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A Holistic View of Building Information Modeling Education in Post-Secondary Institutions

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Introduction

BIM 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.[1] It is predicted to become 100% in the next few years, especially for MEP coordination.[1] The construction industry has been adopting BIM to benefit from its improved communication and productivity, better coordination of construction drawings, faster delivery, and lower costs.[2] To support this, construction companies have created new BIM and VDC (Virtual Design and Construction) positions to make the transition from current practice to the one that integrates BIM into their organization.[3]

To keep up with this industry paradigm shift, many CEM programs in the United States have introduced BIM into undergraduate and graduate education.[4] As BIM practices emerge and become codified, it is clear that CEM programs in higher education need to play a vital role in BIM education. To reflect the growing demand for BIM in the construction industry, CEM programs have been trying to teach BIM skills and VDC knowledge to students, integrating with traditional or mainstream courses more broadly.

There have been some studies to evaluate the level of BIM education in higher education. These studies have revealed that BIM education is still in the early adoption stage even though several CEM programs have actively promoted BIM-enabled learning.[5, 6, 7] It may be necessary to understand the reasons why BIM is being slowly adopted in the CEM curriculum and the challenges in implementing BIM technology to support the teaching-learning process. Based on the previous studies, the main obstacles preventing BIM implementation are identified and listed as follows: [6, 7, 8, 9, 10]

- Faculty members' unwillingness to change the existing curriculum
- Lack of resources
    - Number of experts who can teach BIM
    - Faculty time required to make course changes for BIM incorporation
    - Faculty support from colleagues and/or administrators
    - Number of courses which students are required to take for graduation
    - Lack of educational materials
- Level of knowledge required to teach BIM
- Complexity of relatively new software tools (e.g., Revit, Navisworks, Tekla, and Synchro)
- Constant software upgrades, costs, or education

To introduce BIM within the existing curriculum, CEM programs have replaced a traditional graphics course with a new BIM course.[11] This might be a good start for incorporating BIM into the CEM curriculum. However, since BIM has incorporated into a traditional graphics course (typically a freshman-year AutoCAD course), the new BIM course naturally focuses on using

BIM software for drafting and modeling, just like the formal AutoCAD course did. This may be a big misunderstanding of the true meaning of BIM. We believe that BIM is not just using software.

Using BIM 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 force driving the adoption of BIM is the ability to integrate all members of project teams together by communicating ideas more effectively, thereby providing a competitive advantage for innovative firms.[12] Therefore, in incorporating BIM into the CEM curriculum, the main focus should be on fundamental BIM concepts and processes, not on mastering BIM tools.[13]

This paper proposes a holistic view of BIM education in post-secondary institutions. To address the question of "How and in what ways should CEM programs introduce BIM concepts and skills?", we performed a review of BIM curricula in the United States. Then, we conducted a survey of industry professionals to determine what BIM knowledge and skills they seek in hiring graduates of CEM programs. Finally, we proposed a holistic approach for BIM education in the CEM curriculum.

Review of BIM Curriculum

To understand how CEM programs are introducing BIM concepts and processes, we performed an analysis of undergraduate BIM related courses offered by CEM programs in the United States. We reviewed the American Council for Construction Education (ACCE) accredited CEM programs, but not limited to them. We first searched for BIM related courses on the websites of CEM programs. Once BIM related courses offered in CEM curricula had been identified, we reviewed them and contacted the instructors of the courses to request a copy of the course syllabi as necessary.

This analysis of BIM courses helps to understand how and in what ways these programs introduced BIM in their own curriculum as well as the current status of BIM education. In addition, this analysis made it possible to identify discrepancies between the BIM education currently offered in higher education and the type of BIM education expected by construction stakeholders. Table 1 presents several BIM related courses currently offered in the United States.

In this review, we identified that there is a variety in BIM specific contents and general computing topics currently being offered by the CEM programs. Also, we see that many BIM courses in CEM curricula mainly focus on using BIM software for drafting and modeling. In this next section of the paper, we present findings from a survey of industry BIM professionals to understand the industry perspective about priorities for BIM education in higher education.

