Developing a Modular Advanced BIM Course in Construction Management

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Abstract

Due to the rapid adoption of Building Information Modeling (BIM) in the architecture, engineering and construction (AEC) industry, many construction management (CM) programs in the US have introduced BIM in their curriculum. Previous research has revealed that most of the BIM courses offered in CM programs have mainly focused on modeling skills as well as BIM applications in scheduling and estimating. While these topics appear to be important to apply BIM technology, students will not be able to fully understand the BIM process in a construction project without knowing the fundamental workflow of BIM. This paper presents a modular BIM course which was developed to help CM students better understand the BIM workflow and focuses on advanced uses of BIM in construction projects. The course contains three modules: BIM workflow, basic BIM applications, and advanced BIM applications. The BIM workflow module discusses how BIM is addressed in project delivery method, contract, the execution plan, and team building. The basic BIM applications module explains the typical BIM applications in coordination, scheduling, estimating, logistics, visualization, etc. The advanced BIM applications module demonstrates the latest technology advances in the AEC industry that utilizes BIM applications, including laser scanning, virtual reality, and mixed reality. The course objectives and assessment methods ensure that CM students' understanding of BIM will be considerably improved from as a modeling tools or software program to an efficient process, and their insights into BIM will be significantly broadened beyond the existing 3D, 4D, and 5D applications. The highly positive course evaluation demonstrates the effectiveness of these approaches in meeting course objectives, delivering course materials, as well as raising students' interest. This paper will serve as a case study of an advanced level BIM course in CM programs.

Keywords

Building Information Modeling, Construction Management, Education

1. Introduction

The rapid adoption of Building Information Modeling (BIM) in the architecture, construction, and engineering (AEC) industry that has led to an increasing integration of BIM into construction management (CM) programs in the US Offering new BIM courses is one popular approach that many CM programs have employed to incorporate BIM contents into their curriculum. While introducing BIM in new courses is an effective method to quickly cover BIM components, the new courses often focus on specific modeling skills and analysis tools of BIM applications, such 4D scheduling and 5D estimating. Recent research, however, has argued that only knowing how to use BIM applications is not a true understanding of BIM and is in fact far from the expectations of being effective BIM users. It was also believed that without knowing the fundamental workflow of BIM, CM students will not be able to fully understand and utilize BIM to manage the construction process.

This paper presents a newly-developed BIM course that aims to help CM students better understand the BIM workflow in a construction project and utilize BIM to manage the construction process. The course introduces advanced uses of BIM in construction projects and thus requires some BIM exposure in previous CM courses. The course is divided into three modules: BIM workflow, basic BIM applications, and advanced BIM applications. Each of the three modules was distinctly separated but closely connected to complete the course. The BIM workflow module discusses how BIM is addressed in project delivery method, contract, the execution plan, and team building. The basic BIM applications module explains the typical BIM applications in 3D coordination, 4D scheduling, 5D estimating, logistics, visualization, etc. The advanced BIM applications module demonstrates the latest technology advances in the AEC industry that utilizes BIM applications, including laser scanning, virtual reality, and mixed reality. This course will considerably improve CM students' understanding of BIM as a process instead of a modeling tool or software program and significantly broaden their insights into BIM beyond the existing 3D, 4D, and 5D applications. This paper will serve as a case study of an advanced level BIM course in CM programs.

2. BIM in CM Education

2.1. From CAD to BIM

Due to the standard use of paper drawings in the AEC industry, 2D computer-aided design (CAD) drafting has been traditionally used in CM education to facilitate the curriculum across various subjects including estimating quantity and cost, developing construction sequence and schedule, and analyzing site layout and safety risks [1]. While being widely used as a pedagogical tool, it often requires some degree of students' prior experience to interpret 2D CAD drawings since students must perceptually visualize the components of a structure from lines and symbols in a drawing set and mentally combine them into a vir-

tual structure. CM students with little or no previous experience often face challenges and must spend more time interpreting 2D CAD drawings [2].

