



Incorporating Building Information Modeling in Existing Courses: A Systematic Framework for Undergraduate Construction Management Programs

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Abstract

As Building Information Modeling (BIM) has been employed more widely in the construction industry for the last several years, industry expectations of BIM knowledge for construction management (CM) students has emerged and kept increasing. As a result, BIM education in CM programs has been given more emphases, and a number of CM programs in the U.S. have incorporated BIM contents in their curriculum through various strategies. While recent studies have suggested that integrating BIM into existing CM courses is the most practical approach, few frameworks could be found that are able to provide a systematic coverage of BIM in a CM curriculum. To bridge the gap, this paper proposes a framework that integrates BIM education in various existing courses of a CM program. The framework consists of ten CM courses that are organized in a structured system covering all four years of the program. The Autodesk software package is employed to introduce the applications of its two main BIM programs Revit and Navisworks Manage, as well as Robot Structural Analysis Professional. BIM contents and software features are introduced systematically on various topics including basic concepts, architectural components, structural analysis, MEP systems, materials, topography, schedule, coordination, and visualization. The framework aligns most individual CM subjects directly to their respective BIM components through the integration and exposes CM students to BIM from their entry to the exit. When students finish the degree, they will have acquired BIM knowledge and skills in all relevant CM subjects and will be ready for different career opportunities that require BIM. The proposed framework will serve as a case study of how CM programs could implement BIM education more effectively and efficiently.

Introduction

The increasing adoption of Building Information Modeling (BIM) in the architecture, construction, and engineering (AEC) industry has led to an emerging emphasis on BIM education in undergraduate construction management (CM) programs. Despite the great interest, many CM programs are struggling with BIM implementation due to various challenges. This paper first briefly introduces the adoption of BIM in the AEC industry, and then provides a comprehensive review on BIM education in CM programs, including its background, current implementation conditions, existing approaches of implementation, and the challenges that prevent some CM programs from fully implementing BIM. Based on existing approaches, this paper proposes a systematic framework to integrate BIM in existing CM courses that can potentially mitigate some of the challenges. The framework layout, included courses, CM subjects, BIM contents, and software features are detailed and some application examples are demonstrated. The proposed framework will serve as a case study of how CM programs could implement BIM education more effectively and efficiently.

BIM in the AEC Industry

BIM has been developing quickly during the past decade and has now become the “gold standard” of the AEC industry⁴⁷. As one of the most promising developments, BIM is also the basis of many other technological advances and thus has gained significant momentum in the industry^{1, 25}. The McGraw-Hill SmartMarket Reports showed that according to the survey results of 582 stakeholders, BIM was adopted by 71% of AEC firms in North America in 2012, a 75% surge over five years^{29, 47}, and 86% of them had been using BIM for more than 3 years by 2013³⁰. In sectors like mechanical, electrical, and plumbing (MEP) coordination, the adoption is projected to be 100% within the next few years¹². The use of BIM is no longer an optional value-added feature but rather a soon-to-be standard in the AEC industry⁴⁷.

Although BIM has become the trending technology, its uses and benefits have not been maximized in the AEC industry largely due to the lack of skilled BIM professionals^{20, 25, 26, 45}. To apply BIM technology effectively and efficiently, an AEC practitioner has to be cross-trained with both construction knowledge and IT skills¹¹, and the lack of adequate training has been identified as a major challenge and bottleneck to move the industry into the BIM era^{21, 29}.

A number of AEC firms have created new positions to transit from the current computer-aided design (CAD) practice to the BIM or Virtual Design and Construction (VDC) process with various titles such as BIM/VDC Coordinator, Integrated Construction Engineer, Virtual Construction Manager, et al.³ Currently, the majority of BIM training is provided internally within the organization²⁵. Recent surveys have indicated that between 57% and 91% of AEC firms had their in-house BIM training programs^{12, 26}. There are external BIM trainings provided by software vendors or third-party training agencies, but these short-term courses and programs are often not able to meet the expectation of AEC practitioners to become proficient in BIM, and they tend to focus more on the technical side of the software instead of the parametric concept of the BIM process²⁵. While the internal and external trainings are necessary, undergraduate CM programs can play an essential role in fostering the industry innovation by offering students extensive opportunities to receive BIM training in their daily CM courses. The same survey reported that 95% of AEC firms identified BIM/VDC education as being important in undergraduate CM education¹².

BIM in CM Education

Background

CM undergraduate education is a holistic subject that focuses on the management of the construction process with the changing technology of the industry^{2, 15}. Traditional CM curricula present construction and management subjects as fixed, independent, and well-structured topics, such as scheduling, estimating, and modeling, resulting in disconnection, fragmentation, and specialization between CM courses^{6, 9, 39, 44}. Unlike architectural and engineering curricula, CM courses must be able to provide multidisciplinary integration and industry-related topics rather than only on engineering science and technology^{5, 6}. CM curricula must also emphasize fundamental concepts related to information technology^{34, 36}. Due to the rapid development of BIM during the last couple decades, the academia has not agreed on what needs to be included in the CM curriculum^{13, 37}.