Table 1: BIM related courses offered in the United States

Course Name/Institution	Purpose of Course
Building information modeling and integrated practice, **U. of Southern California**	Focuses on building information management concepts and solutions; current BIM technologies; coordination of design and construction; information management throughout building life cycle; project delivery systems and technologies for integrated practice
BIMS, **Texas A&M U.**	Covers what kinds of BIM applications are available; how BIM is used for project acquisition, cost estimation, construction planning, clash detection, and field quality control; and, how BIM can be used for facilities management
Revit fundamentals, **U. of Oregon**	Introduces a new way of thinking about deliverable documents and the collaborative framework that a parametrically virtual model can provide. Focuses on the use of Autodesk Revit to teach the basic skills needed to create and maintain a parametric building model for renderings, working drawings, massing studies, and coordination of disciplines.
BIM, **New Jersey Tech.**	Covers principles and practice of BIM. Topics: architectural office-level BIM implementation and advanced studies in computer modeling systems.
Construction modeling, **Brigham Young U.**	Focuses on the Development of architectural plans using Building Information Modeling; floor, foundation, plot, elevations, sections, and details. Renderings and other advanced modeling techniques.
BIM, **U. of Arkansas**	Explores basic functions of BIM for residential and commercial construction. Topics: geometry, spatial relationships, geographic information, quantities and properties of building components, and the creation of virtual models of buildings that can be used for quantity takeoffs.
BIM for commercial construction, **Purdue U.**	Focuses on utilizing BIM for commercial construction. Topics: geometry, spatial relationships, geographic information, quantities, and properties of building components.
CAD and BIM for construction managers, **Oklahoma State U.**	Covers the use of state-of-the-art 3D design and BIM software to facilitate CAD, estimating, and management skills. Emphasis is on quality, timeliness, and continuous improvement–bid days are used as due dates for projects, as well as accurate CAD drawings.
Introduction to BIM **U.of Nebraska-Lincoln**	Focuses on integration of design, document and construction estimate. Topics: model-based 3D design, file formats, interoperability, and MEP modeling.
Advanced project management concepts, **U. of Washington**	Covers visualization, 3D clash detection, fabrication automation, digital site layout, 4D modeling, as-built model generation, and digital information management using BIM. Explores how visualization and information technologies–3D/4D/BIM and integrated databases–can support project planning and execution.
Construction modeling and information technology, **East Carolina U.**	Focuses on graphical expression of construction and architectural elements through use of 3D and Building Information Modeling (BIM) software including construction document organization and preparation, and specifications.
CAD and BIM tools for construction, **Central Connecticut State U.**	Covers visualization and communication tools commonly used in construction, including AutoCAD, SketchUp, Revit Architecture, and Navisworks.

Survey on BIM Topics

For this study, a questionnaire was developed to capture the industry's current BIM trends and practices and to identify industry's expectations for BIM skills and knowledge of recent graduates. Individuals from construction firms who are directly involved in BIM and VDC were identified. Forty-two BIM professionals from thirty-four different construction companies were invited to this survey by email. The results of this survey were collected through the secure online research suite Qualtrics. The response rate was fifty percent with twenty-one individuals from eighteen different companies in fifteen locations across nine states including California, Colorado, Georgia, Indiana, Maryland, Minnesota, Ohio, Virginia, and Washington.

Table 2 summarizes the results of the survey on important topic areas of BIM-related tasks in the construction companies. The survey results indicate that construction companies actively use BIM as an important tool for clash detection, MEP design and trade coordination, and constructability reviews. On the contrary, construction companies rarely use BIM for temporary structure design and analysis, sustainable design and energy simulation, safety-related analysis, and model-based estimating. These results provide valuable guidance on what areas of topics should be covered when we incorporate BIM into the CEM curriculum.

Table 2: Important topics for BIM-related tasks

BIM-related tasks	Mean	SD
Clash Detection	4.00	0.000
MEP Design and Trade Coordination	3.84	0.488
Constructability Reviews	3.79	0.521
Site Layout and Logistics	3.16	0.933
Visualization & Communication	3.16	0.744
Scheduling & Sequence Planning	3.11	0.788
Shop Drawing & Materials Procurement	2.85	0.853
Integrated Project Delivery System	2.83	0.898
Simulation of Construction Operations	2.79	0.832
Facility Management	2.74	1.068
Model-Based Estimating	2.68	1.029
Laser Scanning	2.63	0.985
Safety-Related Analysis	2.47	1.094
Sustainable Design & Energy Simulation	2.32	0.798
Temporary Structure Design & Analysis	2.21	1.004

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

The BIM professionals also indicate that BIM education in the CEM curriculum needs to focus on "general introduction and knowledge of BIM", "BIM implementation in the construction process", and "roles and responsibilities of General Contractor/Construction Management (GC/CM) and other stakeholders". On the contrary, as shown in Table 3, the topic areas of "BIM and Integrated Project Delivery (IPD)" and "BIM for facility management" are regarded as the least important BIM knowledge and skills.