Using BIM as a pedagogical tool in CM education can assist students in understanding the complexity of construction projects in both the process and product [3] [4]. In addition, many CM students are aware of BIM as the emerging technology used in the industry and have the expectations of learning the latest and most essential paradigm in a CM program [5]. As a buzzword in the AEC industry, however, BIM sometimes misleads CM students to see it as a software program or an acronym for 3D design and modeling. The benefits of BIM in sharing and simulating construction information have often been overlooked in a CM curriculum [6] [7]. Recent research has pointed out that only knowing how to use BIM applications is not a true understanding of BIM and is in fact far from the expectations of being effective BIM users. Without knowing the fundamental workflow of BIM, CM students will not be able to fully understand and utilize BIM to manage the construction process [8].

2.2. BIM Adoption

To better equip students with the capabilities demanded by the AEC industry, many CM programs have incorporated BIM contents into their curriculum [9]. Various teaching methods and course layout have been used in different CM programs to introduce BIM [10] [11] [12]. In general, most CM programs offer BIM in one to three courses and limit its coverage within a single discipline [12] [13]. The implementation strategies include introducing BIM as standalone courses, utilizing cross-discipline BIM courses, adding BIM labs in capstone/project courses, and integrating BIM into existing courses [14].

Pavelko and Chasey performed a survey of 59 construction programs that were 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 covered BIM in their curriculum, of which most were on 3D coordination (82%), about half on 4D scheduling (46%), and a third on 5D estimating (35%) [7] [15]. Becerik-Gerber *et al.* expanded the pool to 26 CM programs that were members of the Accreditation Board for Engineering and Technology (ABET). The findings showed that 60% of them had some BIM components in their curriculum, mostly in one or two elective courses [4] [16], and the most-taught topics were constructability, scheduling, estimating, design, and visualization [7] [16]. Joannides *et al.* surveyed 70 construction programs that were ACCE members and received 35 responses. The results suggested that 83% of them had included BIM in their curriculum with the majority (55%) in one to two courses [9]. The most popular topics were still 3D coordination (37%), 4D scheduling (25%), and 5D estimating (20%) [9].

2.3. BIM Courses

Offering new BIM courses is one popular approach that many CM programs

have employed to incorporate BIM contents into their curriculum. One typical solution is to have an introductory BIM course replace an existing lower level CAD course, such as Construction Graphical Communication or Construction Information Technology [13] [17]. This is viable because students no longer need CAD drafting once they use BIM since 2D drawings can be generated directly from a 3D BIM model. Due to the course conversion, these introductory BIM courses focus mainly on specific modeling skills [9] [18]. The other solution is to offer a new junior- or senior-level elective BIM course as an addition to the CM curriculum. These elective BIM courses often focus on analysis tools of BIM applications, such 3D coordination, 4D scheduling, and 5D estimating, and use model-based project to demonstrate the use of BIM in various CM subjects [11] [12].

The CM program at Arizona State University offered Introduction to BIM as a 1-credit computer application course to teach the concept of BIM process and applications of BIM software [6]. The program further offered a 1-credit BIM lab to accompany the CM capstone course Project Management. The BIM lab covered a range of BIM-related CM topics including site logistics visualization, model-based estimating, 4D scheduling, and clash detection using a variety of commercial packages such as Revit, Navisworks, SketchUp, Bluebeam Revu, and DESTINI Profiler. The capstone course itself also incorporated BIM contents on developing a BIM Execution Plan [7].

The CM program at University of Texas at San Antonio offered BIM for Construction Management as a 3-credit elective course for junior and senior students who had completed CM core courses. As the only BIM course in the curriculum, it covered a wide variety of BIM topics including design and visualization, model-based quantity take-off and estimating, and 4D scheduling, clash detection, and constructability. The course contained lecture sessions to introduce BIM concepts, execution plans, implementation, case studies, and software demonstration, and included lab sessions to provide hands-on practice on Revit (Architecture, Structure, MEP), Navisworks, as well as SketchUp and Primavera P6. The course focused on basic modeling skills, understanding of database, as well as trade coordination with different platforms [19].