2D CAD drafting has been traditionally used in CM curricula as a pedagogical tool across various subjects including estimating quantity and cost, developing construction sequence and schedule, and analyzing site layout and safety risks⁴⁸. While 2D drawings are widely used in the AEC industry, the ability to interpret them mostly depends on students' prior experience. Students have to mentally visualize the components of a structure from the lines and symbols in different drawings and combine them into a virtual structure. CM students with little or no previous experience often face challenges and have to spend more time interpreting the drawings²².

BIM can assist CM students to understand the complexity of construction projects in both the process and product^{7, 35}. CM students also have the expectations of being equipped with the emerging technologies used in the AEC industry. BIM is the latest and most essential paradigm that CM students are aware of and are looking forward to learning³². However, BIM, as a buzzword in the industry, often shifts the focus away from its benefits of sharing and simulating information and misleads students to see it as a software program or an acronym for 3D design and modeling^{15, 16}. Only knowing how to use BIM software to model building systems is not a true understanding of BIM. To be effective BIM users, students should be able to extract the information needed efficiently from building models to manage the construction process²⁵.

Current Conditions

To better equip students with the capabilities demanded by the AEC industry, many CM programs have integrated BIM into their curricula²³. Since there is no commonly agreed approach to introduce BIM, the teaching methods varied^{3, 41, 42}. Most CM programs offer BIM in one to three courses and limit its coverage within a single discipline^{4, 42}. However, becoming skilled in BIM cannot be achieved through one or two intensive courses alone. These courses usually focus on the use of BIM software instead of the process, limiting students' perspective on BIM as a productivity enhancing tool^{26, 42}.

Pavelko and Chasey³³ performed a survey of 59 construction programs that are members of the Associated Schools of Construction (ASC) and the American Council for Construction Education (ACCE). The results indicated that 70% of the respondents had BIM covered in their curriculum. Most of them were teaching BIM for 3D coordination (82%), about half for scheduling (4D) (46%), and a third for estimating (5D) (35%)^{16, 33}.

Becerik-Gerber et al.⁵ expanded the pool to members of the Accreditation Board for Engineering and Technology (ABET) and the National Architectural Accrediting Board (NAAB) and received responses from 101 programs, of which 26 were CM programs. The findings showed that 60% of the CM programs had some BIM components in their curriculum, and most of these were included in one or two elective courses^{5, 35}. The topics most taught with BIM were constructability, scheduling, estimating, design, and visualization^{5, 16}. The study also revealed that CM programs were the latest adopters of BIM among various AEC programs but had a steady growth of deployment since 2008^{16, 35}.

Joannides et al.²³ administrated a survey of 70 construction programs that are ACCE members and received 35 responses. The results suggested that 83% of them had included BIM in their

curriculum, and the majority (55%) implemented BIM in one to two courses. Most construction programs were teaching BIM for 3D coordination (37%), 4D scheduling (25%), and 5D estimating (20%).

Existing Approaches

Since BIM is being implemented gradually, many CM programs have been struggling to understand what and how to teach^{4, 42}. The various implementation strategies that CM programs have employed to incorporate BIM into the curricula can be grouped into four categories: standalone courses, cross-discipline courses, capstone/project courses, and integration into existing courses.

Introducing BIM in standalone courses is an effective approach to quickly cover BIM components. Many CM programs introduce BIM in courses such as Digital Graphical Representation, Graphical Communication, and Construction Information Technology^{4, 43}. These courses often replace an existing lower level CAD course because students do not need CAD once they learn BIM, and thus focus on the specific skills of modeling and basic analysis^{23, 26, 41, 42}. Some CM programs introduce BIM by allowing students to take cross-discipline courses from other programs such as civil engineering workshops and architecture studios²⁶. While this approach is efficient at some extent and takes the maximal use of existing resources, these cross-discipline courses often focus towards design and away from CM topics. Implementing BIM in a capstone project allows students to learn the BIM process in various CM subjects throughout the project cycle. However, teaching BIM within a one- or even two- semester capstone project limits the use of BIM in each CM discipline to only a couple of weeks due to time constraint. As a result, students get only a basic understanding of the BIM process and their BIM skills fall short of the expectation to become fluent.

Integrating BIM into existing courses is considered the most practical way to offer BIM²⁵. This strategy typically divides BIM contents into smaller and manageable topics, and thus is able to provide CM students with a rich and rigorous learning environment and consequently better quality of education^{25, 42}. It is also generally accepted that BIM integration should be distributed over all years of the CM curriculum instead of only in the lower level or upper level courses⁴². Sacks and Pikas⁴² summarized from an Internet discussion in 2011 that BIM education should focus on the fundamental knowledge, such as modeling skills, the parametric concept, and constraints in the first two years, followed by the implementation of specific BIM functionalities in different CM subjects, such as estimating, scheduling, visualization, coordination, system analysis, et al. In the last few semesters, BIM should be incorporated into the broader picture of construction projects to create a holistic understanding of the use of BIM process in professional practices⁴².