Based on this survey data, it can be concluded that BIM education in CEM curricula should emphasize MEP design validation, spatial trade coordination, clash detection with BIM; 3D modeling for project administration; and BIM software skills for visualization and communication.

Table 3: BIM knowledge and skills expected from CEM graduates

Knowledge and Skills	Mean	SD
General introduction and knowledge of BIM	4.50	0.707
BIM implementation in the construction process	4.40	0.966
Roles and Responsibilities of GC/CM and other stakeholders	4.20	0.789
BIM software skills	3.60	0.699
BIM and sustainability integration	3.40	0.699
BIM and IPD	3.10	0.738
BIM for facility management	3.10	0.568

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

In addition, the study asked about what BIM software they use. The respondents indicated that CEM graduates should be able to use BIM software such as Navisworks, Revit Architecture & MEP, AutoCAD, and Sketchup. They also considered Tekla and Synchro slightly important.

A Holistic Approach for BIM Education in the CEM Curriculum

The survey identified that students need to learn basic BIM software skills to leverage higher level concepts in subsequent courses. CEM programs should offer an introductory BIM course at the freshmen or sophomore level to introduce basic BIM concepts and evolution to students and get them familiar with the use of BIM software. However, students do not need to be an expert in creating 3D models because most will not be 3D BIM modelers. Instead, they need to be able to transfer 3D models between software packages, manipulate views and perspectives, and extract information from them. Therefore, the main focuses of the introductory BIM course should be on understanding the purpose of BIM software, workspace and interface, drawing and editing tools, and the use of parametric modeling.

Again, the main objective of the introductory BIM course must be for students to leverage the tools that apply to daily activities. We must not focus on training how to build a model. We must focus on how to use the model to assist daily construction operations. In terms of level of BIM software skills, some of the survey respondents commented as follows:

> "Navisworks is the software we spend the most time in. We do all of our 3D coordination with our subcontractors within this software. Utilizing Navisworks' clash detection feature to determine areas where models are intersecting one another - a clash of the building systems. We then review the model and determine solutions to the clashes, eventually resulting in a clash free model and ultimately clash free installation in the field."

> "We use Revit for model creation and manipulation as needed. If a model is not supplied by the architect or engineer, we will take it upon itself to create a model

> for use during construction. We also use Revit to add specific items to the architect's model that might not have been included or represented in 3D."
>
> "We use SketchUp for quick 3D models to communicate issues and discrepancies, or use it for detailing out a specific area in formal RFIs."
>
> "We typically do not use AutoCAD for 3D model creation, but do use it for creating overlay drawings - typically at conclusion of our trade coordination process with MEP and fire protection trades. It is also used for other various tasks."

After the introductory BIM course, BIM course modules should be incorporated into several CEM courses at the junior and senior level such as MEP systems, planning and scheduling, estimating, structural systems, safety, and project management in the CEM curriculum. This will complement the existing curriculum with emerging BIM practices. CEM students need to learn specific BIM use cases along with the specific domain knowledge. For example, in the construction project management course, students can better learn when and how to use BIM along with principles of project management so as to manage the construction process and facilitate information exchange and collaboration among project participants. Therefore, it is strongly recommended that BIM should be an integral part of the CEM curriculum. Again, the main focus of these BIM modules in junior- and senior-year courses should be on possible BIM use cases and their results, trades/systems that frequently partake in the BIM process, roles and responsibilities of various participants in BIM operations, and management skills to facilitate the BIM process.

Finally, it is recommended for CEM programs to offer a senior level BIM capstone course for students who are interested in learning BIM or wish to purse BIM. Once students have been formally exposed to all aspects of BIM covered in the curriculum, BIM could be the central focus of a capstone project, creating an interactive and collaborative learning environment. This capstone course should integrate all aspects of BIM implementation in the construction process, emphasizing team interactions, project management, decision making, critical thinking, and problem solving. Given all this exposure to BIM, it should be possible to incorporate BIM into a comprehensive review at the end of CEM undergraduate studies.

If a CEM program has an opportunity for collaborative effort with other academic programs in AEC disciplines, it is highly recommended to have an integrated studio for the BIM capstone course. Since early collaboration is essential to the effective use of BIM, integrated studios with AEC disciplines are great ways to provide a learning opportunity where students in different disciplines communicate and collaborate with each other to create a 3D model and use BIM analysis tools for structural analysis, scheduling, clash detection, estimating and their integration. Students need to learn their own roles in team processes and dynamics. Also, they should understand how to manage data in the design to construction continuum and how to work collaboratively for aesthetics, structure, building systems, and performance measures.