Some CM programs chose to offer a BIM module or workshops within an existing CM course instead of offering a complete new course as an alternative approach. The CM program at Colorado State University developed a BIM module within a structures course to present the capabilities of BIM software and other analysis programs, including 3D interactive animations, material schedules and quantity takeoff, material and labor cost estimates, and construction sequence [20]. The CM program at California State University, Chico included seven one-hour BIM workshops in the Construction Methods Analysis course and had industry representatives teach various BIM tools, *i.e.*, SketchUp, Revit, Navisworks, and Solibri, on related CM topics including site layout, model analysis, structural steel sequencing, clash detection, and constructability [21].

The CM program at University of North Carolina at Charlotte proposed a workflow for a BIM course in a CM curriculum. The workflow suggested that the course should be a senior-level course for students who had completed CM core courses such as estimating, scheduling, and project management. The proposed workflow contained five BIM components, namely 3D modeling, cost estimating, scheduling and control, project administration, and contract documents, and covered the two major BIM packages, Autodesk Revit (Architecture, Structure, MEP) and Navisworks, and Vico Virtual Construction Software Suite (Constructor, Estimator, Cost Manager, 5D Presenter) [22].

In general, while introducing BIM in new courses is an effective method to quickly cover BIM components, these new courses often focus on specific modeling skills and analysis tools of BIM applications, such 4D scheduling and 5D estimating. To effectively utilize BIM tools to manage the construction process, fully understanding the BIM workflow in a construction project is of equal importance to CM students [8]. Some existing BIM courses ignored the BIM workflow and as a result, CM students had seen BIM simply as 3D design and modeling or just as a software program without recognizing its benefits in sharing and simulating construction information [6] [7].

2.4. BIM Challenges

Although there are various strategies to introduce BIM, to have BIM fully implemented in CM curriculum, 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 [4] [7] [16]. 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 components [16]. 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 [4] [6] [7] [23] [24] [25] [26] [27]. BIM has a very steep learning curve compared to the traditional CAD drafting and it is also rather challenging for students to self-learn without guidance [22]. 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 [6].

3) No room for new BIM courses in the curriculum [4] [6] [7] [12]. 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 can find enough number of CM courses to enroll in order to meet the degree requirements, which leads to neglecting the necessity of adding new BIM courses to the curriculum [16].

4) Lack of faculty interest or willingness to teach BIM [7] [8] [12] [16] [21] [25]. CM faculty may be unwilling to incorporate BIM into the existing curriculum since the current course provides sufficient materials and the attempt to change requires much effort and many resources [25]. 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 constraints [21]. 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 practice [26].

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

5) No requirements of BIM in ACCE or ABET accreditation criteria has been identified as another challenge from the CM academia [4] [7] [16]. 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 requirement [16]. 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 programs [6]. Without formal accreditation requirements, some CM programs just lack the motivation and incentive to incorporate BIM into the curriculum.

6) 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 curriculum [12].

In addition, lack of textbooks, tutorials, or models to teach BIM [4] [6] [7] [12] [23] was also 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.

## 3. The Advanced BIM Course

3.1. Overview

Based on the review of the contents and limitations of existing BIM courses offered by other CM programs discussed above, the instructor's CM program developed a new BIM course that aims to help CM students better understand the BIM workflow in a construction project and utilize BIM to manage the construction process. The CM curriculum has already integrated BIM contents in

several core and elective courses from lower level to upper level, including Construction Graphics, Building Methods and Systems, Residential Construction, and Construction Planning and Scheduling, and thus most CM students have basic exposure to and understanding of BIM. The curriculum, however, does not have a course that introduces the BIM workflow in a construction project or applies BIM in project-based case studies. As a result, the CM program decided to offer a new advanced BIM course to emphasize the BIM workflow, refresh on basic BIM applications in project-based scenarios, and introduce advanced uses of BIM that are trending in the AEC industry. Designed as an upper level elective course, it requires CM students to have completed certain lower level courses with the integration of BIM to obtain a basic understanding of the concept, modeling skills, and some fundamental applications.

