledge.

Respondents were asked to share their thoughts in respect to how HEIs could best achieve effective inter-institutional collaboration in respect to BIM education. Many existing examples of inter-institutional collaboration were provided by respondents which included:-

1. Joint research projects between HEIs.
2. Virtual conferencing between different HEI student groups.
3. Online sharing of modules.

All of the respondents were in agreement that inter-institutional collaboration offered many advantages and offered a number of suggestions how this could be achieved.

1. Inter-institutional annual national BIM competitions, with rotation of HEIs hosting.
2. By setting up a BIM Academic Forum similar to the UK BAF initiative.
3. Developing a recognized BIM qualification.

A number of suggestions were made by respondents to progress greater collaboration between HEIs in the delivery of BIM programs.

*It would be a matter of establishing who is doing what and how each Institute could contribute. There may be an opportunity to apply for some EU funding if we developed a national BIM educational framework, which would have an inter-institutional BIM program delivered online or in blended format that would be able to respond to the demands and requirements of the different industry stakeholders.*

*My experiences would suggest that it is important to have like-minded people involved who are committed to making it work. It may also be initially worthwhile to try and integrate any inter-institutional collaboration within the existing curriculum (where it fits best) rather than redesigning programs to make this fit.*

#### **4.3.4 Future Directions of BIM Education**

A number of respondents provided further insight into how inter-institutional collaboration could be better achieved in the future. This included a number of suggestions for setting up of a shared BIM Portal with shared resources which would help in embedding BIM properly across all programs. It was suggested by one respondent that this could be hosted by a not-for-profit organization like CitA. It was felt that opportunities also exist on a micro-scale with the development of BIM reusable learning objects that could be shared via an open source environment. It was also suggested that both industry and BIM software suppliers would need to be approached about the funding of such an initiative.

Many respondents would like to see a BAF set up in Ireland, similar to that in the UK. Once respondent felt it was essential that a national BIM educational framework is established for Ireland based on evidence-based research rather than just copying some other national strategy.

## 5. CASE STUDY PROGRAM

### 5.1 Construction IT Alliance

CitA was incorporated as a not-for-profit company limited by guarantee in July 2005. The charter of CitA is the promotion of digital tools within the construction industry, as aids to productivity gains and the predictability of project outcomes. Digital tools have grown rapidly in sophistication since 2005. The widely spoken focus on BIM is one such convergent process, which CitA started to actively promote in its successful 2012 monthly program of seminars. Over the past four years CitA has been leading the promotion of BIM in the Republic of Ireland through its Smarter Building Series program, CitA Skillnet training program, its internationally respected CitA Smart Technology Challenge and the CitA BIM Gathering International Conference.

### 5.2 Curricula

In 2010 CitA entered into a partnership arrangement with the Dublin Institute of Technology to deliver an online Masters Degree in Construction Informatics. The program development was funded by Skillnets who actively supports and works with businesses in Ireland to address their current and future skills needs. The program forms part of the European Master's program in Information Technology in Construction (ITC-Euromaster, <http://euromaster.itcedu.net>) (Tibaut and Rebolj, 2015). This program is offered to AEC graduates who choose from a course pool of modules, which are shared by participating universities. Currently, the ITC-Euromaster delivers over 10 courses jointly developed and offered by academics from five European universities (University of Maribor and University of Ljubljana from Slovenia, University College Cork and Dublin Institute of Technology/Construction IT Alliance from Ireland, and Technical University Graz from Austria).

The main objectives of the ITC-Euromaster project is to organize the knowledge in the field of IT in AEC and to develop an effective environment to support collaborative learning scenarios with distributed lecturers and students (Tibaut et al., 2013). In addition the courses seek to accelerate the transfer of knowledge of IT in construction to the profession, but also accelerate the research and development in the field; to further develop the ITC network and enable better cooperation between participating institutions. Since adequate human resources and expertise in ITC in the AEC industries are scarce, the combined efforts of five international universities have been joined to develop an international multi-institutional postgraduate program (Rebolj et al., 2008). The modules of the ICT-Euromaster course pool were initially developed by academics from nine European universities as part of a EU-funded Socrates Erasmus project between 2002 and 2005 (Tibaut et al., 2013).

The concept of the ICT course pool is shown in Figure 2 below. In this model each individual partner retains its own suite of modules and shares particular modules with other interested partners. Having a larger course pool of modules to choose from gives each partner the opportunity to form new programs and to offer its students specialized knowledge and skills which it could possibly never be able to offer by itself.

Since the course was first designed the course pool has been modified and adapted as the needs of the different partner institutions change. The course pool complements around ten existing obligatory and elective courses. The CitA MSc in Construction Informatics program utilizes a number of these original modules in addition to locally generated and approved modules. A listing of these modules are shown in Table 2.