Challenges

Although there are various strategies to introduce BIM, to have BIM fully implemented in CM curricula, many challenges still exist within the CM programs, the academia, and the AEC industry. Most of the challenges are from the faculty, students, and resources of CM programs:

1. Lack of available faculty to teach BIM^{5, 16, 35}. Due to the high demand of BIM experts in the AEC industry, CM programs may not be able to hire competent new faculty who have been specifically and extensively trained with BIM in their education or industry experience. To many current CM faculty and particularly senior faculty, BIM is a new technology that requires a large amount of time to get familiar and then proficient. It takes even more faculty time to make curriculum changes to incorporate BIM components⁵. For many teaching-focused CM programs, the number of full-time faculty is often small and they usually work full-load with teaching and advising. It is particularly difficult for them to develop and teach additional topics on BIM.
2. Lack of student interest or willingness to learn BIM^{14, 15, 16, 18, 24, 40, 42, 46}. BIM has a very steep learning curve compared to the traditional CAD drafting⁴⁷ and it is also rather challenging for students to self-learn without guidance⁸. Students with previous exposure to CAD may experience difficulties in the transition and students without a clear understanding of building systems and construction methods may encounter a variety of problems in using BIM^{15, 47}.
3. No room for new BIM courses in the curriculum^{14, 16, 35, 42}. The curriculum in most CM programs is already a complete system. When new faculty is unavailable and current faculty is full-loaded, there will be neither the need nor any room to add additional courses on BIM. In addition, almost all students are able to find enough number of CM courses to enroll to meet the degree requirements, which leads to neglecting the necessity of adding new BIM courses to the curriculum⁵.
4. Lack of faculty interest or willingness to teach BIM^{5, 16, 17, 25, 40, 42}. CM faculty may be unwilling to incorporate BIM into the existing curriculum due to the fact that the current course provides sufficient materials and the attempt to change requires much effort and many resources⁴⁰. In addition, the proficient use of BIM takes repetition and practice, which is difficult to achieve in the current lecture-lab settings due to time constraints¹⁷. On some BIM topics, it takes so much time to cover the technical skills that there is very little time remaining for their applications in practice¹⁸.

Other challenges of implementing BIM in CM curricula come from the CM academia and the AEC industry:

5. Lack of textbooks, tutorials, or models to teach BIM^{15, 16, 35, 42, 46} was identified as a main issue when BIM was first introduced into CM programs a decade ago. After over ten years of development, this is no longer a challenge since various textbooks and tutorials have been authored and many AEC firms have shared their projects and models with CM programs interested in introducing BIM to the curriculum.
6. No requirements of BIM in ACCE or ABET accreditation criteria has been identified as another challenge from the CM academia^{5, 16, 35}. Most CM programs are accredited through ACCE or ABET and their curriculum strictly follows the accreditation criteria. Both agencies have not specifically indicated having a BIM course as an accreditation requirement⁵. Currently, most CM programs apply BIM components in the category of computer applications or information technology of the accreditation criteria since BIM topics utilize a variety of computer programs¹⁵. Without formal accreditation requirements, some CM programs just lack the motivation and incentive to incorporate BIM into the curriculum.
7. Although the demand of BIM professionals is high in the AEC industry, unclear and inconsistent expectation of BIM skills on CM graduates has been considered a challenge that prevents some CM programs from introducing BIM to the curriculum⁴².

Proposed Framework of BIM in CM Education

Overview

Although integrating BIM into existing CM courses has been suggested as the most practical approach in recent studies, few frameworks could be found that are able to provide a systematic coverage of BIM in a CM curriculum. To bridge the gap and also mitigate some of the main challenges identified above (lack of faculty resource and student interest), this paper proposes a systematic framework for BIM education in CM programs. The proposed framework utilizes the most accepted strategy, integrating BIM into existing courses, and follows the approach concluded by Sacks and Pikas⁴² that BIM integration should be distributed over all years of the CM curriculum. The framework employs the most commonly used BIM platform, Autodesk software package^{8, 23}, and covers the primary BIM features of its two main software Revit and Navisworks Manage, as well as Robot Structural Analysis Professional. The proposed framework distributes BIM components through ten CM courses including eight core and two elective over all four years of the program, covering a variety CM subjects such as basic BIM concepts, architectural components, structural analysis, MEP systems, topography, materials, estimating, scheduling, coordination, and visualization. As a result, individual CM faculty gradually introduces BIM to the curriculum only in their specialized areas, which significantly reduces the workload needed to develop new BIM courses. CM students will be exposed to BIM progressively from their entry to the exit, allowing a gradual increase of interest and reception of BIM, and will have acquired adequate BIM knowledge and skills on all relevant CM topics by the time they complete the degree and are ready for the upcoming career.

Layout

The proposed framework integrates BIM contents through ten CM courses over all four years of the program, and a detailed course layout is presented in Table 1 as well as the integrated BIM topics. The framework starts with one freshman-level course Construction Graphics, followed by Construction Surveying and Cost Estimating in the sophomore year. During the first two years, students usually have to enroll in a minimum number of credits in general education to meet the system requirements, and it is also the perfect time to raise their interests in CM and BIM. Therefore, three entry-level CM core courses with easy-to-handle and moderate amount of BIM contents are adequate to begin with. Starting at junior year, specific CM subjects are being introduced with relevant BIM topics incorporated into Building Construction Methods and Systems and Construction Structures. These two core courses include the topics on essential components of a physical building. In addition, Residential Construction as an elective course focuses on the residential type of structure. Senior year core courses cover more detailed subjects on Mechanical, Electrical and Plumbing Systems and Construction Planning and Scheduling. Student Competitions is being offered in some CM programs as an elective course to prepare students for the ASC Student Construction Management Competition and the National Association of Home Builders (NAHB) Student Chapters Residential Construction Management Competition (RCMC). Project Management /Capstone Experience serves as the concluding course of the framework and also the curriculum to provide CM students the experience of managing a comprehensive construction project on all subjects in a team environment.