The course is divided into three modules: BIM workflow, basic BIM applications, and advanced BIM applications. The BIM workflow module discusses how BIM is addressed in project delivery method, contract, the execution plan, and team building. The basic BIM applications module explains the typical BIM applications in 3D coordination, 4D scheduling, 5D estimating, logistics, visualization, etc. The advanced BIM applications module demonstrates the latest technology advances in the AEC industry that utilize BIM applications, including laser scanning, virtual reality, and mixed reality. This course will considerably improve CM students' understanding of BIM as a process instead of a modeling tool or software program and significantly broaden their insights into BIM beyond the existing 3D, 4D, and 5D applications.

3.2. Course Objectives

The course objectives were developed to match the CM curriculum needs in BIM contents and in the meanwhile align with the six levels of cognitive learning process in Bloom's Taxonomy, as illustrated in Figure 1. Anderson *et al.* revised the original taxonomy and defined the cognitive learning process as "remember, understand, apply, analyze, evaluate, and create" from lower- to higher-order thinking skills [28]. As shown in Table 1, five course objectives were developed
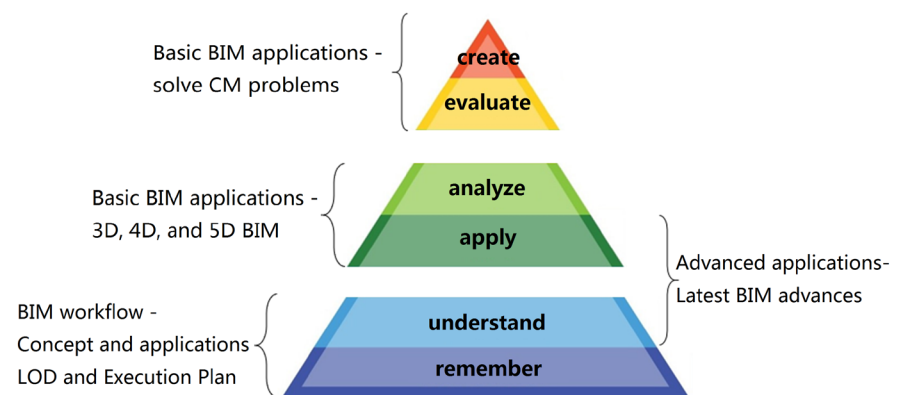
Figure 1. Alignment of course modules and objectives with Bloom's taxonomy.

Table 1. Course objectives associated with Bloom's taxonomy.

	Course Objective	Course Module	Bloom's Taxonomy
1.	Understand the concept of BIM and its applications in construction management	BIM workflow	Remember and understand
2.	Describe different Levels of Development (LOD) and components of BIM Execution Plan	BIM workflow	Remember and understand
3.	Perform model-based planning, estimating, scheduling, coordination, and visualization	Basic BIM applications	Apply and analyze
4.	Apply BIM in project-based scenarios to solve CM problems	Basic BIM applications	Evaluate and create
5.	Demonstrate the latest BIM advances in the AEC industry	Advanced BIM applications	Understand and apply

for the three course modules. The BIM workflow module aims for Objective 1 "Understand BIM" and Objective 2 "Describe Levels of Development (LOD) and BIM Execution Plan", both of which belong to lower-level cognitive learning process "remember" and "understand". The basic BIM applications module aims for Objective 3 "Perform BIM applications", which covers mid-level cognitive learning process "apply" and "analyze", and Objective 4 "Apply BIM in project" which contains higher-level cognitive learning process "evaluate" and "create". The advanced BIM applications module aims for Objective 5 "Demonstrate BIM advances", covering lower- to mid-level cognitive learning process "understand" and "apply".

3.3. Course Layout

Table 2 presents the course topics associated with their respective objective in each course module. The course topics were scheduled based on a standard 15-week semester with 2 weeks reserved for exams, presentations, and holidays, which leaves 13 full weeks of classroom instruction. The course topics include a combination of lectures, computer labs, demonstrations, and hands-on equipment operation.

