Building Information Modeling in Graduate Construction Engineering and Management Education

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ABSTRACT

With the growing use of Building Information Modeling (BIM) and allied technologies such as energy modeling, laser scanning and surveying, graduates of construction engineering and management (CEM) programs need an increasing number of computer technology concepts and skills. CEM programs across the country are updating their curriculum offerings to include computing generally and Building Information Modeling (BIM) specifically. In this paper, we focus on the question of Building Information Modeling in the context of graduate education and specifically ask in what ways should software generally and BIM specifically be incorporated into CEM graduate education? In this paper we present a review of CEM graduate programs and discuss ways that computer technology generally and BIM specifically can be incorporated into the curriculum. This paper will include the results of a survey of industry professionals to determine if, how and in what ways BIM education is valued by the industry. A majority of BIM managers surveyed thought that graduate education is important for BIM professionals. From this survey, we see a coupled need: technological education in the context of CEM topics. Our review of current graduate coursework in CEM aligns with the survey findings in that BIM courses focus on the CEM uses of technology and some are application specific (e.g., estimating) while others are project focused (e.g. design team coordination). This findings suggests that BIM workflow could be incorporated into many of the CEM topic coursework as BIM become more prevalent in the industry.

INTRODUCTION

BIM has and continues to initiate changes in the practices of professionals in Construction Engineering and Management (CEM). According to the 2012 McGraw Hill SmartMarket Report, BIM adoption in the United States has surged from 28% in 2007 to 71% in 2012. In some sectors, such as MEP coordination it is predicted to be

100% in the next few years (McGraw Hill 2012). Fifty percent of the industry is using BIM and its adoption will increase, expecting positive returns from the use of BIM technology. BIM in education has followed suite. Many CEM programs in the US have introduced BIM into undergraduate and graduate education (Barison and Santos 2010, Lee et. al. 2012).

Utilizing BIM technology has major advantages for construction. It allows for an efficient construction process that saves time and money and reduces the number of RFIs and field coordination problems, compared to traditional practices. Perhaps the most important point is that the use of BIM technology improves the ability to integrate all members of project teams together by communicating ideas more effectively and provides competitive advantage for innovative firms. As BIM practices emerge and become codified, it is clear that BIM should be part of graduate education in construction. Like many construction topics such as estimating and scheduling, it is less clear what concepts and where in the curriculum BIM should be brought into construction education curriculum and what should be left to company training and field experience. As graduate programs are only one or two years in length, we need to develop targeted, concept based coursework that prepares students for successful careers is an increasingly high-tech, fast-paced environment where new practices are emerging around technology.

To address the question of how and in what ways should CEM graduate education introduce BIM concepts and skills, we first conducted a review of Graduate BIM curriculum in the US. We then conducted a survey of industry professionals to determine what BIM knowledge and skills they seek in hiring graduates of CEM programs. We then conclude with recommendations for CEM graduate education.

BACKGROUND

In the literature, there is an emphasis on BIM concepts for CEM graduate curriculum, where understanding the computer application concepts (e.g. object-oriented software) and BIM processes is more important than mastering the BIM tools (Hietanen and Drogenumller, 2008). Kymmell (2008) emphasizes that the fundamental BIM concept to be taught and learned is collaboration, basic software skills are introduced in university settings, but mastered in on-the-job training.

To understand how CEM graduate programs are introducing BIM concepts and processes, we performed an analysis of graduate courses with BIM. We reviewed the American Council for Construction Education (ACCE) accredited CEM programs, but not limited to them. We reviewed forty-seven CEM graduate programs in the United States. Fourteen academic institutions (30%) out of the forty-seven CEM graduate programs introduce BIM in their graduate curriculum (Table 1). Nineteen programs (40.43%) teach BIM specifically and/or construction informatics—the science concerned with the collection, classification, manipulation, analysis, storage, and retrieval of information…managing the “I” of BIM—generally in their graduate curriculum. Table 1 was created based on the analysis of graduate courses offered by the ACCE accredited CEM programs (ACCE). Four general categories became clear: concept building, software theory and application, projects and application specific. These categories are not mutually exclusive as the concept

classes often have some software theory and skill components, and vice versa. The classes are categorized as to their main emphasis and focus. Schools are listed alphabetically in Table 1.

