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A Preliminary Study on Upper-Level Building Information Modeling Education for Construction Management Students

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BACKGROUND

Over the last decade, attention to building information modeling (BIM) has been steadily growing. Without a doubt, BIM is an evolving technology that will affect all aspects of design and construction in the future. BIM not only creates a collaborative working environment for building design and construction but also offers greater operational efficiency and effectiveness of supply chains in the construction industry. Perhaps the greatest advantage of using BIM technology is the capability to promote transparency and collaboration among all members of project teams, thereby reducing waste and saving time and money throughout the entire processes of construction. Utilizing BIM technology, participants involved in a project are able to communicate ideas more effectively and provide competitive advantages for project teams. This is one of the main reasons why BIM is being rapidly adopted by the construction industry.

According to the 2012 McGraw Hill SmartMarket Report, a majority of BIM experts have realized that the use of BIM technology has allowed them to generate positive outcomes in construction markets.[1] The main benefits of using BIM are summarized as follows:[2, 3, 4, 5, 6]

- Better communication and understanding through accurate geometrical representations
- Reduced errors and omissions in construction documents
- Marketing potential for enhancing company image
- New services to offer
- Fewer RFIs (requests for information/interpretation) and field coordination problems
- Reduced rework, conflicts, and changes

Although BIM has been widely adopted in the construction industry, one of the key constraints hindering the wider realization of the benefits of BIM for construction is the lack of personnel with both construction knowledge and BIM skills.[7, 8] Harmann and Fischer[9] refer to this shortage as a major bottleneck to the BIM age. Several researchers[7, 8, 9, 10, 11] have investigated the status of BIM implementation within the construction industry. They conclude that appropriate BIM education and training must be prioritized to maximize the business values and benefits which can be obtained by utilizing BIM.

A majority of American Council for Construction Education (ACCE)-accredited construction management (CM) programs now offer BIM content to their students. Nevertheless, in 2013 Sacks and Pikas[17] argued that BIM education in the United States is still in the early adoption stage. It is necessary to understand the reasons why BIM is being so slowly adopted in CM curricula. The primary barriers to BIM implementation in CM curricula include the following:[12, 13, 18, 19]

- Faculty members' unwillingness to change the existing curriculum

- Lack of resources including educational materials, number of experts to teach BIM, time required to make curriculum changes, and number of required courses within the curriculum
- Complexity of relatively new BIM software tools, software upgrading, costs, and training
- Level of knowledge required to use and teach BIM software

In addition, there are no standards and criteria established by accrediting agencies such as the ACCE for BIM education. This may be one of the reasons why many CM programs are still struggling with incorporating BIM education in their curricula. To support industry innovation, CM programs should offer BIM education to students for their future careers.

Innovative construction companies (e.g., Turner, Skanska, Whiting-Turner, etc.) have created new BIM and virtual design and construction (VDC) positions as they transition from traditional practices to ones integrating BIM technology into their organization. To reflect this industry demand and change, CM programs have been gradually introducing BIM in their curricula. In literature, the importance of BIM education for students' future careers is widely recognized.

In 2009, Sabongi[12] evaluated how well BIM had been implemented in the undergraduate curriculum by collecting data from construction programs taught by members of the Associated Schools of Construction. Wong et al.[8] in 2011 studied the status of BIM education in several countries/regions and reviewed several approaches to incorporating BIM into CM curricula. Becerik-Geber et al.[13] in 2011 investigated the level of BIM integration into architecture, engineering and construction (AEC) curricula.

Clevenger et al.[14] describe the approach taken by the CM department at Colorado State University to promoting BIM-enabled learning. Lee et al.[15] propose a guideline to leverage BIM in CM undergraduate education. Furthermore, Dossick et al.[16] discuss how BIM should be incorporated into CM graduate education.

The main objective of this study was to investigate BIM competencies CM students should learn before entering the workforce. To accomplish this objective, investigators reviewed current BIM technology and identified topic knowledge areas required of comprehensive BIM education from the industry perspective. In addition, investigators identified existing BIM-related courses offered by ACCE accredited construction education programs to investigate current status of BIM education. Based on the results of this study, investigators discussed and suggested how construction educators can help students prepare for their future professional career in terms of BIM education in the construction management domain.

