
AC 2012-4816: LEVERAGING BUILDING INFORMATION MODELING TECHNOLOGY IN CONSTRUCTION ENGINEERING AND MANAGEMENT EDUCATION

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Leveraging Building Information Modeling Technology in Construction Engineering and Management Education

Abstract

Emerging technologies and practices such as Building Information Modeling (BIM) and Virtual Design and Construction (VDC) have the potential to advance the quality of education in Construction Engineering and Management (CEM). The integration of technology and data practices into CEM curriculum is essential because the industry employers and students demand more practical knowledge and hands-on experiences than ones in other domains do. Furthermore, many educational technology researchers argue that current students prefer to using technology for what they are learning since they are technology savvy. As the information and communications technology changes rapidly, it becomes more critical. BIM technology and VDC practices continue to arouse interest because they bring several major benefits in terms of improving the student learning and the effectiveness of teaching. In addition, it might be helpful to use BIM technology in drawing students' active engagement. The educational benefits are threefold: practical industry preparedness, improved learning, and increased engagement.

The main purpose of this study is to analyze various applications of BIM in CEM programs from the literature and establish BIM education framework in CEM curriculum. To accomplish that, this paper first investigates the roles and benefits of BIM technology in construction education and then reviews how BIM technology has been implemented in the CEM curriculum. In addition, this paper suggests how best to integrate BIM technology into the CEM curriculum for educating students to be well prepared for the construction industry. The suggestions on this paper can be used for a guideline for instructional strategies related to BIM. Therefore, CEM programs can have the benefits of BIM technology for their own curriculum through appropriate BIM incorporation.

Introduction

Building Information Modeling (BIM) has been a growing trend in the construction industry over the last five years. According to Young et al.³⁷, almost 50% of the industry is using BIM and its adoption will increase, expecting positive returns from the use of BIM technology. 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.

Keeping up with this growing industry trend, adequate BIM training is essential to successful BIM adoption. Although BIM has gained significant momentum in the construction industry, one of the key issues in utilizing BIM technology is lack of individuals who have BIM skills and knowledge. Cook¹¹ states that highly skilled cross-trained staffs with both construction and IT skills are required to implement a BIM. Hartmann and Fischer¹⁹ identify the lack of BIM

practitioners as a major bottleneck to move the industry into the BIM age. Young et al.³⁷ also indicate that the lack of adequate training is the greatest challenge to adopting BIM in the construction industry. In parallel with industry, CEM programs in higher education need to find a way to leverage the BIM technology to their curricula so that students can master it before entering the workforce.

Many construction companies have created new BIM and VDC positions to make the transition from current practice to the one that integrates BIM technology into their organization. The title for the position is not well defined yet. Those individuals who are BIM savvy are internally called with various titles such as BIM Construction Officer, BIM Coordinator, BIM Project Manager, Integrated Construction Engineer, and Virtual Construction Manager⁵. Regardless of its title, they are responsible for implementing BIM on their projects while balancing traditional operations duties. Therefore, it is certain that there is a strong need for more individuals with experience and knowledge of BIM technology and VDC practices.

Up to now, almost all BIM and VDC training have been done internally within construction firms. One of the industry BIM experts said, “If an employee needs to get introduced to BIM, just to understand the basics, we have entry-level classes for them to take. We also have a group of individuals that have the title of Integrated Construction Engineer (ICE). These individuals go through an intensive in-house training program to make them fully capable of meeting our company’s advanced BIM necessities.” Another of the industry BIM experts mentioned, “Operations employees can attend optional courses related to BIM that our Corporate Knowledge Center offers. In-depth training is reserved for our ICEs.”

Like most skills do, the skill of using BIM technology cannot be gained through intensive courses. In most cases, those courses fall short of the expectation to become fluent in BIM. Also, external trainings offered by software vendors almost always focus on the technical software side of things, not the VDC processes inherent with BIM adoption. To foster industry innovation, CEM programs need to think how best to offer considerable opportunities for teaching BIM and VDC to students, integrating with traditional or mainstream courses more broadly.

