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Implementing a Vertically Integrated BIM Curriculum in an Undergraduate Construction Management Program

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The popularity of Building Information Modeling (BIM) as an integral concept in the Architecture, Engineering, and Construction (AEC) industries has motivated its necessary inclusion in Construction Management (CM) education. Implementing BIM as a mainstream, elective or integrated subject within an established undergraduate curriculum is challenging due to limitations such as available teaching time, knowledge retention in students and the flexibility of the curriculum to adapt with a fast developing technology. Pedagogy must combine fundamental learning of theory, practical experience and the use of technology in a collaborative environment to effectively implement BIM. Vertical integration is one such method that was implemented and evaluated to promote BIM education in the undergraduate Construction Management program at Arizona State University. This article discusses the evolution of the BIM curriculum and focuses on the vertical integration of upper-division and lower-division students for a Site Logistics assignment to improve upon the BIM education continuum. Evaluation and surveys revealed that this methodology increased the appreciation for learning BIM, promoted the use of BIM tools for in-class projects and created an understanding of the importance of information management.

Keywords BIM education, collaboration, construction education, vertical integration

Introduction

The relative importance of Building Information Modeling (BIM) and management in the construction industry is an established fact supported by several past academic and industry-sponsored research studies. The most often cited survey is the Smart Market report by McGraw-Hill (2009), which in its latest edition established that 70% of the Architecture, Engineering, and Construction (AEC) industries have embraced BIM as a technological, philosophical, and cultural concept. Construction education has often emulated the advancements in the construction industry and this trend is most obvious in relation with BIM education (Becerik-Gerber, Gerber, & Ku, 2011). According to Badger and Robson (2000), raising the level of expectations in construction management (CM) education requires continuous change to maintain alignment of industry and academic

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needs. This is especially true for BIM education, where rapid transformation in BIM tools must be accompanied by a similar change in classroom pedagogy and instruction.

At the most basic level, BIM encompasses three subject areas; parametric modeling, information management and work processes for its implementation. The popularity of BIM as a buzzword in the industry often shifts the focus away from the combined benefits of the software programs and information management concepts and leads most students to believe that BIM is a single software program or a 3D geometric model. Such notions are misleading, if not harmful, for younger students beginning their CM program. Hence, it is pertinent that the value of both information modeling and information management is impressed upon the students from an earlier stage in their undergraduate program.

The fundamental concept behind BIM is the iterative accretion of reliable information, which if managed correctly, can help simulate scenarios for effective decision-making. Early collaboration amongst project stakeholders is crucial for ensuring project information is reliable, accurate and consistent. Collaboration is typically simulated in classrooms through group assignments, where students take on different roles in teams, either based on different majors (e.g., an architecture student is grouped with an engineering student and a CM student) or based on assigned roles (e.g., the instructor assigns group members project roles such as "architect," "engineer," etc.). Rarely is there any focus on integrating lower and upper division courses. Knowledge sharing amongst different groups with varying levels of skills and expertise (e.g., an upper- and lower-division course) is a more accurate representation of the industry.

Vertical integration in the context of medical curricula is defined as the "integration of basic knowledge and skills, such as biology, in the clinical context." Horizontal integration is defined as the "integration of knowledge and skills between the clinical subjects" (Snyman & Kroon, 2005). Borrowing from medical education, the authors define Vertical integration in BIM education as the integration of different levels and areas of expertise, allowing students to gain an early appreciation for certain skills and developing a continuity in CM curriculum. It mirrors the practices of the construction industry where experts from different fields form alliances to collaboratively develop an effective solution. It is also a common practice in the industry to pair experienced employees with new hires or interns, to foster a team that has the knowledge of experience and new technology. Bringing this model to academia, the main idea is to promote collaboration by employing a method of "subcontracting" between classes at different levels (Ghosh, Parrish, & Chasey, 2013b).

This article discusses the motivation for the development of a vertically-integrated BIM curriculum for an undergraduate Construction Management (CM) program. It further argues why vertical integration is well-suited for BIM education through a case study of a vertical integration teaching module that was designed, implemented and evaluated by the authors over two academic semesters.

Literature Review

Vertical Integration

An example of vertical integration from medical education is the pairing of undergraduate students possessing lesser skills with post-graduate students for purposes of simulation training such as medical emergencies (Rosenthal, Worley, Mugford, & Stagg, 2004). These skills are required by both sets of students but at a lesser skill level for the undergraduate students. Such exercises enable students to gain an early appreciation for certain skills and their relevance in future stages (Ghosh et al., 2013b). This pedagogical style aims at delivering each subject as an integrated function of several disciplines. Students are therefore better prepared to apply a complete conceptual knowledge than they would be if these topics were presented in a fragmented fashion multiple times across multiple courses (Vidic & Weitlauf, 2002).

BIM Education Research

In 2008–2009, Pavelko and Chasey (2010) developed a study to understand industry's expectations of BIM skill levels for new graduates and the corresponding academic support in universities. Responses received from 70 AEC firms indicated that 77% of the respondents foresaw an increased use of BIM. Almost all (95%) required new hires to have an understanding of BIM concepts and associated skills rather than isolated expertise in just one particular software program. These data are consistent with the McGraw-Hill Smart Market report that lists "more internal staff with BIM skills and more readily available training in BIM," as two out of the twelve top ways of improving the value of BIM (McGraw-Hill, 2009). With increasing awareness, the impact of BIM use for critical decision making is evident across areas of construction project management, including project delivery methods, procurement, project management, preconstruction, construction services, commissioning, business operations and facilities management. This increases the need for individuals who can balance BIM with traditional operations (Lee & Dossick, 2012).