CURRENT BIM TECHNOLOGY

BIM technology can significantly enhance students' learning and engagement.[20] To determine effective methods of BIM education in the CM curriculum, essential BIM technology and practices must first be identified, with a focus on how and in what ways BIM concepts and skills can be introduced in CM education. The general types of BIM technologies and how they support CM curricula are listed below.[15]

3D technology enables users to create 3D models in detail on the X, Y, and Z planes. This technology is most widely used to visualize complex building structures and systems. Users can create accurate geometrical representations of a building for visualization and reporting. 3D technology can be used to support students' understanding of complex building structural elements or systems. Also, students can visually identify interferences among complex structural, mechanical, electrical, plumbing, and fire protection systems, which is better known as clash detection.[21]

4D technology enables users to better understand how a construction project might be phased and built in a time sequence. The construction industry has recently become interested in this technology. It allows users to clarify major trade work coordination and site logistics planning and perform what-if analyses.[22] In addition, construction methods and technology, scheduling and sequence planning, time/space conflict analysis, safety hazard analysis, and other project control issues over time can be studied using 4D technology.[23]

The concept of cost-over-time added to 3D models has made ***5D technology*** possible. 5D technology allows users to perform accurate quantity takeoffs and facilitate the cost estimating process by integrating BIM models with quantities and cost data.[24] This technology is not as popular in the industry as 3D and 4D technologies are. Users still need to takeoff quantities from 3D model geometry, which may be inaccurate. However, individual line items of the estimate can be highlighted in the model and users can track the budget visually using 5D technology.

SURVEY ON TOPIC KNOWLEDGE AREAS FOR BIM EDUCATION

For this study, investigators surveyed industry experts to understand the current practices of BIM in the construction industry and identify the practical topic knowledge required of BIM education. First, investigators piloted the survey methodology before the actual distribution of this survey. Six individuals from three different companies participated in the pilot study. Respondents provided comments on the clarity and format of the survey instrument. Investigators subsequently revised the survey instrument to improve the quantification of data gathered. The refined survey was then sent to targeted industry experts in various regions across the United States. The targeted individuals were industry experts directly involved in BIM or VDC at construction companies. They all are responsible for making the transition from traditional practices to ones that integrate BIM technology into their companies while balancing their traditional operational duties. Thirty-three BIM experts were selected on a distribution list and invited to the online survey through email. The Survey Monkey online survey tool was chosen as a means of eliciting and administering data anonymously. Because there are not many BIM or VCD managers, the sample size of this survey was rather limited.
Of the thirty-three experts contacted, seventeen individuals from thirteen different companies in eleven different locations responded between March 18, 2015 and April 16, 2015. Table 1 shows the locations of the survey participants.

Table 1. Locations of the BIM Experts Participated in the Survey

# of Respondents	Location
2	Atlanta Area
1	Austin Area
1	Boston Area
1	Denver Area
1	Detroit Area
2	New York City Area
1	Phoenix Area
2	San Francisco Bay Area
2	Seattle Area
2	St. Louis Area
2	Washington D.C. Area

The overall response rate was 52%. All companies represented in the survey responses focused on commercial building construction. Eighty-eight percent (n=15) of respondents reported having worked in the construction industry for more than 5 years. All the respondents agreed that BIM education in CM programs is essential.

To identify the needs of the construction industry, the following questions were asked on the survey:

- What BIM technology does your company focus on for BIM operations?
- What specific area of BIM would your company like operations employees to have extensive knowledge of?

The results of these questions are summarized in Tables 2 and 3. As shown in Table 2, the respondents consider 3D technology ($\bar{x}$=4.88) very important to visualize detailed conditions and communicate with subcontractors and suppliers. Also, 4D technology ($\bar{x}$=4.18) is important to visualize the phasing schedule of the project and identify space conflicts due to dynamic phasing plans of occupancy. Unlike 3D and 4D technologies, 5D technology ($\bar{x}$=2.65) is not widely used for BIM operations.