Table 1. Specific BIM-Related Courses in CEM Graduate Programs

Concepts, Processes and Practices	
Louisiana State U. CM 7220: BIM for Construction Management	Concepts related to the implementation of BIM… for visualization, marketing, quantity take-off, scheduling, coordination, & facilities management.
U. of Florida BCN6785: Construction Information Systems	Fundamental principles and practices of Building Information Modeling (BIM) and Virtual Design and Construction (VDC) …
U. of Oklahoma CNS 5313: BIM	… (BIM) course is designed to develop in depth knowledge of BIM as a tool and as a method for the design, construction, and operations …
U. of Washington CM 515:Innovative Project Management Concepts	Examination of innovative techniques for planning and managing construction projects including …BIM…
Virginia Tech BC 5984: Advanced Topics in BIM	… BIM in its larger context as a method for understanding, explaining, predicting and improving how buildings (as complex systems)…
Software Theory and Application, Tools and Skills	
Arizona State U. CON 575: Information Technology in Const.	Uses virtual construction methods to improve the construction enterprise…communications, facility modeling, and decision making.
Oregon State U. CE 505: 3D Laser Scanning and Imaging	Fundamental principles of 3D laser scanning and LiDAR, including sensor types, acquisition… Introduction to BIM.
Texas A&M U. COSC 642: Construction Information Technology	Exploration of emerging technologies for the construction industry including hardware and software systems such as BIM, RFID, Mobile…
Texas A&M U. COSC 650: Advanced Construction Visualization	Introduction to the theory and application of 3-D computer models in the design/build construction process; creation, positioning in 3-D space…
U. of Nebraska-Lincoln CNST440/840: Introduction to BIM	…object-oriented building development tools that use 5-D modeling concepts, information technology and software interoperability …
Projects and applications	
Texas State U. TECH 5313: Building Information Modeling	..supervisory role in the design process. Coordination of site work, structural, architectural, mechanical, electrical, and plumbing...
U.of Southern California CE 570: BIM for	Multidisciplinary and geographically distributed virtual project teams used to simulate engineering

Collaborative Construction	and construction problems.

Table 1. Specific BIM-Related Courses in CEM Graduate Programs (cont.)

Application specific: e.g., Estimating and Scheduling	
Bowling Green State U. CONS 5400: Advanced Practices in Construction...	Sustainable design and green building practices…lean design, lean construction, BIM, energy independence...
Roger Williams U. CNST 525: PreConstruction Planning and Project Delivery	…alternate methods of project delivery… estimating and scheduling during the pre-construction stage of a project to include BIM
U. of Arkansas CNMG 7318: BIM and 4D Simulation	Advanced techniques of using BIM together with scheduling control to do 4D simulation.
U. of Nebraska-Lincoln CNST879: Construction Management… Systems	Computer applications of estimating and research topics... Virtual 3D, BIM applications in support of Estimating and risk analysis...

In addition, general Computing courses in CEM Graduate Programs were reviewed. Due to paper length limits, we cannot include this list here. Topics in computer in CEM generally cover file management, networking systems, spreadsheets, databases, presentation software, virtual environments, interoperability, ontology, information flow, and knowledge management systems. For example, U. of Nebraska-Lincoln's CNST860: Construction Visualization and Simulation course covers Topics include construction visualization software, basic data structure and programming, interoperability, and building simulation.

In this review, we see a variety in the types of BIM specific content and general computing topics currently being offered in US CEM graduate programs. In this next section of the paper, we present findings from a recent survey of industry BIM professionals to understand the industry perspective about priorities for BIM specific education at the graduate level.