The academic survey by Pavelko and Chasey (2010) of 59 member institutions of the Associated Schools of Construction (ASC) and the American Council for Construction Education (ACCE), indicated that 70% of the respondents were offering BIM in their program. At the time, in 2008–2009, most schools concentrated on teaching BIM for 3D coordination (82%), some used it for scheduling (46%), and even fewer for estimating (35%). A similar survey by Becerik-Gerber et al. (2011) expanded the survey pool to include member institutions from the ASC, ACCE, the Accreditation Board for Engineering and Technology (ABET), and the National Architecture Accrediting Board (NAAB), eliciting responses from 101 programs in the US. Fifty-six percent of the respondents were teaching BIM. Of these, 60% of the construction programs had infused BIM concepts in their traditional courses. The survey also found that most construction programs taught BIM for constructability, 4D scheduling, and model based estimating, followed by design, visualization, sustainability and cost control (Becerik-Gerber et al., 2011). These studies indicate that the adoption of BIM in construction management programs at the undergraduate level has seen a steady increase since 2008. The two popular approaches of BIM integration are either as a stand-alone course or the integration within existing courses. However, since the ACCE mandates the inclusion of 15 hours of computer applications in the curriculum (ACCE, 2014), the latter is the preferred approach for curriculum delivery.

Challenges in BIM Adoption

The importance of BIM education is fairly well researched and it has been concluded that it is essential for students to have a fundamental knowledge of BIM tools and processes before they join the workforce (Becerik-Gerber et al., 2011; Lee & Dossick, 2012; and Ghosh et al., 2013b). Past research and the authors' experience indicates that although the necessity for BIM adoption is crucial, there are several struggles faced due to the prevalence of a change averse mindset, investment costs in technology, lack of faculty

Table 1. Challenges in the adoption of BIM in a construction management program

Source	Challenges identified
(Ghosh, Parrish & Chasey, 2013b)	• Limited example models for demonstrating BIM use for collaboration • Failure of BIM tools in permeating to other construction specialties like heavy civil, horizontal and underground construction
(Ghosh, Chasey & Root, 2013a)	• Lack of BIM skill retention due to discontinuity • Limited available time outside of coursework to practice software use • Overloading of coursework • Lack of enthusiasm from students because of complexity
(Lee & Dossick, 2012)	• Requirement of faculty trained in BIM
(Becerik-Gerber et al., 2011)	• Lack of experts to teach BIM • Lack of resources – teaching, funding and administrative • No formal identification of BIM in ACCE or ABET accreditation criteria's
(Sabongi, 2009)	• Complexity of BIM and uncertainty about choice of software • Students' lack of interest or willingness to explore new technology • Lack of support from faculty
(Ibrahim, 2007)	• Conflicting ideologies of teaching BIM as a graphical software application versus teaching the core concepts behind it

trained in BIM and complexity of the software programs. Table 1 classifies a few common challenges.

It is also important to consider the background knowledge of the students in predicting their learning curves. CM students who are not familiar with authoring 2D drawings, 3D models or both may face greater initial struggles in comparison with engineering and architecture students who will likely have a faster learning curve for drawing and modeling based on prior coursework.

Background

Pedagogy Models of BIM Education at Arizona State University

Considering the limitations, especially those posed by accreditation criteria and existing course loads, most CM programs in the United States have found it practical to include BIM in a series of existing courses that often involves restructuring of the existing syllabi and schedule (Lee & Dossick, 2012; Ghosh et al., 2013b). This pedagogy model helps students build a knowledge base of BIM in relation to the subjects they are already studying. Some other curricular trends are introduction of BIM modules replacing the existing CAD or Information Technology course, offering BIM as a part of the capstone course or offering a BIM module in addition to specialty topics such as Lean Construction, Sustainable Design and Construction and Integrated Project Delivery. Pikas, Sacks, and Hazzan (2013) offer a comprehensive view of the integration of BIM within seven courses in a construction engineering and management curriculum.

At the Del E. Webb School of Construction (DEWSC) at Arizona State University (ASU), BIM is offered as a single credit lab that accompanies the senior-level CON453 Project Management core course (Ghosh, Chasey, & Root, 2013a). The lab covers a range of case-based project management scenarios such as visualization of site logistics, model-based estimating, 4D scheduling, and clash detection, using a variety of commercially available software packages such as Autodesk Revit®, Navisworks®, Trimble SketchUp®, Bluebeam Revu®, and Beck Technologies DProfiler™. The 3-credit Project Management lecture incorporates BIM modules such as developing a BIM Execution Plan, an introduction to alternative project delivery methods, and utilizing technologies such as laser scanning for quality control, safety etc. Figure 1 represents the chronology of the different curricular models, since the first class taught in Fall 2008. These iterations are a reflection of the lessons learned from student feedback and an effort to continuously improve the BIM curriculum. The appointment of industry members, alumni and graduate students researching in BIM as the instructors for the course ensures the relevance of the topics taught. The 3D models, construction drawings and/or case studies used are typically recently completed projects on or near the university campus. This allows the opportunity for conducting site visits and encourages interaction of students with industry mentors. The CON453 BIM lab follows a pattern of individuals learning a BIM software (through instructor-provided instructional material) followed by an in-class group assignment that addresses a project management scenario rooted in a real case study. All group work is done in a collaboration space. Table 2 outlines a few typical lab assignments.