Summary

BIM continues to initiate changes in the practices of professionals in the CEM domain. To keep up with this industry paradigm shift, many CEM programs have introduced BIM into undergraduate and graduate education. As BIM practices emerge and become codified, it is clear that CEM programs in higher education need to play a vital role in BIM education. To reflect the growing demand for BIM in the construction industry, CEM programs have been trying to teach BIM skills and VDC knowledge to students, integrating with traditional or mainstream courses more broadly.

To introduce BIM within the existing curriculum, CEM programs have replaced a traditional graphics course with a new BIM course. This might be a good start for incorporating BIM into the CEM curriculum. However, since BIM has incorporated into a traditional graphics course, the new BIM course naturally focuses on using BIM software for drafting and modeling, just like the formal AutoCAD course did. This may cause a big misunderstanding of the true BIM because BIM is not just a design tool. Therefore, in incorporating BIM into the CEM curriculum, the main focus should be on fundamental BIM concepts and processes, not on mastering BIM software.

BIM can affect everything we teach. The most effective way to bring BIM into the CEM curriculum is that BIM should be an integral part of the CEM curriculum. BIM education in CEM curriculum should emphasize MEP design validation, spatial trade coordination, clash detection with BIM; 3D modeling for project administration; and BIM software skills for visualization and communication. This study also found that BIM education in the CEM curriculum needs to focus on "general introduction and knowledge of BIM", "BIM implementation in the construction process", and "roles and responsibilities of General Contractor/Construction Management (GC/CM) and other stakeholders".

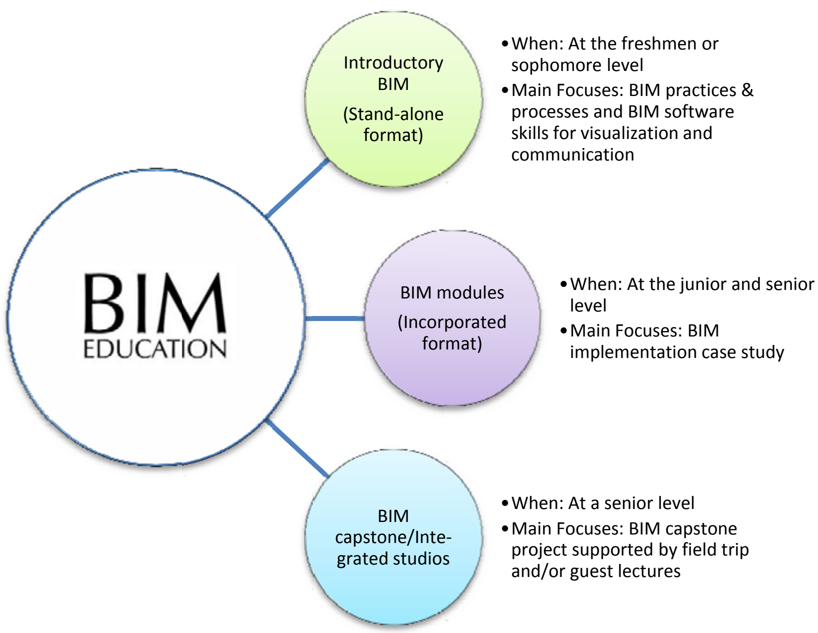

Figure 1: A Holistic View of BIM Education in CEM Curriculum

This paper proposes a holistic view of BIM education in post-secondary institutions. There are three major steps students can build and harness BIM skills and knowledge within the CEM curriculum. Figure 1 summarizes a holistic approach of BIM education in the CEM curriculum.

Conclusions

Currently, the construction industry expects CEM graduates to be fully aware of what BIM is. As the industry continues to realize more and more benefit from using the technology, it is apparent that it will be in CEM curriculum to stay. Similarly to other industries, BIM will eventually become the norm in all the construction communities. Then, BIM will become fully integrated into the undergraduate curriculum. Keeping up with this industry demands, CEM programs have to clearly identify, in collaboration with the industry, to what extent students should be exposed to BIM technology and what level of BIM skills and knowledge students must have to prepare their own professional career.

Finally, it is proposed that the most practical approach to BIM education would be the integration of BIM into mainstream CEM courses. Using BIM as an integrated format in construction education will be able to provide students with a higher quality of education. A rich and collaborative learning environment will be achieved through purposeful attempts of integrating BIM into various course contents. Above all, the administrative support and commitment will be essential to successfully leveraging BIM in construction education.

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