Research Objectives and Scope

The main objective of this study is to encourage the incorporation of BIM into CEM curriculum more broadly. The sub-objectives include examining the revolutionary nature of BIM; exploring various applications of BIM in CEM curriculum from the literature; and developing a framework for leveraging BIM in CEM education. The research scope for this paper is limited to the extensive literature review.

The pursuit of these objectives generates the following questions about BIM and its potential impacts on CEM education:

- What efforts have been made in CEM programs to reflect the BIM needs of the industry?
- What issues have been found in implementing BIM in CEM curriculum?
- Which topics should be introduced in CEM education?

To address these questions, an extensive literature review was conducted 1) to explore BIM's impact on the industry; 2) to study the published cases of BIM implementation in CEM curriculum; 3) to observe different pedagogical methods and lessons learned; and 4) to identify some resistance and barriers resulting from BIM implementation in CEM curriculum.

BIM in Construction

To understand BIM in the context of CEM curriculum, we need to first understand how BIM has enhanced and changed industry practices. BIM has been in the spotlight over the last five years although the BIM technology in some forms has existed over 20 years¹⁸. Nowadays, BIM takes a major role during the design and construction phases of a project, and there is a growing focus on the use of BIM for operations and maintenance. The use of BIM may change the ways that projects are conceived, designed, communicated, and defined¹. In addition, integrated uses of BIM challenge traditional roles and responsibilities of designers, builders, and owners³³. The entire project team must work together in an efficient and effective way to deliver successful projects.

Building Information Modeling is a process of generating, using, and managing high-quality information for better, faster, cheaper, and safer building environments³³. In construction, BIM is a parametric modeling tool that is most commonly used to coordinate building requirements, communicate the RFIs that result from the coordination process, identify problems, and simulate and analyze potential impacts due to required changes. All these things are possible due to the BIM capability of building a project in a virtual space prior to starting work in the field³². From project managers' perspective, one of the great benefits from using BIM is that they can keep the job site safe as well as minimize the waste of materials¹⁵. With the use of BIM, many aspects of the construction industry will be transformed. As a result, general contractors need strategic thinking of the BIM processes to achieve the following objectives¹⁴:

- Analyzing constructability
- More accurate quantity surveying
- Optimized construction sequencing
- Improved trade coordination
- What-if analysis and change management
- Supporting effective team communication
- Improved safety and quality

BIM can be implemented or integrated with one of the following technologies⁷:

- 3D Technology
 - Enables users to create a 3D building model on the X, Y, and Z planes
 - Used for clarification and visualization of project requirements
- 4D Technology
 - Enables users to see how it might be phased and built
 - Right for clarity of scheduling, including resource, coordination effort flow into construction, and anything that might affect the outcome of the project schedule

- 5D Technology
 - Enables users to explore the budget cost of a project over time
 - Applicable for integrating BIM models with cost data to facilitate the cost estimating process
- Laser Scanning Technology
 - Enables users to acquire building spatial data in 3D with high fidelity and low processing time
 - Cut out for documentation of existing conditions

Industry practices are more developed than five years ago. However, BIM technology is still in a nascent phase of development. Along with its demand, BIM technology itself may evolve quickly or be supplanted by another technology in several years. Although the specific software may change, we propose that CEM programs need to develop an approach to teaching with technology to meet the needs within the construction industry. Above all, BIM technology can play a vital role in improving the quality of construction education, considering the importance of hands-on experiences in construction. It will enable students to become critical thinkers by analyzing various options and applying what they have learned to a virtual world.

Efforts toward BIM in Construction Education

Educators have proposed that Building Information Model is a powerful teaching tool that supports the visualization^{4, 27} as well as synthesis of new knowledge²⁶. There have been two strategies to introducing BIM into construction engineering and management curriculum: (1) As a stand-alone course in computer applications^{8, 13, 35, 38} and (2) As modules to existing courses^{10, 16, 24}.

In a survey of general contractors in the Southeast conducted in 2007, approximately 70% responded that they are either using or considering using BIM in their companies, while 75% considered students with BIM skills as having an advantage over candidates who did not in the job market².