Table 2. BIM Technology Used for BIM Operations

	N	Min.	Max.	Mean	SD
3D BIM for Visualization & Communication	15	4	5	4.88	0.32
4D BIM for Scheduling & Sequencing	15	3	5	4.18	0.51
5D BIM for Quantity Takeoff & Estimating	15	1	4	2.65	0.76

Note: Likert scale ranging from 1 (not important) to 5 (very important).

Table 3. Specific Knowledge Necessary for BIM Operations

	N	Min.	Max.	Mean	SD
Clash Detection	15	4	5	4.71	0.46
Constructability Review	15	3	5	4.24	0.64
Site Planning & Utilization	15	2	5	4.24	0.81
Phase Planning	15	3	5	4.18	0.62
Field Management	15	2	5	3.41	0.84
As-Built Model	15	2	5	3.18	0.71
Existing Conditions Modeling	15	1	5	2.94	0.87
Model-Based Estimating	15	1	4	2.65	0.76
Fabrication	15	1	4	2.35	0.84
Safety Planning & Training	15	1	4	2.29	0.75
Site Layout	15	1	4	2.29	0.67

Note: Likert scale ranging from 1 (not important) to 5 (very important).

Table 3 shows that ‘Clash Detection’ ($\bar{x}$=4.71) is the most important area for industry BIM operations. In addition, the respondents are using BIM for ‘Constructability Review’ ($\bar{x}$=4.24), ‘Site Planning & Utilization’ ($\bar{x}$=4.24), and ‘Phase Planning’ ($\bar{x}$=4.18). Several of the respondents rated ‘Field Management’ ($\bar{x}$=3.14) among critical areas of BIM.

REVIEW OF CURRENT BIM EDUCATION

With the realization of the importance of BIM education, CM programs have been gradually introducing BIM in their curricula. Many CM programs now offer BIM content to their students. While it is essential for CM students to learn such BIM software skills, this study builds on the work of Lee and Yun[25] who emphasize that the introductory BIM course focusing on BIM software skills must be offered at the freshmen or sophomore level when the concepts of Construction Graphics and Plan Reading are introduced. After the introductory BIM course, BIM course modules should be incorporated into several junior and senior level courses addressing MEP systems, project management, and planning and scheduling. As the results of the survey shows in Table 3, CM students should be able to utilize BIM technology to solve construction project problems such as clash detections, constructability issues, phase planning before entering the workforce.

To examine the current status of BIM education within the CM curriculum in the US, investigators analyzed undergraduate courses offering BIM content. This study focused on the baccalaureate CM programs accredited by the ACCE, the accrediting body for the great majority of construction-related programs in the US. BIM courses taught in programs such as Architecture and Design were excluded from this study since they usually focus on creating 3D design models with 3D modeling software such as Revit or SketchUp.

In total, seventy-four baccalaureate degree construction education programs accredited by the ACCE were included in the study. Approximately 61% (n=45) of these offered BIM education. Seventy-one undergraduate courses offering BIM content were identified and reviewed for this study. Of these, 10% (n=7) of the courses were offered to freshmen level students; 27% (n=19) to sophomore; 27% (n=19) to junior; and, 36% (n=26) to senior level students. All of the courses were divided into two groups[25]:

- Introductory BIM courses, which focus on BIM software skills to create 3D architectural or detail models. This group of BIM courses mainly emphasize building "B" and modeling "M" without information "I".
- Upper-level BIM courses, which focus on the use of BIM for managing the construction process. This group of BIM courses mainly emphasize the whole BIM process for critical thinking and problem solving with "I".

Based on the two categories, investigators identified twenty-three upper-level BIM courses (32%) from twenty different programs and forty-eight introductory BIM courses (68%) from thirty-four different programs. In other words, 27% (n=20) of all ACCE-accredited CM programs offer upper-level BIM courses and 46% (n=34) of all the ACCE-accredited programs offer introductory BIM courses. This indicates that only 12% (n=9) of the programs help students get prepared for comprehensive BIM education. Table 4 presents the BIM-related courses teaching upper-level BIM concepts currently in the accredited construction programs.