Feedback from students indicated that there was a lack of continuity through the years and that they would prefer an earlier introduction to BIM. As a result, a stepped progression (see Figure 1) was introduced in the academic year 2011–12 with the introduction of a 3D modeling component along with the sophomore-level Working Drawings Analysis course. Working Drawings Analysis is a lecture that covers an overview of construction drawings and how they are organized, recognizing the various building components and

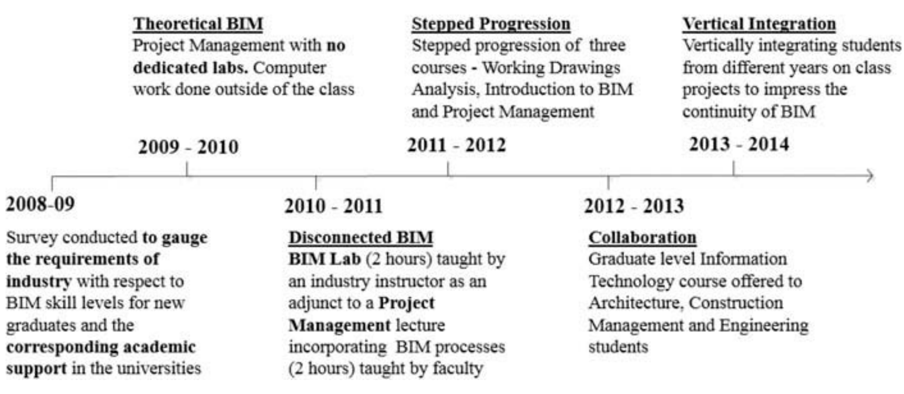


Figure 1. Chronology of BIM education at ASU.

Table 2. Typical BIM lab assignment examples for CON453

Software	Individual learning (Software purpose)	Group assignment (Case based scenario)
SketchUp®	Conceptual Modeling: Creating generic 3D models of basic building elements, applying materials and textures, and importing 3D models from an online library.	Develop a site logistics plan
Revit®	Model management: Creating and detailing 3D models, creating sections, elevations and multiple views, changing material and element properties, and deriving quantities for estimating.	Complete quantity take-offs and estimate
Navisworks®	Navigation and file types: Understanding the differences between .nwd, .nwc and .nwf file types, navigating the user interface, walking and exploring the 3D model, importing different file types, setting up for coordination and generating reports.	Complete clash detection and coordination activities

different construction methods annotated on such drawings. Along with understanding concepts on paper drawings, students spend a maximum of 8 hours learning 3D modeling and modifying construction documents in a BIM authoring tool (Ghosh et al., 2013a).

In Summer 2012, the development of a "pod-based" collaboration space was commissioned at ASU that would host all BIM, IT and group-work related courses. This was a major step in co-locating students and providing a preview of an environment to expect when they enter the workforce (Chasey, Ciszcon, Ghosh, & Hogle, 2012). While this promoted collaboration during class time, most students were still restricted to their cohort. Two concerning areas were observed that required more research:

1. How can we extend the concept of "collaboration with BIM" beyond the senior level Project Management BIM lab? and,
2. How can we maintain a continuity of BIM education through the length of the construction management program?

Evaluation and Assessment of BIM Curriculum

According to Farrow, Liu, and Tatum (2010), the motivation for students to excel in the classroom comes from how the curriculum is delivered and assessed rather than solely focusing on 'what' is being taught. This requires the development of measurable learning objectives that can function as benchmarks for further development. Limited published literature focuses on the assessment of BIM education. A research study by Macdonald (2012) suggests the development of a framework represented in four stages relating to the levels of achievement: illustration, manipulation, application and collaboration (IMAC). This framework is applied to assess the entire construction curriculum against parameters such as; building technology, environment, management, IT and specialism in AEC.

Based on Bloom's taxonomy (Bloom et al., 1956); Ghosh and colleagues (2013b) developed a set of BIM learning objectives at ASU that are similar to the (Macdonald, 2012) study. The evaluation plan lists the cognitive learning indicators serving as the benchmarks against which the students' learning outcomes would be measured (see Table 3). The learning objectives are currently assessed through surveys measuring students' evolvement of BIM knowledge, both through an individual course and across the curriculum. It is anticipated that younger students would show aptitude and knowledge but will lack the ability to evaluate and create early on, but will identify themselves as capable of evaluation and creation later in their tenure at ASU (Ghosh et al., 2013b).

Table 3. BIM Evaluation Plan for ASU*

	Cognitive learning indicators		
Learning objective	Knowledge	Application	Evaluation
1. Develop an understanding of what constitutes BIM	Identify what is BIM and what is not BIM	Identify BIM tools	Ability to define BIM in terms of CM processes
2. Demonstrate the ability to use BIM tools for purposes of documentation, co-ordination, visualization and information exchange	Memorize steps and methods of operating software. Identify what tool is used for which purpose.	Operate BIM tools	Ability to use a BIM tool effectively and in the correct method to get desired results
3. Apply the concepts of BIM to a Construction Management problem	Recognize the employment of BIM for certain CM cases/scenarios	Use BIM tools to inform decisions	Justify the use of BIM for certain use-case scenarios mirroring a real world situation
4. Gain an understanding of BIM as a collaborative tool	Define BIM use for collaborative decision making	Apply BIM in a collaborative environment	Ability to use BIM effectively as a team to resolve a common project management scenario

*Learning objectives and indicators adapted from (Gronlund, 1981).