Table 1. Four-Year Course Layout and BIM Topics

Year	Course	BIM Topics and Software Tools
Freshman	CM 12x	Introduction to BIM, basic modeling skills
	Construction Graphics	Revit Fundamentals
		Core course
Sophomore	CM 21x	Profile leveling, topographic surveying
	Construction Surveying	Revit Toposurface
		Core course
	CM 23x	Material quantity takeoff
	Cost Estimating	Revit Materials and Schedule
	Core course	
Junior	CM 33x	Architectural and structural components
	Building Construction Methods and Systems	Revit Architecture, Revit Structure
		Core course
	CM 35x	Structural analysis
	Construction Structures	Robot Structural Analysis Professional
		Core course
	CM 45x	Architectural and structural components
	Residential Construction	Revit Architecture, Revit Structure
		Elective course
Senior	CM 33x	Mechanical, electrical, and plumbing systems
	Mechanical, Electrical and Plumbing Systems	Revit Systems
		Core course
	CM 42x	Advanced modeling skills, visualization
	Student Competitions	Revit Architecture, Navisworks Viewpoint Animation
		Elective course
	CM 44x	4D scheduling, visualization
	Construction Planning and Scheduling	Navisworks Timeliner Simulation
	Core course	
	CM 48x	Construction coordination
	Project Management	Navisworks Clash Detective, Navisworks Animator
	/Capstone Experience	Core course

Figure 1 displays the BIM software tools to be used in framework over all four years in a systematic and structured approach. Freshman-level students will focus mostly on the fundamentals of BIM and basic modeling skills. In sophomore courses, materials, schedule, and topography features in Revit will be introduced to assist Cost Estimating and Construction Surveying. The major features of Revit Architecture and Structure will be applied in junior-level Building Construction Methods and Systems and Construction Structures to help student obtain a comprehensive understanding of the building components. In addition, Robot Structural Analysis Professional will be employed to facilitate load distribution and structural analysis. Senior-level courses will integrate advanced and more complicated BIM topics with the use of Revit Systems (used to be Revit MEP) and Navisworks Manage. Timeliner, Animation, and Clash Detective will be utilized for 4D scheduling, visualization, and construction coordination in various upper-level courses.



Figure 1. BIM Software Tools Introduced in the Four-Year Framework

Courses

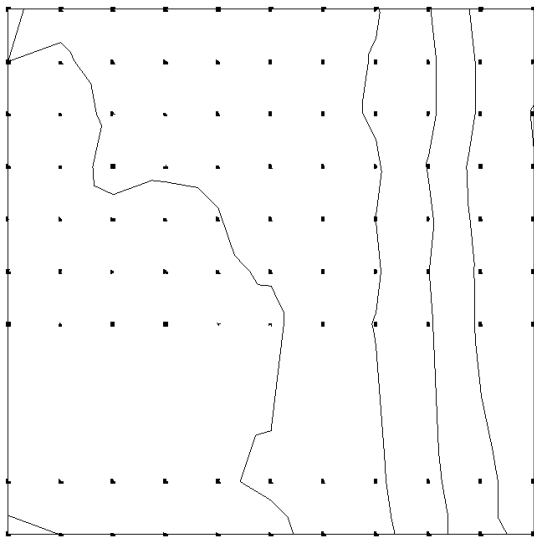
Freshman Year

CM 12x Construction Graphics. Construction Graphics is usually an existing core course with various names such as Graphical Communication or Construction Information Technology. Many CM programs used to have it as the introductory course to CAD and are restructuring it into a BIM introductory course. Using BIM in a CM preparation course affords students a better understanding of construction tasks and enhances their spatial perception^{18, 27}. The restructured course will focus on BIM fundamental knowledge as well as basic modeling skills using Revit general modeling features.

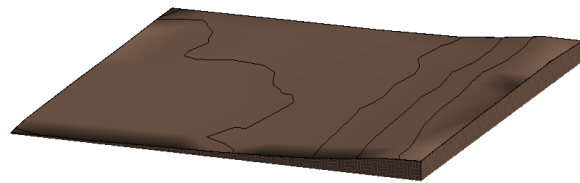
Sophomore Year

CM 21x Construction Surveying. Construction Surveying is a core course in most CM programs, but not a typical course to include BIM contents since most surveying topics are not directly related to the structure itself. A few specific surveying methods, however, can be used to develop a model for the existing site environment before construction begins, such as profile leveling and topographic surveying. Profile leveling is a repeated leveling process to obtain grid-pattern elevation data within an area, usually the construction site. Elevation data can be easily reformatted and imported into Revit to create a model of the existing site topography. Figure 2 shows the grid-pattern elevation data obtained by students in the course. Contour lines can be generated from the elevations by Revit Toposurface feature and a site model can be created to

reflect the site topography. Topographic surveying uses a total station to record the position and elevation of other site features besides the contour lines. The position and elevation data can be imported into Revit first, and then the site features can be modeled individually. A more convenient method for topographic surveying is to use a laser scanner. The laser scanner will record the spatial information of point clouds of all objects around it along with their color. After deleting unneeded object point clouds, the model will be able to show a more realistic existing site environment.