Table 4. BIM-Related Courses Teaching Upper-Level BIM Concepts

Course Name/Institution	Course Description
Project Controls III, **Auburn Univ.**	Software applications for construction projects scheduling and cost control measures; expanding students' exposure and competency in software applications related to BIM.
BIM in Construction, **Drexel Univ.**	Emphasis will be placed on the use of BIM to support current construction activities such as design review, coordination, scheduling, logistics, estimating, and project close-out. Topics will include an introduction to 3D BIM modeling, 3D coordination and clash detection, 4D visual scheduling and logistics, 5D estimating, and BIM for Facility Management.
BIM in Construction, **Georgia Tech**	Theory and application of BIM in the A/E/C industry with emphasis on constructability, scheduling. Front End Planning (FEP) and construction monitoring.
BIM for Construction Management, **Georgia Southern Univ.**	Highlights the merits of BIM in promoting productivity and profitability in the construction industry. Topics include ……… its impacts on construction industry; ……… application of BIM authoring and analysis skills for construction projects. The course emphasizes hands-on modeling skills and the utilization of BIM technology to solve construction project problems.
BIM; Introduction to BIM II, **Milwaukee School of Engineering**	Prepares the student to utilize BIM as a coordinated, integrated and consistent approach to a building project in design and construction decision making …….. Students are ……. to produce high-quality 3-D designs and construction documents, along with cost-estimating, and construction planning.

Introduction to BIM, **North Carolina A&T State Univ.**	Emphasis is placed on research and integration of architectural, structural, MEP, specifications and cost estimating of building systems for decision modeling using BIM.
Construction Management Capstone, **North Dakota State Univ.**	Applying knowledge and skills learned in the previous courses, BIM, and other software programs to prepare a bid proposal and an on-site construction management plan for a building project.
Introduction to Virtual Design and Construction, **Oregon State Univ.**	Use of design and construction information models for making estimates of quantities and cost, and for determination of constructability problems.
BIM for Commercial Construction, **Purdue Univ.**	The study of commercial jobsite planning and coordination. Trade coordination, visualization, and communication are emphasized. Activities include collision detection reports, construction animations, and professional presentations.
Computer Applications for Professional Practice, **Roger Williams Univ.**	Explores new modes of contemporary practice, specifically Integrated Project Design/Delivery, and the role of BIM .... explore the use of BIM and related analytical tools to get immediate feedback ……. focus on developing proficiency in the use of BIM ……… looking at how this tool and related computer technologies are changing the way that information is generated and utilized within the practice environment ……… explore how information, including cost, scheduling and building material usage, is shared among the various parties involved in the design and construction process.
Advanced Construction Practice, **Southern Polytechnic State Univ.**	This course will prepare students to participate in formal interdisciplinary competitions ………….. Following the competition, additional topics involving the use of BIM importance of a collaborative team effort from owner, developers, architects, engineers, constructors, technicians and consultants is the overall focus of this course.
Building Information Modeling Applications I, **Southern Polytechnic State Univ.**	A course on study of BIM for pre-construction applications. The course ………. includes integration of estimates and schedules with BIM…. also prepares the students to identify conflicts caused by architectural, structural, mechanical, plumbing, and electrical systems during pre-construction stages.
BIM System, **Texas A&M Univ.**	Exploration of a data-rich, object-oriented, and parametric digital representation of the facility, from which views and information can be extracted and analyzed for construction project acquisition, planning, and control.
Advanced BIM, **U. of Arkansas** at Little Rock	BIM functions for complex commercial construction; topographic information of sites, project datum, quantities and properties of building components, building sustainability analysis, documenting projects, and detailing of MEP or structural designs; rendering of exterior and interior views.
3D Modeling for Construction, **U. of Florida**	Course explores a number of computer graphics programs and how they can be combined to enhance construction communications. Includes 3D modeling software, HTML and VRML authoring tools and illustration and drawing programs.
Introduction to BIM, **U. of Florida**	Learn current BIM software to identify design errors and improve the construction process.
Managing with BIM, **U. of Minnesota** at Twin Cities	Introduced as a management guided, rather than technical BIM program offering