As listed in Table 3, learning objectives 1–3, at all cognitive levels, can be fulfilled by the course curriculum covered in the CON453 Project Management lecture + BIM lab. Group assignments are introduced in the BIM lab to achieve learning objective 4. However, it is observed by the authors that there is a gap between the anticipated and actual learning by the students, particularly for higher cognitive indicators (apply and evaluate). The authors hypothesize that the lack of true collaboration at the undergraduate level is because students taking the CON453 class are coming in with largely the same set of background knowledge gained from the same or similar course work earlier in the CM program. (Although CON453 is open to students from other majors, including architecture and engineering, the students enrolled are almost exclusively CM majors.)

Research Methodology

Yin (1994) describes case study research as an "empirical inquiry that investigates a contemporary phenomenon within its real life context." Even though this method faces criticism because the results are often not easily reproducible, it is a preferred strategy when generating and extending theory from real world observations. In action research, the researcher creates the phenomenon before it is evaluated, seeking to create localized solutions for specific situations. The purpose of this research is to provide a "proof of concept" of a new pedagogical model for BIM education through a case study approach. The authors of the paper restructured their existing curriculum to incorporate the vertical integration assignment, hence the research method is that of a "case study with an action research." The objectives of the study are to:

1. Promote an appreciation for BIM as a collaboration tool,
2. Develop an understanding of BIM as an information modeling and management process and,
3. Maintain continuity of BIM education through the years in the CM program.

For this purpose, a pedagogy model of vertical integration was implemented as a pilot study by the authors in the 2013–2014 academic year. The pilot was a year-long study spread over two semesters. It incorporated two courses: CON252 Building Materials and Methods and CON453 Project Management + BIM lab. Table 4 compares the two courses.

The first phase of the pilot study was implemented and tested in Fall 2013. The implementation required pre-planning by the instructors to synchronize schedules, learning objectives, evaluations and instructions. The lessons learned from the Fall semester were used for improving the model, and these improvements were deemed effective based on student evaluations in Spring 2014.

Assignment for Vertical Integration Pilot Study

A "site logistics" assignment was used for the Vertical Integration pilot. The assignment centered on an existing construction site on campus (a five-story 137,000 sq.ft, classroom, office, and retail building that began construction in early 2013). Students from both classes had the opportunity to walk the site through organized site visits. The students were expected to study the site, the surroundings and the schematic design drawings of the project (provided by the architect) thoroughly before starting to identify risks and develop solutions.

Table 4. Comparison of the two courses for vertical integration

	CON252	CON453
Course title	Building materials and methods	Project management + BIM lab
Course level	Freshman	Senior
Semester(s) offered	Fall and Spring	Fall and Spring
Enrollment	40-60 students	20-40 students
Credits	3	3 (lecture) + 1 (lab)
Prerequisites	None	Building materials and methods, working drawings analysis, project scheduling and estimating, microcomputer applications
Course learning objectives relevant to vertical integration activity	1. Understand the vernacular of the construction industry 2. Develop a sense of how a building comes together 3. Identify stakeholder roles in the process of construction 4. Develop an understanding of what constitutes BIM (refer Table 3, BIM learning objective #1)	1. Explain the project management process, including defining, planning, executing, controlling and closing. 2. Apply the concepts of BIM to a Construction Management problem (refer Table 3, BIM learning objective #3) 3. Prepare for real life challenges faced in the industry through collaboration and interaction with peers. (refer Table 3, BIM learning objective #4)
BIM modules taught	None	BIM authoring software programs, BIM concepts and PM decision making using BIM
Previous BIM experience of students	Only 10% of the class familiar with 2D CAD and/or SketchUp	50% familiar with SketchUp and Revit

Senior level students in CON453 work in groups of four for this assignment. The goal, for CON453, was to design a holistic site plan for a new building construction project, incorporating construction materials, site equipment and site logistics, to alleviate project management concerns that are likely to arise during construction. The CON 453 students represented a team from the general contractor (GC). Lower-division students in CON252 pose as specialty contractors or consultants for the GC. Their objective was to provide necessary recommendations based on their expertise in building materials, construction methods and workforce analysis to aid in developing the site plan.

Learning Objectives

The authors anticipated that the CON252 (lower division) students would develop an appreciation for the importance of their coursework after experiencing how their materials and methods knowledge could contribute to site planning. Moreover, the authors also anticipated that when the CON 252 students' suggestions were incorporated into the upper-division students' project management plans, the lower-division students would understand how their coursework was relevant to future courses and the field of CM. The authors also hoped that the assignment and collaboration would initiate a discussion about BIM that addressees both BIM's visual capabilities (through the site logistics assignment) and the importance of information management for effective BIM implementation.

For the CON453 (upper division) students, the authors anticipated that the students would develop an appreciation for the importance of collaboration with specialty contractors who provide valuable information about construction materials and methods, particularly as related to overall site planning and management. In turn, this facilitates the understanding of BIM as a collaborative information management process rather than simply a 3D model developed by a single entity. Additionally, the assignment required that CON453 students develop and communicate a comprehensive plan based on inputs received from multiple sources, a skill that would be necessary in their CM careers.

Deliverables

The CON252 students were expected to observe and analyze the site and then provide recommendations for site logistics and planning in the form of an informal memo. For example, the CON252 students suggested using just-in-time delivery of precast concrete beams to address the lack of laydown area onsite.