That is in stark contrast to a 2009 survey of forty five ASC schools, where “Respondents reported that 6.5% teach AutoCAD as a stand-alone course.” “Only one institution (less than 1% of respondents) reported that its program offers BIM as a stand-alone course. BIM is incorporated in other courses in 9% of programs.”³⁰ In addition, Becerik-Geber et al.⁶ investigated, in 2011, the level of BIM integration into the current construction related curricula. They identified that most of the CEM programs newly started offering BIM courses and revealed that 57% of the engineering programs and 36% of the construction management programs need BIM courses at the undergraduate level. According to this study, “Only slightly over half of all programs offer BIM courses and almost one fifth of all programs still don’t have any plans to offer BIM courses.”⁶

From civil engineering and construction management programs, there are several published cases where educators report on efforts incorporate BIM in their curriculum, thereby qualifying and, in some cases, quantifying the benefit of BIM technology in construction engineering and management education.

Table 1. Published Cases of BIM Implementation in CEM Curriculum

Curriculum	Lessons Learned	Reference
Stand-Alone BIM Course	Limitations in using Revit in creating various models; Better understanding of the architect's role in design and construction process	Woo ³⁸ , Dupuis et al. ¹³
MEP(Mechanical, Electrical, and Plumbing) Lab Course	Interactive and collaborative learning environment; Student's active learning on MEP coordination	Korman & Simonian ²³
Interactive Teaching Modules Focusing on Structures, MEP Systems, and Energy Modeling	Better student's ability to understand complex construction systems	Clevenger et al. ¹⁰
Engineering Graphics Course	Better understanding on building structures and components; Improved student's ability to see building objects in 3D	Sacks & Barak ³¹
Cross-Curriculum Teaching Module in Construction Management and Structural Engineering Education	Helped students to 1) Learn the roles and responsibilities of other disciplines; 2) Understand the complexity and variety of information between different disciplines; and 3) Learn collaborative work environment for the construction process	Richards & Clevenger ²⁹
Capstone Course	Difficulty in using BIM tools for a capstone project; Students' strong interest in learning BIM technology	Azhar et al. ³
Estimating Course	Better understanding on construction plans; Improved accuracy of student's quantity takeoffs	Gier ¹⁶ , Sylvester & Dietrich ³⁴
Interactive Homework Modules for Materials & Methods Course	Effective course content delivery; Positive perceived impact on students' learning	Glick et al. ¹⁷
Project Management	Helped students to 1) Learn how different project management methods integrate with each other, 2) Integrate change management tasks in a class assignment, and 3) Learn how to optimize project plans.	Peterson et al. ²⁸
Scheduling Course	Student's willingness to use BIM; Enhanced understanding on construction means and methods	Hyatt ²⁰

Many of the cases above present “pilot projects” where BIM is being deployed in a course for the first time. These efforts toward BIM in construction education show the great potentialities of successful BIM integration in the existing CEM curriculum. In the next few sections, the authors propose a broad framework that suggests how BIM can be taught as a skill as well as how it supports and improves existing CEM pedagogy.

Roles of BIM Technology in CEM Curriculum

From a review of literature, the authors' own experience, and personal correspondence with other BIM educators, the authors have determined that BIM technology can be applied to provide an opportunity to significantly enhance students' learning and engagement. It can also support interactive and collaborative learning environment in which students can explore and share other's opinions and thoughts^{12, 25}. Consequently, BIM technology will be able to facilitate the process of students' active learning and knowledge construction. For effective application of BIM in CEM programs, faculty must identify proper technology that works best for their specific construction courses. The following introduce the general types of BIM technology and how they could support CEM curriculum.

3D Technology

3D technology enables students to create a virtual model of the project for better clarification and visualization. Due to this fact, 3D technology can be used in CEM curriculum to provide students a better understanding of building structures, MEP systems, building codes, and materials. In terms of virtually constructing projects prior to starting work in the field, 3D technology can be also used to teach the quality control procedures available.