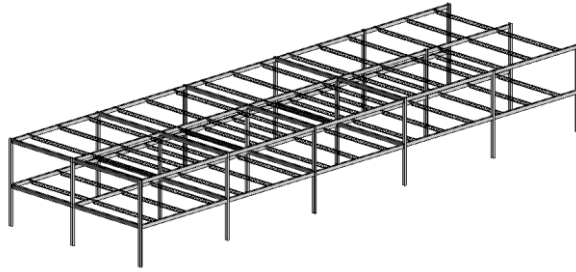
Grid-Pattern Elevation Data



Site Topography Model

Figure 2. A Site Topography Model Created from Profile Leveling

CM 23x Cost Estimating. Cost Estimating is one of the core courses that have the most potential to implement BIM and will also benefit greatly. Traditional estimating courses use CAD drawings for quantity takeoff, either with hard copy plans or computer programs such as Onscreen Takeoff. A main problem of using CAD drawing for takeoff is that since each individual sheet (plans, elevations, and sections) was produced independently, the possibility of information inconsistency between each other is high²². With BIM integration, model-based estimating is able to eliminate these errors because a building component is the same object in any view or sheet. Moreover, with the Revit Schedule feature, the quantity and dimensions of most building components can be obtained automatically with no calculation errors, as seen in Figure 3, thus the time-consuming quantity calculation process is largely reduced. In addition, by linking the quantities of building components to a cost database program such as Sage Timberline and RSMeans CostWorks, the pricing process can be handled more efficiently than the traditional process of looking for pricing information repeatedly in a cost manual^{25, 35}.



<Structural Framing Schedule>			
A	B	C	D
Family	Type	Length	Count
K-Series Bar Joist-Angle Web	12K1	23' - 0"	29
K-Series Bar Joist-Angle Web	12K1	25' - 0"	30
W-Wide Flange	W12X26	48' - 0"	8
W-Wide Flange	W12X26	63' - 6"	8
W-Wide Flange	W12X26	72' - 0"	2
W-Wide Flange	W12X26	97' - 0"	2
W-Wide Flange	W12X26	120' - 0"	4
W-Wide Flange	W12X26	160' - 6"	4

<Structural Column Schedule>			
A	B	C	D
Family	Type	Length	Count
W-Wide Flange-Column	W10X33	24' - 0"	27

Figure 3. Quantity Takeoff of a Steel Structural Frame Generated By Revit Schedule

Junior Year

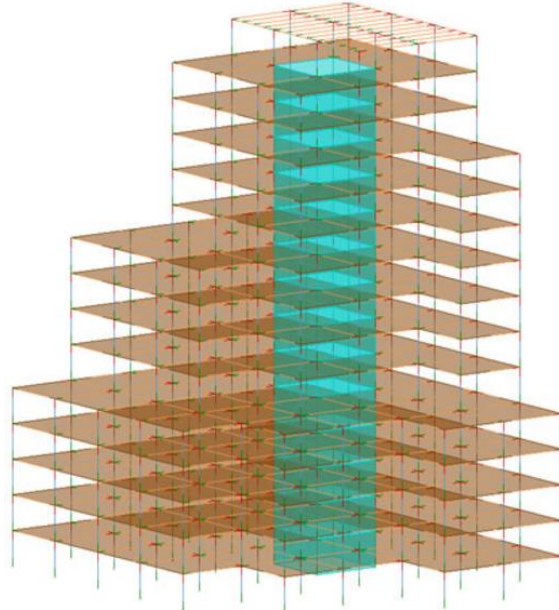
CM 33x Building Construction Methods and Systems. This core course is often combined with materials and offered as Construction Methods and Materials. Since construction methods are practical topics, the traditional approach requires extensive field experiences from the instructor, and students learn particular methods from the instructor's past projects. While it may sound interesting to listen to a real-life story, it does not enhance student comprehension of how to apply the methods in other projects^{10, 44}. Using BIM models allows to demonstrate different architectural and structural components of the building and helps students visually see how they are connected to form a system, and further understand what methods are needed to complete the system³⁵. For example, students are able to see through concrete and find out how reinforcement is placed, or cut a wall and see the inside materials and structures. One shortcoming of using Revit to demonstrate the structural systems is that for some components, it does not depict the actual construction process, such as walls, floors, roofs, and concrete members^{19, 22}. Walls are modeled in Revit by structuring all the elements first including stud framing, sheathing, insulation, gypsum board, and siding or brick veneer, and then placing the single entity to the building model. Floors and roofs are modeled in similar process. Concrete components do not need formwork when modeling, and reinforcement is added after the concrete is finished.