BIM I: Introduction to Building Information Modeling, **U. of Nebraska** at Lincoln	This course instructs CAD users on the effective use of BIM for Integration of design, document and Construction Estimate. Topics include: model-based 3D design, file formats, interoperability, and MEP modeling.
Introduction to BIM, **U. of Nebraska** at Lincoln	Introduction to object-oriented building development tools that use 5-D modeling concepts, information technology and software interoperability to design, construct and operate a building. Construction visualization used as a communication and collaboration tool to manage project details.
BIM for Construction, **U. of Oklahoma**	Emphasizes the skills and knowledge required by the constructor to participate in the creation, projection, and execution of a project using BIM. Students combine knowledge of materials, methods, drafting, estimating and scheduling with BIM computer applications.
BIM for Construction Management**, U. of Texas** at San Antonio	Introduction to techniques used in development and management of BIM. Emphasis on constructability and management.
Virtual Construction, **U. of Washington** at Seattle	Examines the use of BIM for managing the construction process and facilitating collaboration among project participants.
Information Technology in Design and Construction, **Virginia Tech**	Building delivery and project management improvements through the use of computer applications are explored, including scheduling software, BIM tools, and VDC simulation software and their corresponding theories and concepts the integrate design and construction.

DISCUSSIONS AND SUGGESTIONS

Based on the findings from this survey of industry BIM experts, the demand for BIM operations employees to have extensive BIM knowledge is concentrated in four topic areas: clash detection, constructability review, site planning and utilization, and phase planning (Refer to Table 3). In addition, field management is a rising BIM area in the current industry as shown in Table 3. After the review of the seventy-four ACCE-accredited CM programs, this study identified that approximately 61% (n=45) of these offered introductory or/and upper-level BIM education and about 27% (n=20) currently have the upper-level BIM courses meeting the industry needs. This indicates that twenty-five programs only teach introductory BIM; eleven programs only teach upper-level BIM, and only nine programs teach both introductory and upper-level BIM. Based on the findings of this study, the programs only offering introductory BIM courses need to extend their BIM education for comprehensive BIM education.

CM students should be able to define fundamental knowledge areas of industry BIM operations; identify the BIM technology and process; and, apply them to BIM analysis to solve construction problems such as clash detections, constructability issues, and phase planning.

Lee and Yun[25] emphasize that the introductory BIM course focusing on BIM software skills must be offered at the freshmen or sophomore level. For a sample course, Milwaukee School of Engineering offers an introductory BIM course whose course description is:

"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. 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."

This is an excellent example of an introductory BIM course. After the introductory BIM course, upper-level BIM course modules, focusing on the entire BIM process related to the topic knowledge areas required of comprehensive BIM education, should be incorporated into several junior and senior level courses such as mechanical, electrical, and plumbing (MEP) systems, project management, and planning and scheduling. Lee et al.[15] in 2013 proposed the most practical approach to comprehensive BIM education is the integration of BIM course modules into mainstream CM courses. Therefore, to meet industry needs, BIM course modules should be incorporated with BIM technology into upper level undergraduate courses and developed with the following topics (Refer to Table 3) in mind:

- Clash detection during the coordination process
- Design and analysis of constructing complex building systems
- Site utilization layout for temporary facilities, assembly areas, and material deliveries for all phases of construction
- Construction sequence and space requirements on a building site
- How to access, read, and update BIM information at the construction site

BIM has gained significant momentum over the past decade, with leading construction companies increasingly utilizing BIM technology to improve the construction process and thereby maximize profits. There is an enormous demand for individuals with BIM skills and knowledge. As described earlier in this paper, one of the key barriers to implementing BIM technology is the lack of BIM expertise within the construction industry. It is clear that BIM should be part of CM undergraduate education.

LIMITATIONS

As with any research study, there are certain limitations that should be noted. This study attempts to investigate BIM competencies CM students should learn before entering the workforce. Investigators focused on BIM or VDC professional at construction companies from various regions across the United States, which caused the sample size of this survey to be rather limited. In addition, the response rate (52%) is rather low, considering the sample size (N=33). However, all the participants of the survey were representative of the population. As mentioned above, the which actually caused this study to being rather limited. Therefore, this study focused more on a preliminary study than a complete study. This paper reports the results of a preliminary study on BIM education and merely discusses and suggests how construction educators help students get prepared for their future professional career in terms of BIM education in the domain of construction management.

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