SURVEY AND RESULTS

Individuals from construction firms who are directly involved in BIM and VDC were identified to receive a survey intended to better understand the current practices and trends in BIM used in construction as well as their expectations for recent college and university graduates' BIM skills and knowledge. A questionnaire was created and disseminated via email to 42 BIM professionals employed in 34 different companies located across the United States. Survey results were collected through the secure online research suite Qualtrics. The response rate was 50% with 21 individuals from 18 different companies in 15 locations across nine states including California, Colorado, Georgia, Indiana, Maryland, Minnesota, Ohio, Virginia, and Washington. Of those responding to the survey, five (23.8%) had

graduate degrees, fourteen (66.7%) had bachelor degrees, and two (9.5%) had associate degrees listed as their highest level of education. Ninety-five percent reported having worked in the architecture, engineering and construction (AEC) industry for over 5 years. Most respondents were from larger companies with average annual revenue of over $500 million and 250 or more employees.

Two thirds of the respondents reported that their company has a BIM training program and the majority (57%) reported that the training occurs in-house. While this training is essential and necessary, respondents also viewed postsecondary education in BIM as important. Of those responding to the level of education appropriate for BIM education, 95% identified both Virtual Design & Construction Systems (management of BIM based projects) and Project Planning and Scheduling as being important in the education of undergraduate Construction Management students.

When asked about graduate education for BIM professionals, 63% (n=12) responded that graduate education is important. Brief descriptions were provided to help clarify the degree listed, as some of the degrees are non-traditional. For example, Master's of Science in Construction Informatics was described as a construction specific information management degree, while the Master's of Business Informatics is a mix of business and information systems without CEM content. Table 2 shows the responses when asked about the seven specific master's degree options.

Table 2. Master's Degrees Most Relevant to BIM Professionals

Topic	Mean	Median	Standard deviation
Master's of Science in Construction Management	3.21	3	0.85
Master's of Engineering in a civil discipline	2.74	3	1.05
Master's of Engineering with construction focus	3.06	3	0.94
Master's of Science in Construction Informatics	3.00	3	0.88
Master's of Business Administration	1.63	1	0.76
MBA with specialization in Construction Management	2.58	3	0.77
Master's of Business Informatics	2.00	2	1.00

Note: Likert scale ranging from 1 (not relevant) to 4 (very relevant)

Topical Relevancy. Respondents were asked about 14 individual topics, which were derived from numerous sources such as existing Business Informatics programs, Construction Informatics programs, as well as topics generated from informal conversations with BIM professionals. Short definitions were provided for each topic to ensure a common understanding of the topic. For example, the Introduction to Construction Informatics focuses on knowledge and application of specialized computer software packages (BIM & others), management of outsourced IT services.

Respondents were asked to rate, on a Likert scale, how relevant the topic is for graduates interested in a BIM career. The two lowest scoring topics, "Applied Knowledge Management" ($\bar{x}$=2.32) and "eBusiness in Construction" ($\bar{x}$=2.53) are the more traditional business informatics courses. These two were found less relevant than either "Research Methods" ($\bar{x}$=2.63) or "Thesis" ($\bar{x}$=2.78), which many times are viewed as least relevant in general to some in industry. The six highest rated topics

constitute, as a group, a series of courses focused on applications and practices of BIM. Table 3 provides the finding for all 14 topics in the survey.