3.3.1. BIM Workflow Module

The BIM workflow module takes the first four weeks of the course covering the most important topics pertaining to how to start a construction project with BIM included as a management tool, as detailed in **Table 2**. These topics have often been overlooked when BIM is introduced in a CM curriculum but are actually a critical component of knowledge for students to understand the role of BIM in a construction project. The module starts with an introduction of the value of BIM, followed by selecting the appropriate project delivery method and contract for BIM. Design-build and CM at risk as well as the new Integrated Project Delivery method have been considered to have the capability of leveraging BIM tools and practices [29]. Professional organizations such as American

Table 2. Course topics in each course module.

Course Module	Course Objective	Course Topics	Course Schedule
BIM Workflow	1. Understand BIM	The Value of BIM	Week 1
		Delivery Methods for BIM	Week 2
		Contract Types/BIM Contract	Week 2
	2. Describe LOD and BIM Execution Plan	Levels of Development (LOD)	Week 3
		BIM Execution Plan	Week 3
		BIM Team and BIM Kickoff Meeting	Week 4
Basic BIM Applications	3. Perform BIM Applications	Model-Based Estimating	Week 5
		Site Logistics	Week 6
		BIM Scheduling	Week 7
		Construction Coordination	Week 8
		Document Control	Week 9
	4. Apply BIM in Project	Revit Lab: Model-Based Estimating	Week 5
		Navisworks Lab: Site Logistics Plan	Week 6
		Navisworks Lab: 4D Scheduling	Week 7
		Navisworks Lab: Clash Detection	Week 8
		Bluebeam Revu Lab: Doc Control	Week 9
Advanced BIM Applications	5. Demonstrate BIM Advances	ReCap Lab: Laser Scanning	Week 10
		Stingray Lab: Real-Time Walkthrough	Week 11
		VR Experience with Rift/Vive	Week 12
		MR Experience with HoloLens	Week 13

Institute of Architects (AIA), Associated General Contractors of America (AGC), and Design-Build Institute of America (DBIA) have specific BIM contracts available for commercial use (AIA E203, ConsensusDocs 301, and DBIA E-BIMWD) [29]. The module further explains in detail the Levels of Development (LOD) and the components of a BIM Execution Plan, followed by different roles in a BIM team and what to expect in the BIM kickoff meeting. Overall, the BIM workflow module forms the foundation of the course and is critical for CM students to fully understand the BIM process in a construction project.

3.3.2. Basic BIM Applications Module

As introduced earlier, the CM curriculum has already integrated BIM contents in several courses, and thus most CM students have had exposure to basic BIM tools. As a result, the basic BIM application module focuses on refreshing on these basic applications by applying them in project-based scenarios. The basic BIM applications module follows the BIM workflow module and takes the next five weeks out of the 13-week course schedule, as presented in Table 2. The module covers the most used BIM applications including model-based estimat-

ing and scheduling, site logistics, construction coordination, document control, etc. The module features a one-hour lecture session plus a two-hour lab session in a week for each topic. The lecture session aims to refresh on the use and benefits of the applications as well as to introduce the project-based scenario, and the lab session focuses on instructor demonstration and students hands-on practice on the scenario. Lab sessions include an Autodesk Revit lab on model-based estimating, three Autodesk Navisworks labs on site logistics plan, 4D scheduling, and clash detection, respectively, and a Bluebeam Revu lab on document control. The BIM software used in the lab sessions are the most popular commercial packages that are being used widely in the AEC industry. When students complete the first two modules, they will be well-equipped to meet the expectations of future employers as an effective BIM user.

3.3.3. Advanced BIM Applications Module

The advanced BIM applications module aims to introduce and demonstrate the latest technology advances in the AEC industry that utilize BIM applications. This module follows the basic BIM applications module and takes the last four weeks of the course. Based on the research areas of the instructor, four topics are selected for this module including laser scanning, real-time walkthrough, virtual reality (VR), and mixed reality (MR), as shown in Table 2.