4D Technology

4D technology, linking a 3D model to a planned project schedule, enables students to see how it might be phased and built in time series. This technology allows for clarifying major trade work coordination and site logistics planning. "Construction Means and Methods" and "Safety Hazard Analysis" can be also studied with 4D technology.

5D Technology

The concept of cost over time added to 4D models has made 5D technology possible. 5D technology allows students to explore what the budget/estimated cost of a project might be at any given point in time during the project.

Laser Scanning Technology

3D laser scanning can be used in CEM curriculum. However, 3D laser scanning devices might not be available in class due to the expense of the equipment and the training required to use it. Regardless of its availability, this technology also needs to be introduced to students. Students should be able to describe what benefits and unique implementations of 3D laser scanning technology are in the construction industry.

BIM Software for Construction Management

The emerging new functionalities and the proliferation of BIM software packages possess challenges for academia and industry alike. Table 2 shows several BIM software packages currently available for construction project management. The software packages provide BIM functionality in a variety of ways, but any competitive BIM software has basic functionality that allows for:

- The identification of design conflicts by visualizing building components in 3D

- The support for project coordination by showing color-coded tasks or resources on objects as well as communicating in 4D
- The optimization of construction sequences by linking any 3D design data with imported schedule data
- The real-time digital distribution of changes of the 3D objects and 4D schedule

Table 2. BIM Software for Construction Management⁹

Company	Product
Autodesk	Navisworks
Bentley	Navigator ConstructSim
Innovaya	Visual Simulation
Vico Software	Vico Office Suite
Tekla	BIMsight Structures
Gehry Technologies	Digital Project: Viewer
Synchro	Synchro Professional Synchro Project Constructor

A Framework for BIM Integration into CEM Curriculum

Students need to know how to use BIM to build basic skills and knowledge to create 3D building models. However, they do not need to become a 3D modeler who creates the geometry in BIM models. For this reason, the focuses of BIM in CEM curriculum should be on extracting or inserting information on the construction process and resources required, adding phases to the resources, and creating a building phasing files based on the planning and scheduling.

Table 3. BIM Technology, CEM Topics, and Typical Coursework

BIM Technology	CEM Topics	Coursework	Introductory BIM Skills, Contracts, Project Administration, Capstone, Integrated Studio
3D Technology	Building Structures; Building Codes & Materials; Quality Control; MEP Systems	Building Systems and Codes; Construction Materials; Mechanical and Electrical Systems	
4D Technology	Construction Means and Methods; Scheduling; Trade Work Coordination; Site Logistics Planning; Safety Hazard Analysis	Construction Techniques and Methods; Planning and Scheduling; Construction Safety	
5D Technology	Estimating; Budgeting	Construction Estimating	
Laser Scanning	Quality Control; Quantity & Volumetric Surveys; Site Modeling and Lay Outing; Accurate As-built Data of Buildings; Benchmark of Pre-Existing Conditions	Construction Surveying; Facility Management	

As aforementioned, the main focus of BIM education should be on the processes of construction management, not on the software. Due to this fact, it is extremely difficult to teach BIM through a single course. In this framework, the authors propose that BIM should be an integral part of the CEM curriculum. A stand-alone BIM course is also needed as a freshmen or sophomore level course to introduce basic BIM concepts and to enable students to get familiar with BIM tools. After the course, BIM elements should be incorporated in other junior and senior level courses as shown in Table 3.

Construction Contracts

Early integration is the key to the success of BIM project. For this reason, Integrated Project Delivery (IPD) needs to be taught. Students need to learn the importance of IPD associated with BIM projects for successful BIM implementation. The general contractor's role and responsibility in the BIM process need to be taught. BIM contract negotiation and risk allocation also need to be explored for students to identify best practices for integrating BIM into project contracts.

Construction Surveying

With the 3D laser scanning devices, all the 3D points can be collected incredibly quickly to define shapes and surfaces. Students need to be introduced to this survey technique. They should be able to describe what benefits and unique implementations of 3D laser scanning technology in the surveying process. In addition, students should illustrate the reason why 3D survey information is critical to BIM-centric process.