The CON453 students were expected to: (1) evaluate recommendations and provide feedback to their consultants, represented by CON252 students; (2) develop a comprehensive site logistics plan with appropriate representations; and (3) communicate the intent of using BIM as a visual tool. The CON453 deliverable requirements includes a written evaluation of the CON252 recommendations, a site logistics model (in a BIM authoring tool) and presentation to an industry guest.

Evaluation

An informal in-class survey based on qualitative feedback was conducted for CON252 right after their part of the assignment, i.e., providing recommendations to CON453.

Two anonymous surveys were conducted for CON453 at mid- and end-of-semester to gauge student learning and receive feedback. These were short, eight-question surveys with five questions based on a Likert-type scale, two questions as a multiple-choice, and one question for comments and feedback. The response rate was:

- 91% for mid-semester and 70% for end-semester surveys for Fall 2013,
- 93% for mid-semester and 100% for end of semester surveys for Spring 2014.

The surveys for CON252 and CON453 are posted on the website: faculty.engineering.asu.edu/parrish/research/

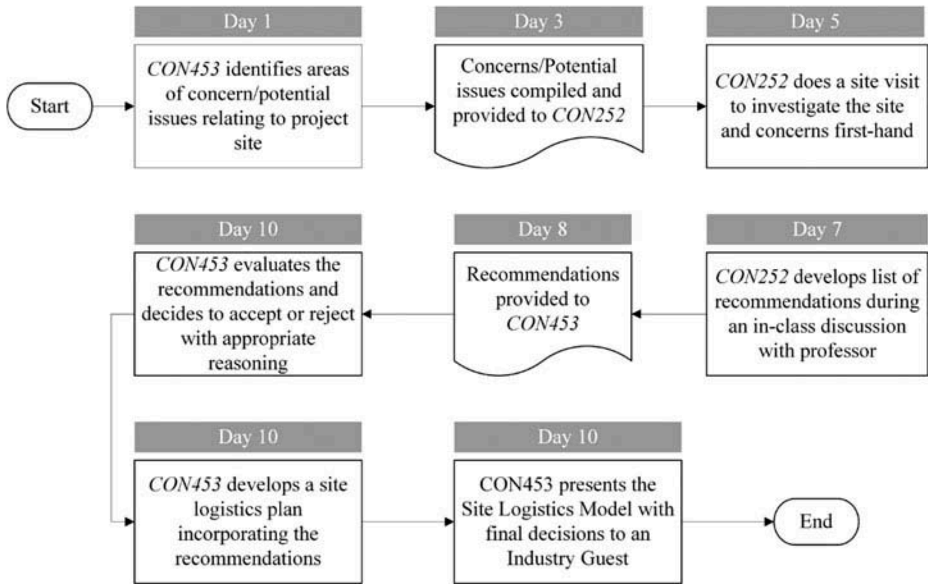


Figure 2. Process flow of the Vertical Integration pilot from Fall 2013.

Fall 2013: Vertical Integration as Outsourcing

Figure 2 explains the various steps of the assignment. It was piloted as a 10-day project from start to finish, within the constraints of the existing schedule for both the courses and did not require any extra time to be allocated outside of class. CON252 spent two class periods for this assignment: Day 5 for the site visit and Day 7 for developing recommendations. CON453 spent one class period on Day 10 for analyzing, developing, and presenting their site logistics plans.

Survey results indicate that while there was a general sense of enthusiasm from the CON252 students to take part in the vertical integration, the CON453 students were not as motivated. Only 3% of CON453 strongly agreed that this assignment was useful in helping them understand the value of BIM use for Site Logistics. Since the ideas were transferred via the Teaching Assistants and instructors, there was no face-to-face interaction between CON 252 and 453 students. The model was based on outsourcing rather than co-location. Other observations from CON453 were:

- 76% of the class agreed that using a visual tool like SketchUp helped communicate and present their ideas better than not using it at all,
- 60% of the class agreed that communicating with consultants and evaluating their recommendations was an important step of BIM and project management,
- 43% of the class felt their discussions would have been more fruitful if they were co-located, while 47% were unsure.

Spring 2014: Vertical Integration with Co-location

The experience of the vertical integration pilot study in Fall 2013 and feedback from students helped in identifying areas for improvement for the next offering of this class in Spring 2014.

Three strategies were implemented in the revised model:

1. A risk identification matrix (see website: faculty.engineering.asu.edu/parrish/research/) was provided to the students to offer structure and promote critical thinking. CON453 students were required to identify a potential risk, the risk type, the responsible and affected party and the potential impact.
2. CON453 and CON252 were co-located during the "discussion of recommendations" phase. This included developing a "mitigation plan" based on the risk matrix and then identifying how BIM could help.
3. The schedule was adjusted such that CON453 students had the option of using a combination of BIM tools; SketchUp, Revit and Bluebeam; for developing the final Site Logistics plan.

The timeline for the project was extended to 5 weeks instead of the 10 days to effectively include all the strategies. The modifications and added steps are shown in bold in Figure 3. The deliverable requirements and grading criteria remained unchanged. The only additional time allocation was for the CON453 students for co-locating with the CON252 students during the "site logistics activity." For planning and logistical ease, the CON453 students were given the option of sending one or two representatives from each group, whomever was available during the CON252 class time.