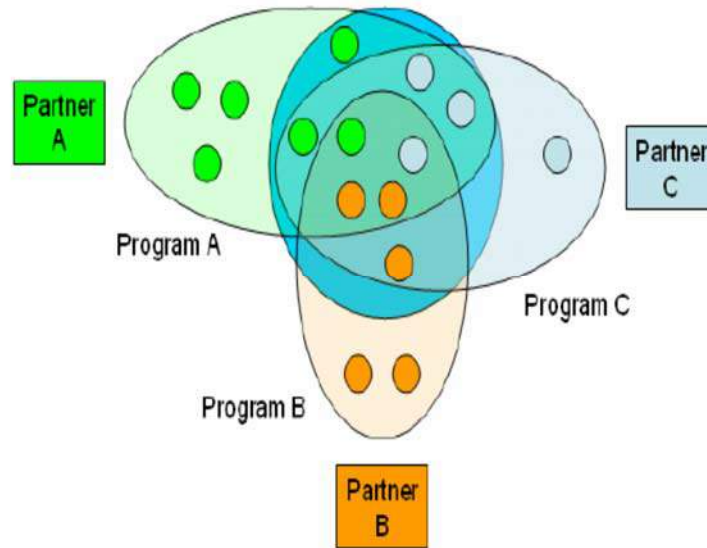


Figure 2. The ITC Course Pool Concept (Rebolj, 2006, pp. 418)

Table 2. Use of Euromaster Course Pool by CitA

Module Title	Obligatory	Elective	Credits
Role of Construction Informatics (course pool)	Y		5
Interoperability and BIM (course pool)		Y	5
Understanding Data Set Management and BIM		Y	5
Project Planning and Scheduling		Y	5
Building Collaborative Technologies (course pool)		Y	5
Sustainable BIM Design and Construction		Y	5
BIM Execution Planning and Project Protocols		Y	5
eCommerce in Construction (course pool)		Y	5
Energy Integrated ICT		Y	5
Automation in Construction (course pool)		Y	5
Knowledge Management in Construction (course pool)		Y	5
Extended Project Modules		Y	5
Master Integrated Project	Y		15
Research Methods	Y		10
Dissertation	Y		30

### 5.3 Learning Environment

Courses in the pool are delivered on a Moodle platform and supported by virtual classrooms. The main purpose of the online platform is to provide consumers with access to course material as well as other functionality, such as timetables, grade books etc. The preferred virtual platform Adobe Connect Pro enables lecturers to deliver online lectures, through the use of participant list, chat, audio and video control, web links, document sharing, application sharing and a whiteboard.

A robust technical infrastructure is a vital part of any e-learning system (Figure 3). The current ITC Euromaster e-learning environment consists of two components: the course management system Moodle (CMS, also known as a Learning Management System (LMS) or a Virtual Learning Environment (VLE)) together with file repository in DropBox, which is the entry point to the program and a Virtual classroom Adobe Connect Pro (Figure 4).

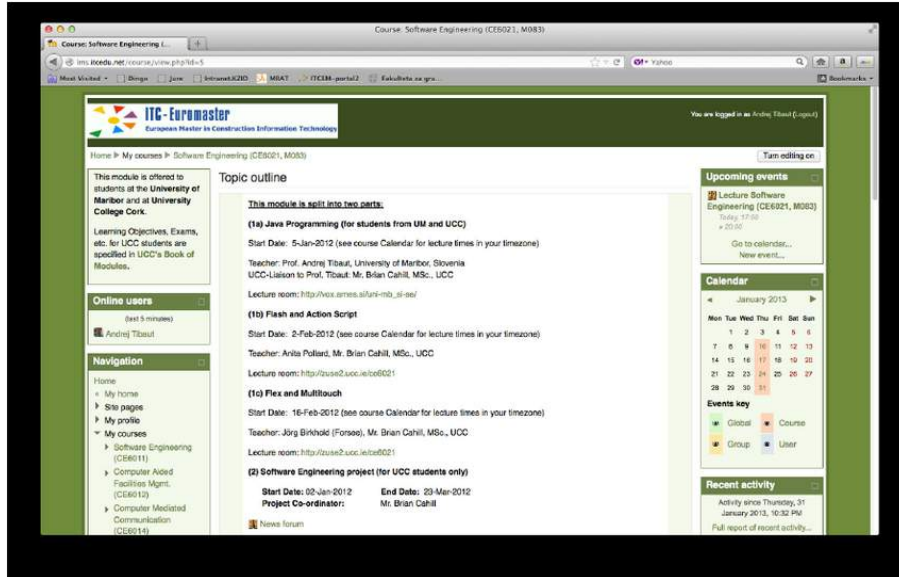


Figure 3. The course management system: Moodle (Tibaut et al. 2013)