1) Laser scanning. The instructor has access to a FARO Focus3D laser scanner through university collaboration and has employed the laser scanner in several research projects. The topic first introduces the uses of benefits of laser scanning in a construction project, then provides hands-on practice to students on setting up and operating the laser scanner, followed by a lab session to process the captured point clouds. The lab session features a workflow of first combining multiple scans with FARO Scene, then editing the combined scan with Autodesk ReCap, and finally modeling architectural and structural designs around the scan with Autodesk Revit.

2) Real-time walkthrough. Traditional BIM walkthroughs are created with either Revit, Navisworks, or Synchro as videos where the audience follow the view of the video and thus have no control over what is being presented. Autodesk introduced a new 3D game engine, Stingray, in 2015 which can create real-time design visualizations. The game engine is particularly beneficial to the AEC industry in that it provides a seamless workflow to bring a design directly from Revit to 3ds Max and then to Stingray. A building model is first imported from Revit to 3ds Max to optimize its visual accuracy, and then deployed with Stingray as an interactive game experience for a real-time walkthrough [30]. Based on this workflow, Stingray has now been merged into 3ds Max for better interactive features and a simplified process. Alternatively, Autodesk Live, introduced in 2016, offers similar interactive visualization through cloud services. This topic in the advanced BIM applications module uses lab sessions to demonstrate the workflow of Revit to 3ds Max to Stingray for a real-time walkthrough.

3) Virtual reality (VR). VR as a buzzword in 2016 has quickly received atten-

tion in the AEC industry. In fact, VR was employed in the industry as early as 2013 in Mortenson's Pegula Ice Arena and Sanford Fargo Medical Center projects [31] [32]. The instructor has a research lab equipped with an Oculus Rift, an HTC Vive, and two VR-ready workstation computers, and this VR equipment have been used in research projects to develop VR applications. The traditional game engine Unity has provided a VR project template for Oculus Rift and the new game engine Stingray has provided a similar template for HTC Vive. With the provided project templates, a Revit model can be converted into a VR project and be viewed with an immersive experience. Alternatively, other commercial applications are available to convert BIM models into VR models directly, such as IrisVR and InsiteVR, for both computer-based VR equipment and mobile VR equipment. This topic in the advanced BIM applications module uses student participation to demonstrate VR experience with Oculus Rift and HTC Vive using a Revit model converted by both Stingray and IrisVR, as demonstrated in Figure 2.

4) Mixed reality (MR). The concept of MR has been brought to attention in the AEC industry since Microsoft released the HoloLens in 2016. MR is different than augmented reality (AR) in that AR applications present augmented information based on physical objects while MR applications combine virtual objects and physical objects in the same environment. The instructor has two units of HoloLens in the research lab for research and educational projects. Unity used to provide a specific HoloLens version for developing MR applications and then have included it in its later updates. Alternatively, MR applications for BIM are also available. 3D Viewer Beta, developed and offered freely by Microsoft, enables BIM users to bring BIM models into MR with some prior conversion efforts in Revit and Navisworks. Trimble released the SketchUp Viewer in late 2016 as the first extensible commercial HoloLens application which enables collaboration and coordination in MR between BIM users. This topic in the advanced BIM applications module uses student participation to demonstrate MR experience with Microsoft HoloLens using the same Revit model converted by 3D Viewer Beta, as demonstrated in Figure 3.