Facility Management

BIM and 3D laser scanning can be used to create both an accurate as-built model of a building and a database for recording the breadth of information developed and associated with building components. The current capabilities of BIM have not been fully exploited in FM systems as of yet. However, students need to learn BIM data exchange standards for facility management and explore how the 3D digital representation of a building system can offer a platform for enhanced interdisciplinary collaboration, the capability to manage change, and the ability to extend information support throughout the building lifecycle.

Construction Safety

3D technology can provide more illustrative site layout and safety plans and support safety communication in various situations. In addition, 4D technology can integrate the safety issues with the construction planning to provide methods for visualizing up-to date plans and site status information. Students should learn the procedures of using BIM for safety planning, management, and communications. And, students need to understand the roles of BIM to create a built environment that successfully integrates safer construction processes.

Construction Estimating

BIM can be used to support cost estimating. Students should be able to extract quantities from a 3D building model and be able to link the data to cost estimate applications such as Sage Timberline or Microsoft Excel for pricing.

Construction Planning and Scheduling

The construction schedule can be integrated with a 3D building model. Students should be capable of linking a Microsoft Project or Primavera with a Revit 3D model to visualize a project schedule. 4D planning and scheduling is generated by adding schedule and resource data to a 3D building model. Students also need to learn how to use BIM for scheduling and sequencing of work.

Project Administration

In terms of managing a construction project, students should be able to articulate the construction of a complex physical model in a 3D building model and identify potential problems with design and construction in order to minimize any associated cost or schedule impacts. The following topics should be taught with BIM tools: design validation and constructability reviews; site logistics planning and trade coordination; safety hazard analysis; verification of existing conditions; and documentation of as-built models. A 4D building model provides an intuitive interface for project team to easily communicate and coordinate the assembling of a building over time as well as analyze various construction options. Students need to learn how to use BIM to support project collaboration and decision-making.

Capstone

Given all the exposures to BIM, it might be possible to incorporate BIM into a comprehensive review at the end of CEM undergraduate studies. Once students have been formally exposed to all aspects of BIM technology covered in the curriculum, BIM could be the central focus of a capstone project, creating an interactive and collaborative learning environment.

Integrated Studios

Since early collaboration is essential to effective use of BIM technology, integrated studios with AEC disciplines are great ways to provide a learning opportunity where students in different disciplines communicate and collaborate 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 role 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.

Limitations on BIM Implementation in CEM Curriculum

Along with the current BIM momentum within the construction industry, CEM programs have to focus on BIM education to enable students to apply BIM technology in their future careers. It is essential for students to learn fundamental BIM knowledge and skills before entering the industry. BIM education in CEM curriculum is still the early adoption stage even though several construction programs have offered BIM courses to their students. It may be necessary to understand the reasons why BIM is slowly adopted in CEM curriculum and the issues in implementing BIM technology to support the teaching-learning process.

Sabongi³⁰ investigated several obstacles to integrating BIM into the undergraduate courses. According to his study, one of the barriers is faculty members' unwillingness to change the existing curriculum for incorporating BIM. Becerik-Geber et al.⁶ identified the reason for slow

adoption of BIM in the construction curriculum. They claimed lack of resources as the primary reason. The resources include number of experts to teach BIM courses, faculty time required to make curriculum changes, support from faculty colleagues and/or administrators, and number of courses which students are required to graduate. Johnson and Gunderson²¹ also indicated one of the challenges to BIM implementation as the complexity of the relatively new software tools. Woo³⁸ identified some challenges to BIM implementation, including the level of knowledge required to use BIM software and lack of educational materials. In addition, Kiviniemi et al.²² mentioned that traditional parameter such as constant software upgrading, costs, or education is the main obstacle preventing BIM implementation.

Suggestions on BIM Integration into CEM Curriculum

BIM has gained significant momentum in a relatively short period of time. Hence, there will be an enormous demand for individuals with BIM skills and knowledge. However, there may be limited room for BIM education since BIM is not formally identified as the ACCE and ABET accreditation criteria. As a result, students might not be interested in taking more courses for BIM education as long as they are not required to graduate. CEM programs need to move quickly to adopt BIM in their curriculum. There are a few studies specifying what capability related to BIM students should have before entering the industry. In addition, there is lack of study for unified and comprehensive BIM integration approach in the CEM curriculum.