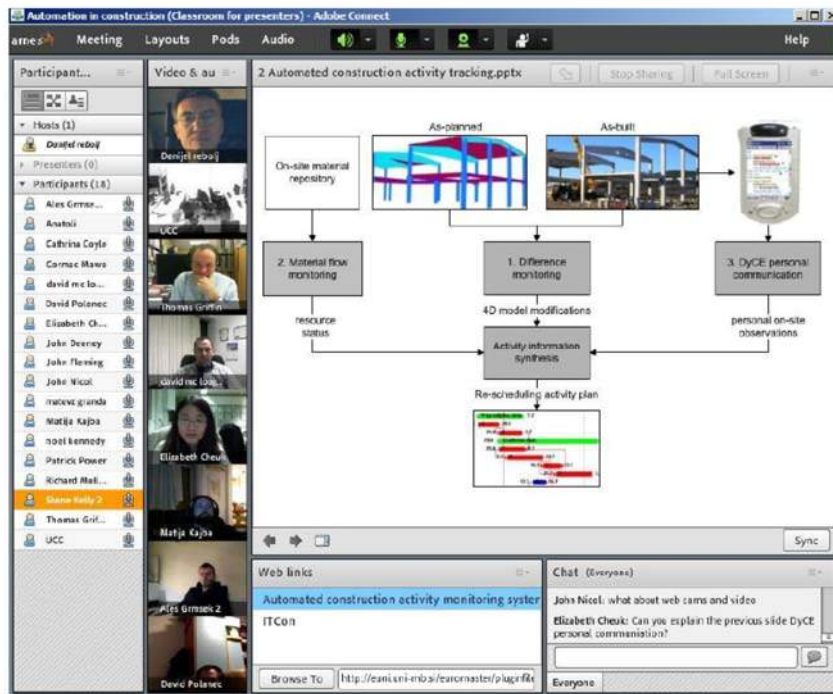


Figure 4 - The Virtual Classroom: Adobe Connect Pro (Tibaut et al. 2013)

The main function of the first is to enable access to teaching and learning material repository, as well as other relevant functions (e.g. forums) and information (e.g. teacher and student list, timetables, grade book, etc.) from any location on the Internet (Tibaut et al. 2013 ).

### 5.4 Program Developments

Following a review of the program in 2013 a suite of three additional BIM modules were introduced to the program.

1. Understanding Data Set Management and BIM
2. Sustainable BIM Design and Construction
3. BIM Execution Planning and Project Protocols

Currently these modules are not extensively shared by in the course pool, however CitA would like to offer these out to all HEIs in Ireland to embed into their program curriculum. It is hoped that in return expertise and module content in other HEIs could in return be placed in the Euromaster course pool.

### **5.5 Benefits of inter-institutional collaboration**

The principal drivers and barriers in seeking this collaboration include sharing and accessing alternative teaching techniques and expertise, increasing knowledge capacity, sharing costs, risks and strengthening areas of weaknesses. Some of the more indirect benefits include encouraging further additional links, enhancing funding opportunities, creating an environment of personal enjoyment in delivering to international audiences and increasing the exposure of individual HEIs to a wider international audience.

## **6. CONCLUSIONS AND RECOMMENDATIONS**

The breadth, depth, quantity and quality of educated and trained professionals in the built environment studying BIM programs across HEIs in Ireland is gaining momentum rapidly. Research carried out by the authors has shown that the training and education offerings are spread across both the south and north of the Ireland, providing a service and expertise for local industry. More global BIM courses focus on design and construction and not on briefing, planning and the impact of BIM to improving the operations of assets. Also training courses largely target technical users rather than management teams and strategic roles in organizations. In addition international BIM education and training is focused on buildings rather than infrastructure and thus requires a broader awareness and expertise in BIM practice across different asset types and across different roles in the industry.

It is generally agreed that the implementation of BIM education and training across the AEC industry is part of an evolving strategy that must reflect a range of other procedural and technical considerations in particular jurisdictions. The need for a formal BIM skills benchmark is necessary and the HE providers of BIM have an important responsibility to make this happen. Greater inter-institutional collaboration in the delivery of specialist programs on BIM or variants of BIM, will allow for the sharing of knowledge, case studies and the cost of the delivery, whilst also ensuring that there is a greater consistency in the learning outcomes attained by learners. This will help to ensure a common recognized platform for BIM skills development across the AEC sector internationally, which can be supported by all key industry, professional and education/training stakeholder interests.

A common theme among respondents was the perception that BIM is disruptive, as it requires breaking down silos of disciplines and cultural change from both the providers and accrediting authorities. Educators must look not at the past as a reason for their education delivery but must now develop a new pedagogy to embed BIM into BE education, a pedagogy that educates BE students for a collaborative future. Professional accreditation leaves little room for additional learning in BIM. Until the Irish Government legislate for BIM, it will be a slow burner in the construction sector and within HEIs. Above all respondents were of the view that more formal collaborations (i.e. research partnerships) with institutions who have less BIM experience for the sake of the growth of BIM adoption in all regions is urgently required. Future Technological University developments in Ireland will support this process.

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