| House interiors in VR | House exteriors in VR |
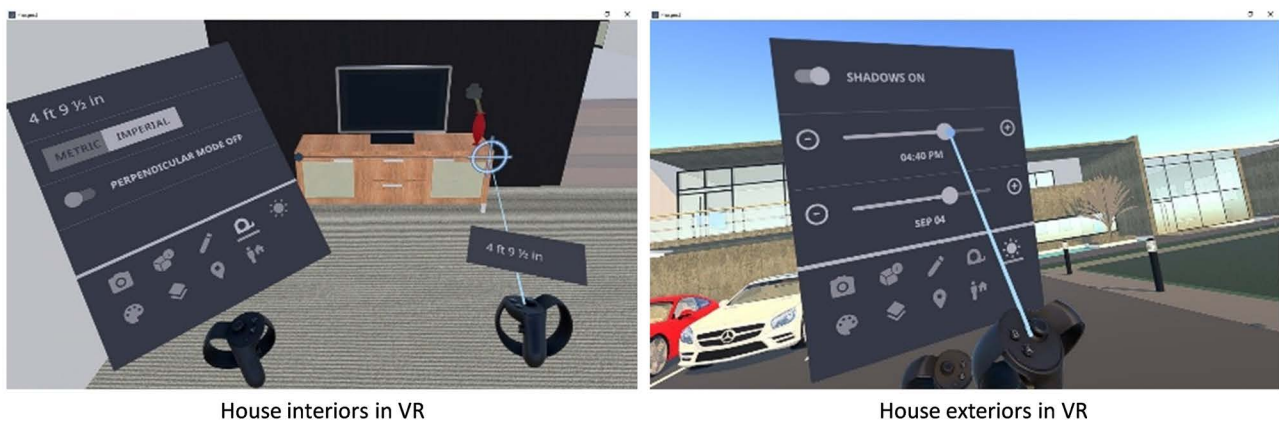
Figure 2. Different VR views of a house model in IrisVR.
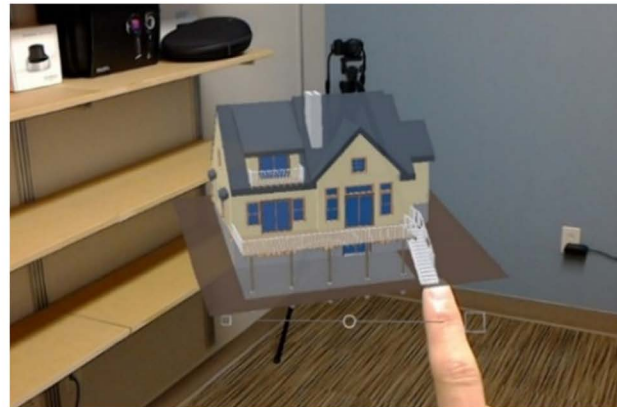
| A house BIM model | The house viewed in MR |

Figure 3. Comparison of a house model in BIM and MR.

3.4. Course Assessment

The course uses a weighted grading system with six categories including participation (15%), three assignments (15%), seven labs (20%), one exam (15%), final project (20%), and final presentation (15%). Labs and the final project weight 5% more than the other four categories because they include more tasks, cover longer duration of the course, and require more efforts to complete. Participation, assignments, exam, and the final presentation weight the same as they contribute roughly the same to the course and require a similar amount of efforts. Participation is graded specifically for hands-on operations such as laser scanning, VR and MR experience.

Each course objective is assessed against the assessment criteria presented in Table 3 by at least two assessment methods. Objective 1 "Understand BIM" is assessed by two assignments and the exam to evaluate students' ability to define BIM, describe the benefits of BIM, and identify the appropriate delivery methods and contract for BIM. Objective 2 "Describe LOD and BIM Execution Plan" is assessed by one assignment, the final project, and the final presentation to evaluate students' ability to differentiate LODs, prepare a BIM Execution Plan from a template, and form an effective BIM team to present the plan. Objective 3 "Perform BIM applications" is assessed by the exam and five labs to evaluate students' ability to describe different BIM applications in CM, identify the BIM tools needed, and perform project analysis with BIM tools. Objective 4 "Apply BIM in project" is assessed by the same five labs, the final project, and the final presentation to evaluate students' ability to justify the use of BIM in project-based scenarios and apply BIM to solve real-world CM problems. Objective 5 "Demonstrate BIM advances" is assessed by participation of hands-on operations and two labs to evaluate students' ability to describe the latest advances in BIM and operate the advanced equipment effectively.

3.5. Course Evaluation

This course is evaluated based on student performance and feedback by the end

Table 3. Assessment methods and criteria for each course objective and course topics.