Survey results indicated that from CON453, 8% strongly agreed and 31% agreed that this assignment was valuable in helping them understand BIM use for site logistics. Other results showed a similar increase from the previous semester:

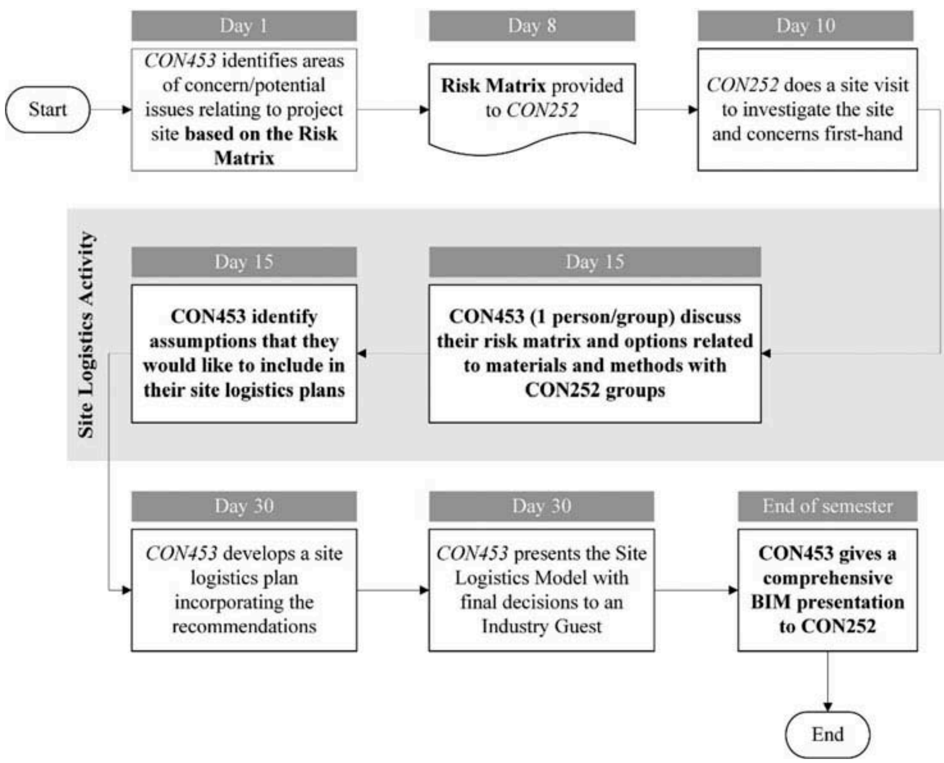


Figure 3. Process flow of the Vertical Integration revised pilot from Spring 2014.

- 85% of the class agreed that using a variety of BIM tools like Revit, SketchUp and Bluebeam helped communicate and present their ideas better than not using it at all,
- 73% of the class agreed that communicating with consultants and evaluating their recommendations was an important step of BIM and project management.

In the Spring 2014 semester, the authors formally surveyed not only the CON453 students, but also the CON252 students. Qualitative feedback from CON252 students showed that 64% felt vertical integration helped them understand the concept of Site Logistics better. Moreover, 82% of CON252 students agreed that working with an upper division CON453 student helped them appreciate the relevance of their course in the context of Construction Management. This highlights an appreciation for a mentor/mentee relationship earlier on in their career.

Discussion

In Fall 2013, the vertical integration model was *ad hoc*. The lower and upper classes did not physically co-locate at any point during the exercise. The information was communicated via the instructors. This felt more akin to outsourcing. Such a situation is not very far from the industry since this is likely to occur in traditional project delivery methods. The feedback received from the students along with observations of the instructors helped initiate three changes:

1. Providing structure using a risk identification matrix,
2. Physically co-locating the lower- and upper-division students and,
3. Expanding the BIM toolbox.

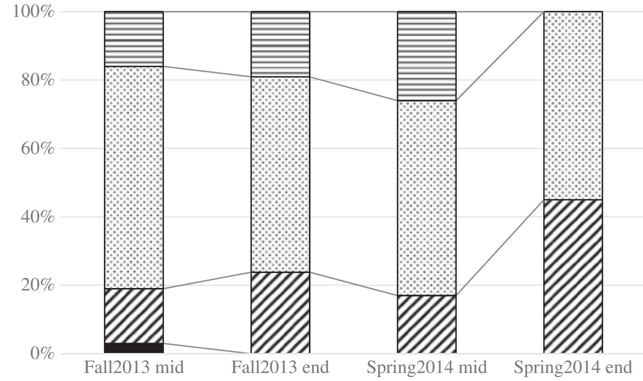
This made the vertical integration model more inclusive, interactive and flexible. The new model for vertical integration was validated in Spring 2014 via student feedback.

Survey results in CON453 indicate that the understanding of what constitutes BIM definitely evolves from mid- to end-semester (see Figure 4). The question asked was: “what is BIM?,” with four answer choices: (1) a single software, (2) a management style, (3) a combination of different tools or programs, and (4) a database. Students were asked to choose the two options that best describe what BIM is. Even though a majority of the students understand BIM as a combination of several different software tools or programs, at the end of the semester more students appreciate BIM as a management style and/or a database. This indicates that there is a positive trend in comprehending BIM beyond its computational capabilities to include the relative importance of the management of the included information.

Validation of Vertical Integration for CON453

A comparison of survey results between Fall and Spring (see Figures 5 and 6) indicate that in Fall 2013, a majority of the students gave a rating between 1 (low) and 3 (medium) to statements about vertical integration; “whether they saw a value of the vertical integration assignment in improving their understanding of BIM,” and in “advancing their thought process.” However, in Spring 2014, we see a distinct shift in the results as more students gave a rating between 3 (medium) and 5 (high) on the same statements.