Table 3. Relevancy of Construction Informatics Topic

Topic	Mean	Median	Standard deviation
Virtual Design & Construction Systems	3.58	4	0.61
Introduction to Construction Informatics	3.50	4	0.62
Project Planning and Scheduling	3.42	3	0.61
Lean and Integrated Project Delivery	3.42	4	0.69
Advanced Collaborative Technologies	3.32	3	0.67
Legal Aspects of Construction Informatics	3.26	3	0.65
Project	3.22	3	0.55
Mobile Computing in Construction	3.21	3	0.71
Advancements in Facilities Management	3.05	3	0.78
Sustainable Design & Construction	2.84	3	0.83
Thesis	2.78	3	0.55
Research Methods	2.63	3	0.76
eBusiness in Construction	2.53	3	0.7
Applied Knowledge Management	2.32	2	0.75

Note: Likert scale ranging from 1 (not relevant) to 4 (very relevant)

Topical Appropriateness for Level of Education. To contextualize the graduate level coursework, we asked the respondents to determine the appropriate level (undergraduate and graduate) of each topic (Figure 1). Some overlap is to be expected between undergraduate and graduate education. A topic is often introduced at the undergraduate level and then further expanded in graduate studies. Figure 1 shows both the overlap but also a relatively clear separation between what BIM professionals expect in undergraduate and graduate topical content.

The “Thesis” and “Project” topics were considered to be the most appropriate for graduate level education by the respondents at 84% and 74% (respectively). When considering more content based topics, “Legal Aspects of Construction Informatics” (74%), “Advanced Collaborative Technologies” (68%), “Advancements in Facilities Management” (68%), and “Lean and Integrated Project Delivery” (63%) were all viewed as important to graduate education specific to BIM professionals. The topic of Lean and Integrated Project Delivery was particularly interesting as it ranked very high for both undergraduate and graduate education where the other topics tended to be generally more aligned with one level of education or the other.

Respondents to the survey question concerning the appropriateness of topics by level of education were permitted to select either, both, or neither. Figure 2 shows the topics that respondents felt appropriate at both levels of education. Forty-seven percent of those who responded felt that evaluating the key issues in the management of integrated BIM based projects (Virtual Design & Construction Systems) is an important topic for both undergraduates and gradates.