CM 35x Construction Structures. Construction Structures is usually considered one of the most difficult core courses in CM programs since it involves a large amount of structural analysis calculations. The traditional approach to teach structural design is to focus on a linear sequence of topics such as statics, strength of materials, concrete, masonry, steel, and wood design by calculating loads, tributary area, reactions, moments, shears, et al.^{32, 38} While mathematical computations do help students understand the design criteria of structural components, it does not emphasize the importance of overall concepts and the behaviors of structural systems. The use of BIM introduces a highly efficient and collaborative method to teach structural design and analysis. The BIM platform allows students to divide the structural system into separate portions and analyze the behaviors of individual structural components³². Revit structural analytical model is a built-in feature that provides a simplified 3D presentation of the structural elements, as demonstrated in Figure 4. With the help of Structural Analysis Toolkit for Revit add-on, students are able to perform basic static analysis and gravity analysis through the Autodesk cloud. Robot Structural Analysis Professional offers more advanced features of structural design

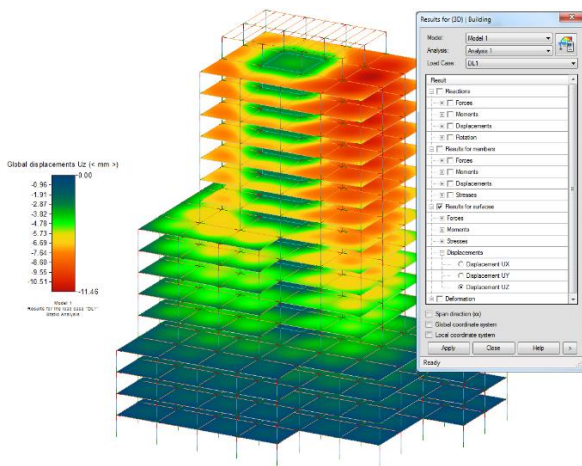
and analysis, such as steel, concrete, and timber design, structural load analyses and combinations, composite beam design, wind load simulation et al., which tremendously facilitates the teaching and learning experiences and reduces the amount of manual calculations.



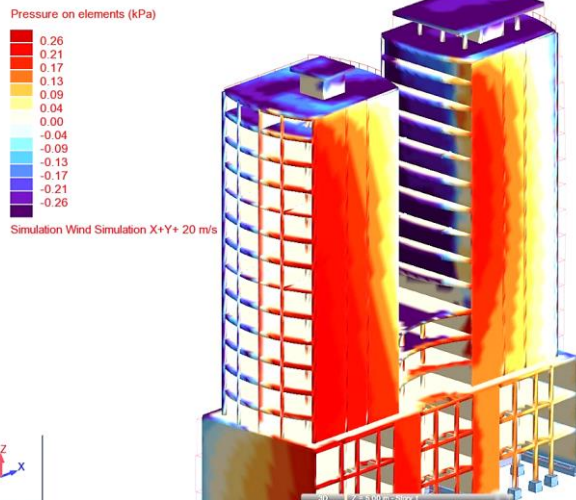
Physical Structural Model



Revit Structural Analytical Model



Static Analysis by Structural Analysis Toolkit for Revit



Wind Load Simulation by Robot Structural Analysis Professional

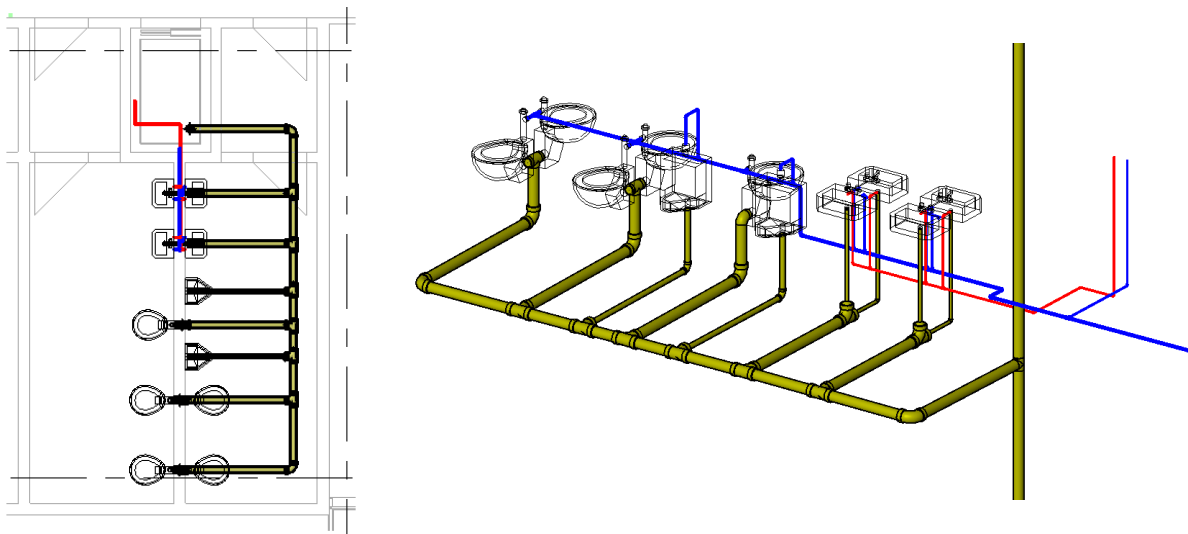
Figure 4. Application of the BIM Platform in Structural Analysis (pictures obtained from autodesk.com for demonstration)

CM 45x Residential Construction. Residential construction as an elective course focuses on the design and construction of residential buildings. As a specific construction market in the U.S., residential buildings are typically constructed with shallow foundation and timber framing. Although all residential buildings serve the same purpose, the construction process varies a lot depending on the design, aesthetics, and the structure type whether it is a single family house, an apartment building, or a nursing home. BIM can be effectively incorporated into the course to

assist the architectural and structural design of different types of residential buildings and demonstrate the various construction methods.