In near future, all students will embrace BIM in construction education. Based on the rapid adoption of BIM over the past few years, it will be a necessary skill for graduates to remain competitive in the job market. The construction industry and academia always look to the automotive manufacturing industry as a comparison where having a core understanding of 3D modeling and other advanced systems is a requirement. The most important skills needed in the CEM field are:

- Ability to model detailed conditions in 3D
- Ability to assemble and review a clash detection model
- Basic Revit modeling and manipulation skills
- Ability to create 4D models using a schedule
- Basic AutoCAD skills
- Ability to apply and work with new technology

BIM technology enables users to be successful for scheduling, coordination, laser scanning, or other use cases. However, without an established workflow, the results can be subpar or inconsistent. There are many processes involved in BIM adoption. Fundamentally, the use of BIM requires planning and prep work to ensure successful implementation. These plans and processes change over time based on lessons learned and developments in technology. There are a wide variety of processes and steps for each virtual construction use case. Having standards in collaboration with the industry may be essential, particularly when incorporating BIM technology into CEM curriculum.

As aforementioned, BIM education in CEM programs should mainly focus on larger industry trends and processes, not on the software. However, a basic software understanding is also important. CEM programs need to teach the followings.

- BIM evolution
- BIM uses and interactions among various project stakeholders
- Types of BIM software
- Basic software understanding of select applications
- Management skills to facilitate the BIM process
- Understanding of the trades/systems that frequently partake in the BIM process

Currently, the construction industry expects CEM graduates to be fully aware of what BIM is, but understand they may not have been fully exposed to it in their studies. This would be the main reason why construction firms have their own in-house training to meet their business necessities. Obviously, as times change, BIM will become fully integrated into the undergraduate curriculum. As the industry continues to realize more and more benefit from using the technology, it is apparent that it should be in CEM curriculum to stay. Similarly to other industries, BIM will eventually become the norm in all the construction communities.

Conclusion

A majority of leading construction firms are increasingly utilizing BIM technology to improve their construction processes, expecting its values and benefits. BIM have the great potential to provide. It is inevitable that CEM students will move into a world which demands that they are adept at using BIM technology. 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.

Just providing students BIM tools such as Revit, AutoCAD, Google SketchUp, etc. and teaching how to create a modeling of building systems in a virtual reality is not true BIM education. Only if students know how to use BIM software to create 3D building models, it is difficult to say that they know how to use BIM. It might be said that they learned computer graphics. To be BIM users who are not BIM modelers, they should be able to correctly extract information necessary for the construction process from 3D and/or nD models. The main objective of using BIM is to efficiently manage the information produced through the construction processes and to enable construction management more effective through better communication and collaboration.

BIM technology can play a vital role as the comprehensive interface of construction knowledge in CEM curriculum. CEM programs need to offer BIM technology to help students derive insight about CEM functions. Using BIM technology will be able to assist students in more confidently understanding building systems, cost estimating, planning and scheduling, and trade coordination issues. In addition, by virtually constructing a project and going through all the constructing process, students can be better prepared for professional practice.

The most practical way to offer BIM to students would be to incorporate it into a series of required courses. Using BIM technology as an integrated format for construction education can be able to provide students better quality of education. A rich and rigorous learning environment could be achieved through purposeful attempt of integrating BIM into various course contents.

The BIM incorporation may require that more faculty members be able to use BIM technology. For this reason, faculty members who teach BIM-incorporated courses will need proper training and appropriate version of BIM software should be acquired for educational use. In addition, the faculty members should stay in touch regularly with the industry to create guidelines that reflected the industry practices and reconfigure the course contents or BIM cases. Above all, the CEM program's commitment to the use of BIM technology within the CEM curriculum will be essential to successfully leveraging BIM in CEM education.

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