Since this is a discrete non-parametric data type based on values selected on a Likert-type scale, the authors conducted a statistical analysis known as the Mann-Whitney-Wilcoxon (MWW) test to validate the results further. The MWW analysis tests



	Fall2013 mid	Fall2013 end	Spring2014 mid	Spring2014 end
Database	16	8	26	0
Combination of software	65	24	57	55
Management style	16	10	17	45
Single software	3	0	0	0

Figure 4. Evolution of understanding 'what is BIM?'

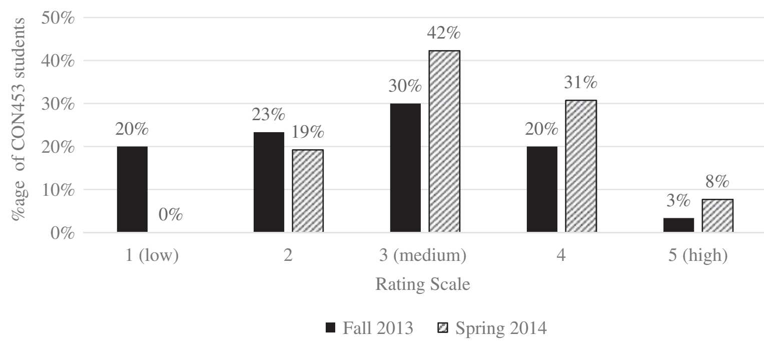


Figure 5. CON453 students' perceived value of Vertical Integration for illustrating how BIM can be effective for Site Logistics.

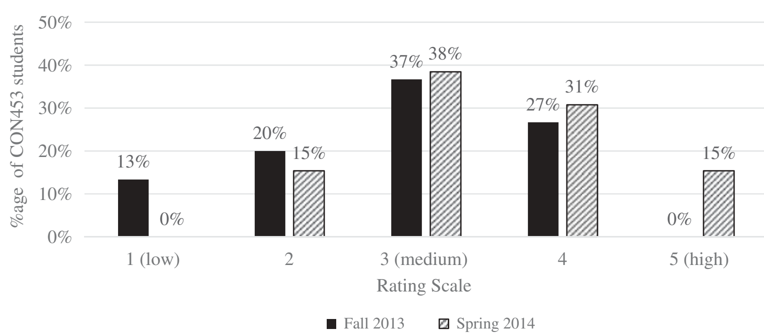


Figure 6. CON453 students' perceived value of Vertical Integration for advancing their thought process relating to BIM and Site Logistics.

the null hypothesis of two populations against an alternative hypothesis. The hypothesis is tested as follows:

1. Null hypothesis (H_0): The medians of the values from Fall and Spring are equal and,
2. Alternative hypothesis (H_a): The median value from Spring is greater than the median value from Fall.

The MWW test returned a p value = 0.0220 for question "a" (usefulness in understanding your use of BIM and its use for site logistics) and p value = 0.0203 for question "b" (advancing your thought process) at a confidence interval of 95% (see Table 5). Since both the p values are less than 0.05 (*i.e.*, alpha associated with a 95% confidence interval), it can be inferred that students from Spring 2014 were more confident with their answers than students from Fall 2013. Thus, the authors can conclude that the changes to the vertical integration assignment implemented in the Spring 2014 semester improved the use of BIM for site logistics.

To further validate the findings, grades received by CON453 students on the assignment were analyzed (see Table 6). The data show that the average score increased from 43.67 to 49.46 from Fall to Spring. In addition, the variance reduced from 11.29 to 2.48 indicating that the grades for Spring were clustered together. All students, therefore, improved. The authors attribute the improved average, as well as the reduced variance, to the fact that the Spring 2014 assignment was clearer and more structured, which allowed students to better meet the instructor's expectations.

Scaling the model across courses at ASU

This model of vertical integration can be adopted for any course that has a functional use for BIM. For example; the Revit assignment can be integrated with the Estimating course and a

Table 5. MWW test results

For the Site Logistics group assignment, you received feedback from CON252 who acted as your consultants for the assignment. On a scale of 1 to 5 (1 being least and 5 as the highest) rate the following:

Question	Semester	N	Median	p value
a. Usefulness in improving your understanding of BIM and its use for Site Logistics	Fall 2013 Spring 2014	29 26	3 3	0.0220
b. Advancing your thought process	Fall 2013 Spring 2014	29 26	3 3	0.0203

$\alpha = 0.05$

Table 6. CON453 grades for site logistics assignment (out of 50 possible points)

	Min. score	Max. score	Average	Median	Variance
Fall 2013	37	48	43.67	44	11.29
Spring 2014	45	50	49.46	50	2.48

Navisworks 4D scheduling can be integrated with the Planning and Scheduling class. This implementation however, requires a clear strategy that outlines: (1) how to align the learning objectives for CON453 with these other courses, (2) how to implement the assignment (e.g., co-locate or outsource), (3) alignment of course schedules to ensure that students have the necessary skills and knowledge to engage in the vertical integration assignment and (4) grading criteria and assessment materials for each course. Development of this strategy requires up-front planning by the instructors.