Senior Year

CM 33x Mechanical, Electrical and Plumbing Systems. The MEP course usually serves only as an introductory course to the mechanical, electrical, plumbing, and fire protection systems for CM students because more advanced topics are covered in mechanical engineering and electrical engineering programs. The traditional teaching approach is to use CAD drawings to explain the design and layout of the ducts, pipes, and conduits, and the challenge is that it is sometimes difficult to perceive the spatial location of the systems. When BIM is employed, the 3D presentation of the systems will be able to provide students with obstruction-free views to help them understand the system design. Figure 5 demonstrates the comparison of a restroom plumbing plan shown in a CAD plan versus in a 3D view, both created with Revit Systems (used to be Revit MEP). In addition, with the help of BIM, CM students will have a better understanding of the system concept since the MEP components are grouped by their systems and the information of all the ducts, pipes, and conduits are linked to their respective MEP equipment such as an air handling unit, boiler, or switchboard.



A Plumbing Plan in 2D CAD

The Same Plumbing Plan in 3D BIM

Figure 5. Comparison of a Restroom Plumbing Plan in CAD and in BIM

CM 42x Student Competitions. Some CM programs offer Construction Student Competitions as an elective course to prepare students for the region ASC student competition and the national NAHB student competition. The ASC competition requires student teams to submit a comprehensive management plan for a project within 18 hours. There are usually four to five divisions, including commercial, residential, design-build, heavy highway, and specialty, and the management plan will cover all CM topics starting from the pre-construction stage. The NAHB competition focuses on residential buildings and provides student teams two to three months to prepare and present a development plan for a residential neighborhood. The use of BIM has become an increasing trend and sometimes a requirement in the competitions. Since students will concentrate on a particular project, it makes this course a great opportunity to introduce

advanced modeling skills as well as different visualization methods such as image rendering and walkthrough animations.

CM 44x Construction Planning and Scheduling. Construction Planning and Scheduling is a core course that requires CM students to develop a logical sequence of construction. CAD drawings have been traditionally used to develop network models to present activity relationships and create bar charts to depict the construction sequence²². The challenge is that it requires a lot of experience and practice to obtain a full understanding of the structure from a complete set of CAD drawings, and students with weak background will have difficulties interpreting the drawings and visualizing the structure^{22, 31}. With the help of BIM, students can see the virtual building and are even able to take it apart to see all the components inside, which significantly assists them to understand the physical constraints and how all the elements are connected to each other, and eventually develop a logical construction sequence. In addition, once the network model or bar chart has been created, the construction schedule can then be integrated with the BIM model to generate a 4D schedule²⁵. A construction schedule from Microsoft Project or Primavera P6 can be easily imported into Naviswork Manage, and each activity can be linked to its respective building components in the BIM model. Using the Timeliner Simulation feature, the BIM model will be virtually constructed according to the construction sequence from the imported schedule, as illustrated in Figure 6. Students will then be able to visually inspect if the animated construction sequence includes all building components and meets all physical constraints.

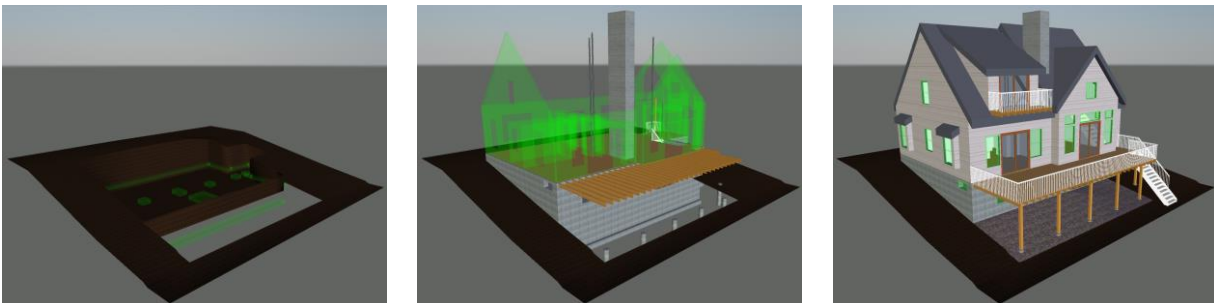
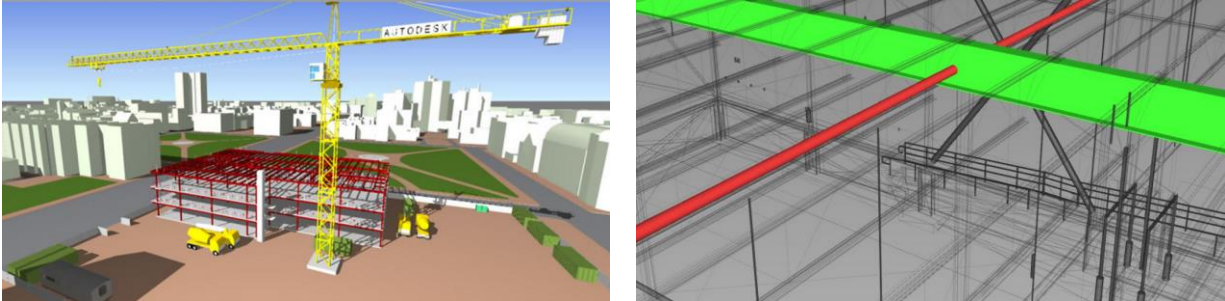