Course Objective	Course Topics	Assessment Methods	Assessment Criteria
1. Understand BIM	The Value of BIM BIM Delivery Methods BIM Contract	Assignments and exam	Ability to define BIM, describe its benefits, and identify BIM delivery methods and contract
2. Describe LOD and BIM Execution Plan	Levels of Development BIM Execution Plan BIM Team and Meeting	Assignments, project, and presentation	Ability to differentiate LODs, prepare a BIM Execution Plan, and form an effective BIM team
3. Perform BIM Applications	BIM Estimating Site Logistics BIM Scheduling Coordination Document Control	Exam and labs	Ability to describe different BIM applications in CM, identify the BIM tools needed, and perform project analysis with BIM tools
4. Apply BIM in Project	Revit Lab Navisworks Labs Bluebeam Revu Lab	Labs, project, and presentation	Ability to justify the use of BIM in project-based scenarios and apply BIM to solve problems
5. Demonstrate BIM Advances	Laser Scanning Real-Time Walkthrough VR and MR Experience	Participation and labs	Ability to describe the latest advances in BIM and operate the equipment effectively

of the course via the following methods:

1) Monitor student performance in each course objective. The student performance goal of the CM program is that 80% of student achieve 70% or above grade. The course adopts this goal for each course objective and monitors the percentages of students meeting the goal.

2) Conduct student surveys at the end of the semester. The survey includes a unified student rating of instruction (SROI) used across the university and a questionnaire specifically designed for this course. The SROI was used to track the performance of course materials and instruction. The questionnaire records students' ratings and comments on each topic of the course, including the difficulty of lecture and lab materials, the readiness of lab programs and equipment, the shortcomings and potential improvements, etc. The feedback of questionnaires was used to improve future course offerings.

3) Compare and analyze the evaluation results of both student performance and student surveys in each course offering. The comparison and analyses are used to track the course performance over time and improve overall course quality.

During the first course offering, student final grades averaged at 90.8% with a median of 94.5% and a minimum of 79.7%, which has met the student performance criteria. The SROI averaged at 4.5/5.0 for the instructor and at 4.6/5.0 for the course, which were both higher than the institution average.

Student survey feedback showed highly positive results of this course. The students greatly valued the offering of this new course and recommended it to other students in the CM program. Some of the student comments include:

• Very interesting class. I enjoyed it! Learned a lot of new things.
• Very hands on in learning the material, I feel as if though I will be able to re-

tain this knowledge and use it in my job in the near future.

- The labs are interesting and legitimately fun.
- The classes are extremely interesting with all of the tech we get to use hands on. The instructor does a very good job at thoroughly explaining the processes in BIM labs, and his interest and enthusiasm for BIM makes it even more enjoyable.
- This is a great class to get advanced knowledge in construction software, and I highly recommend taking the course to everyone.

4. Conclusions

As the rapid adoption of BIM in the AEC industry, many CM programs in the US have introduced BIM in their curriculum to meet industry expectations. A review of current literature suggested that existing BIM courses often focused on specific modeling skills and analysis tools of BIM applications while overlooking the fundamental workflow of BIM in a construction project. Recent studies have also argued that only knowing how to use BIM applications is not a true understanding of BIM and is in fact far from the expectations of being effective BIM users.

This paper presents a modular BIM course that aims to help CM students better understand the BIM workflow in a construction project and utilize BIM to manage the construction process. The course focuses on advanced uses of BIM in construction projects and includes three modules: BIM workflow, basic BIM applications, and advanced BIM applications. Five course objectives were developed to match the CM curriculum needs in BIM contents and align with the six levels of cognitive learning process in Bloom's Taxonomy. In each course module, specific course topics were introduced and associated with a course objective. The course objectives and assessment methods ensure that CM students' understanding of BIM will be considerably improved from as a modeling tools or software program to an efficient process, and their insights into BIM will be significantly broadened beyond the existing 3D, 4D, and 5D applications. The highly positive course evaluation demonstrates the effectiveness of these approaches in meeting course objectives, delivering course materials, as well as raising students' interest. This paper will serve as a case study of an advanced level BIM course in CM programs.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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