Limitations and Challenges

This pilot study was spread over two semesters, Fall and Spring, and included students from different academic years. This was possible since the two courses, CON252 and CON453, are offered in both semesters. The authors envision this model becoming an embedded aspect of the curriculum rather than an experimental project. This would require buy-in and commitment to continue this assignment from professors in both the lower- and upper-level classes. While this assignment does not require time outside of class from the CON252 students, the CON453 students need to co-locate and thus spend extra time. Moreover, the instructors have to dedicate time to planning the logistics for this integration (e.g., synchronizing schedules, classroom availability for co-location, developing grading criteria reflecting learning objectives and developing surveys to gauge learning and effectiveness of vertical integration). Classrooms equipped with virtual communication technologies can alleviate some of the limitations with physical co-location and varying schedules.

Second, since this was a pilot study, the authors created and administered the assessments. A third-party evaluator should review and potentially revise the assessment tools for future implementations of the vertical integration assignment. Though the authors' assessments indicate that the assignment was improved from the Fall 2013 to the Spring 2014, the assessment tool did not include a solicitation of comments that may help to further improve the assignment.

The third challenge is a common problem for CM courses that leverage a "live" project for experiential learning: the building project used for this assignment will be completed, and hence the assignment will need to be updated to reflect the characteristics of a new "live" project. In order to best promote learning in both the lower- and upper-division courses, the "live" project should be close enough to campus for both set of students to visit. Using an immersive 3D environment with virtual reality could offer a potential solution for curriculums unable to leverage a "live" project.

The authors also note that one limitation of this research is a relatively small sample size. Only two semesters worth of data were collected, comprising two courses in each semester. Thus, students from a total of four courses were surveyed, yielding a sample size of 143 students. While the authors find the results from these students encouraging, they also recognize that this sample size is not enough to definitively state that vertical integration is an effective way of teaching BIM to CM students regardless of circumstance. Rather, these results provide encouragement for broader adoption of the vertical integration framework for BIM education.

Future Research

A critical aspect of any new teaching method is evaluating its success beyond the immediate boundaries of its implementation. One of the objectives of this pedagogy model of Vertical Integration is to maintain a continuity of learning BIM throughout the years in the ASU CM program. To validate this hypothesis, it is important to assess the lower-division CON252 students after 2 years to analyze their retention of BIM knowledge through longitudinal surveys.

Providing a background structure and co-locating are important considerations that contribute to the success of vertical integration for both the lower- and upper-division students. Both these features require time commitments by students and instructors and instructor flexibility. It should be researched how to expand this pedagogy model beyond the physical and administrative restrictions of the academic curriculum, e.g., include a third level with industry participation.

For this particular pilot study, the senior level CON453 students were taught a BIM tool and the management of information through a case based scenario, specifically, Site Logistics. As noted earlier, not having the flexibility of using different BIM tools was identified as a limitation in the first round of implementing the pilot. This led to the instructors introducing flexibility of BIM tool use, which in turn also extended the time period of the pilot. While the concept of information modeling and management remains consistent, there are several BIM authoring and simulation tools that are popular, with additional features being developed at a fast pace. Future research must consider the question; how can we generalize BIM such that students can adopt the aspects of the tool that they require for their study?

Conclusion

This article described the motivation, implementation and progression of a Building Information Modeling curriculum in the undergraduate Construction Management program at the Del E. Webb School of Construction, Arizona State University. It also described the development of learning objectives that form the backbone for a holistic BIM education, assessment and evaluation. The authors of this study developed a pedagogy model of Vertical Integration borrowing from medical education and their own experiences in the construction industry. This model was applied as a pilot project in two courses; lower-division Building Materials and Methods (CON252), and upper-division Project Management + BIM lab (CON453); for a Site Logistics assignment based on a live construction project near the ASU campus. The first implementation was in Fall 2013, which was based on a model of outsourcing. Lessons learned from the initial implementation were incorporated into a revised model based on co-location and validated with a new group of students in Spring 2014.

From the pilot study, the authors are able to conclude that the two most critical aspects for the success of Vertical Integration are upfront planning and co-location. Analysis of survey data and assignment grades indicate that three interventions; providing assignment structure using a risk matrix, physical co-location and expanding the BIM toolbox; together helped in improving the assignment deliverable of site logistics for CON453 and advancing their thought process. A majority of students from CON252 in Spring 2014 indicated that Vertical Integration helped them appreciate the relevance of their course in context of CM and provided an early notion of what constitutes BIM.

The vertical integration pilot was designed to fulfill three primary objectives: (1) promote an appreciation for BIM as a collaboration tool, (2) develop an understanding of BIM as an information modeling and management process and (3) maintain continuity of learning through the years. Survey results indicate the fulfillment of the first and second objectives. In order to prove the validity of this pedagogical model in proving the third objective, the authors' suggest conducting a longitudinal survey after couple of years when the current year of CON252 students are enrolled in the CON453 course. From the observations of the authors, it can also be concluded that students from both the courses developed a sense for the value of integration and collaboration, which is reflective of the modern construction industry. These results indicate that vertical integration contributes to the BIM learning objectives as applied to the two courses (see Tables 3 & 4): developing an understanding of what constitutes BIM, applying BIM to a CM problem and gaining an understanding of BIM as a collaborative tool. For vertical integration to be successful, additional effort is required from instructors including developing up-front planning with clear deliverables, learning objectives and grading criteria. It is also essential that they have knowledge of the available infrastructure support for facilitating co-location.

In conclusion, it can be said that vertical integration for the undergraduate Construction Management curriculum helped students in understanding the significance of the information management piece of BIM. It also instilled an appreciation for co-location, information sharing and the validity of a particular subject such as Building Materials and Methods in the larger perspective of BIM use for Construction Management and Construction Management itself.

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