Figure 6. 4D Construction Scheduling with Navisworks Timeliner

CM 48x Project Management/Capstone Experience. Most CM programs offer Project Management as the concluding course if Capstone Experience is not available. Both courses are similar in the contents except that Capstone Experience typically uses a real-world project and focuses the CM topics on the specific scenario. The course always uses a student team setting to allow interdisciplinary collaboration, and all aspects of project management and administration are integrated for problem solving and decision making to successfully deliver a project³⁵. The existing approach makes the course a perfect one to combine and review all the BIM topics covered in other courses and also to introduce BIM applications for construction coordination^{25, 35}. Site logistics and subcontractor coordination are the two subjects that BIM is most commonly used in construction coordination. Navisworks Animator can be used to depict how the construction site is laid out and how all construction equipment are going to move, as illustrated in Figure 7. Navisworks Animator differs from Navisworks Viewpoint Animation in that Viewpoint Animation creates walkthrough animation with still objects while Animator makes objects move, typically construction equipment such as cranes and trucks. Navisworks Clash

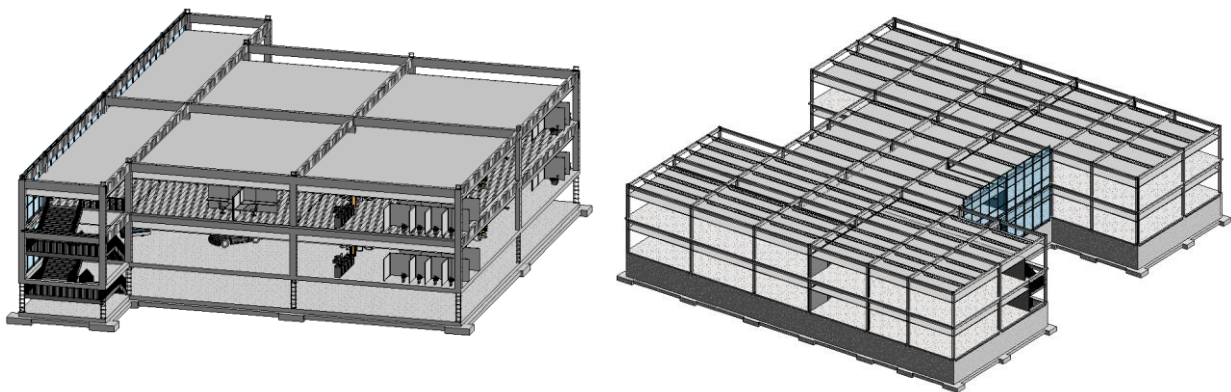
Detective is used extensively in the industry to perform conflict checks, particularly between the BIM models from different subcontractors. Figure 7 shows a clash detected between a steel member and a plumbing pipe. At the completion of this course, students will be able to apply BIM knowledge in all relevant CM subjects and thus be ready for their upcoming career.



Site Logistics Created by Navisworks Animator Clash Detected between Steel and Plumbing
Figure 7. BIM Applications in Construction Coordination (pictures obtained from autodesk.com for demonstration)

Assessment

The proposed framework has only been partially implemented in the author’s CM program, and as a result an assessment of the complete framework is not yet applicable. Student evaluation is available in five courses that have implemented BIM components based on the framework, and the results from CM 33x Building Construction Methods and Systems are briefly discussed as an example. The course was offered by the same instructor using the same materials during two consecutive semesters. Instruction was entirely based on the textbook in the first semester and was incorporated with BIM contents in the second semester. A BIM model was first used to explain how different building components are connected, and the students were then asked to develop a structural model of either reinforced concrete or steel with Revit, as demonstrated in Figure 8. The survey results showed that by implementing BIM, student progress on learning objectives of this course increased from 3.5/5.0 to 4.1/5.0. Students also commented on the implementation of BIM that using BIM in the course was “helpful and beneficial” and “gave us a real life look at it.”



Reinforced Concrete Structural Model

Steel Structural Model

Figure 8. BIM Structural Models Developed by CM Students

Once the proposed framework is fully implemented, future research will be developed to focus on a comprehensive assessment plan of the framework. Student evaluation ratings in each individual course before and after BIM implementation will be first analyzed and compared to reflect the effectiveness of incorporating BIM contents in the individual courses. Questionnaires on student experience of BIM components in the curriculum will then be distributed in the capstone course to assess the effectiveness of the complete framework. The evaluation ratings and questionnaire comments will be used later to develop amendment strategies to further improve the effectiveness of the framework.

Conclusions

As BIM has become the “gold standard” of the AEC industry, it is of significant importance that CM programs train future construction professionals in the capabilities and advantages of BIM technology^{38, 47}. Although a number of recent studies have suggested that integrating BIM into existing CM courses is the most practical approach, few frameworks could be found that are able to provide a systematic coverage of BIM in a CM curriculum, and many challenges still exist during the implementation. To bridge the gap and also mitigate some of the main challenges, this paper proposes a systematic framework for BIM education in CM programs. The framework integrates BIM content into ten CM courses in all four years of the program, covering most CM subjects, relevant BIM topics, and software features. When students finish the degree, they will be well-equipped with BIM knowledge and skills and will be ready for various career opportunities that requires BIM. The proposed framework will serve as a case study of how CM programs could implement BIM education more effectively and efficiently.

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