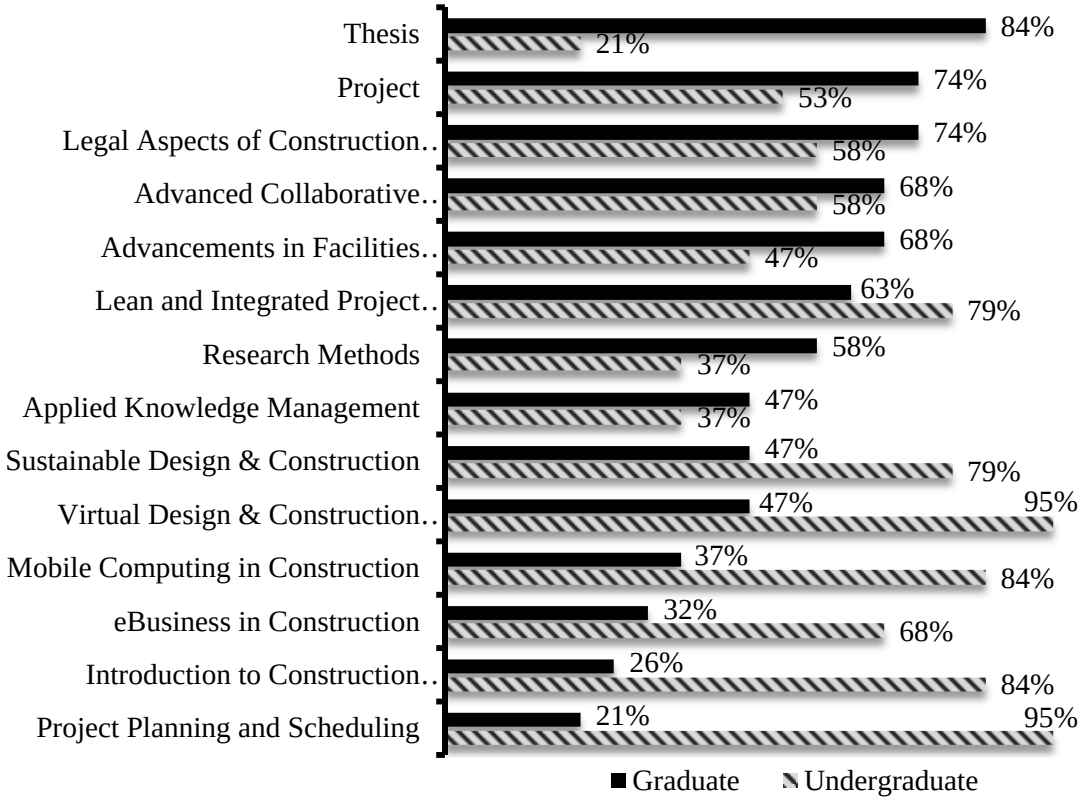

Figure 1. Appropriate Construction Informatics Topics at the Undergraduate vs. Graduate Levels

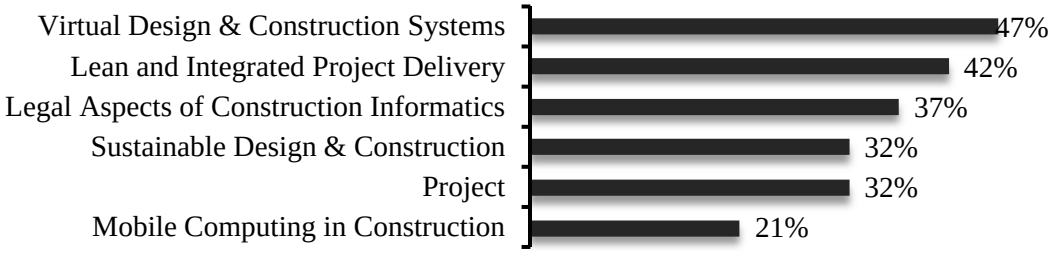

Figure 2. Construction Informatics Topics Appropriate for both Undergraduate and Graduate Levels

Type of Education. When asked about what type of education they perceive as being the most valuable, BIM professionals were mixed in terms of hands-on practical experience, software training, or other structured post-secondary education. However, it was cited by several respondents that it is more about the management and collaboration rather than strictly software manipulation. One respondent succinctly summarized the views of many in his statement regarding the most valuable type of education, “Team collaboration skills…too much technology for everyone to be an expert…need to manage teams to divide and conquer.” Another respondent stated, “A BIM professional needs to be more advanced than your average construction professional because you cannot specialize in one area and succeed in BIM.”

SUMMARY AND CONCLUSION

This research effort was focused on evaluating the viability of graduate education that focuses on construction computing in general and building information modeling specifically. What we found is that while the US industry statistics report BIM adoption at 70%, we find only 30% of CEM graduate programs currently cover BIM. However, in our analysis of CEM graduate curriculum that is currently being offered, there is a strong alignment with the industry priorities. In our survey, the industry professionals emphasized BIM uses such as estimating, lean, visualization and collaboration; and the classes reviewed in this paper focused on these topics either as broad survey courses covering a variety of BIM uses, or as specific topics, such as estimating, that focused on one application of BIM tools.

In our industry survey, we found that general computing knowledge was not as highly valued when it was taught without the CEM context. The use of the software and knowledge of computing systems alone were not deemed as valuable for CEM BIM professionals as they need to work within CEM teams and projects, communicating and collaborating with design and construction professionals. The CEM domain topics are of equal importance as computing to graduates who wish to pursue BIM. As one CEM faculty stated after seeing a general contractor present on how they use BIM at a ASC conference in 2009, “Before this, I thought that BIM is just a design tool. Now I understand that it will effect everything we teach.” We propose that learning BIM software theory, tools and skills in CEM contexts such as estimating, safety, site planning, lean construction, coordination and collaboration, appear to be the most effective ways to bring BIM into our graduate curriculum.

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