

Deriving Learning Outcomes for BIM Implementation into the CSM Curriculum based on Industry Expectation

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Building Information Modeling (BIM) has grown in popularity and use over the past decade. The advantages to using BIM throughout the construction phase of a project and on the construction site have been researched and have proven beneficial. The growing trend, especially in larger companies, is that most members of a construction team will access a virtual building model in some fashion during the course of a project. With the growth of BIM use in construction it is important for colleges and universities with a construction management or related degree to properly expose their students to BIM related technologies and practices in order to prepare them for the workforce. This paper looks at the background efforts within the Department of Construction Science and Management (CSM) at Clemson University to implement BIM into its current undergraduate curriculum. Accreditation constraints and university requirements and how they affect curriculum changes are discussed in respect to the decision to implement BIM in a module format. The linking of module learning outcomes to industry needs and current CSM courses is also discussed.

Key Words: Building Information Modeling (BIM), Education, Curriculum Design, Learning Outcomes

Introduction

Building Information Modeling (BIM) is commonly defined as the creation of a model to support the exchange of various types of information to multiple users involved in the design, delivery, and operation of a facility through a data rich, object-oriented, intelligent and parametric digital representation of the facility (Eastman et al. 2008). BIM is the process of using a building information model, or virtual building model, to support activities that take place throughout the life of a building. The model used during the process contains different types of information to support these activities.

BIM use has grown from a design tool into a near necessity for delivering major construction projects. In a 2012 survey, 74% of contractors reported they used BIM in some form and 55% are using BIM on at least 60% of their projects (Fitch, 2012). Similarly, an internal survey to the Department of Construction Science and Management (CSM) Industry Advisory Board members was conducted. Since these organizations are often the companies who hire CSM graduates, their perspective is important to this research. In this survey, 71% of the participating companies are implementing BIM to some degree. Notes from the survey include that BIM usage is not centralized to a BIM manager, but rather most field and office personnel up to superintendents and project managers have some contact with BIM. This suggests that a graduate of CSM as an employee of a construction firm is very likely to have contact with BIM while on the job. Granted there are still many organizations and companies that do not currently utilize BIM. Yet, with BIM's growing popularity, it is important for universities and colleges with a construction management or similar program to properly prepare their students for a work environment where BIM is utilized (Molavi and Shapoorian, 2012; Sacks and Barak, 2010).

This paper examines the formal implementation of BIM into the undergraduate curriculum of the CSM department at Clemson University. Alumni and the Industry Advisory Board have noted that formal exposure to BIM is needed within the educational curriculum to properly prepare students for the workforce. Otherwise, these students would soon be at a disadvantage and need to either pick up the understanding of BIM on their own or through on-the-job experience. With this motive, the CSM department has explored options for implementing BIM into its current curriculum. This involved three main steps:

(1.) Examine how other universities have implemented the use of BIM

(2.) Determine what exposure to BIM is necessary
(3.) Develop a BIM implementation plan that will fit within the curriculum

The first objective was done through a literature review to see what other universities have published. This included examining their findings and perceptions of program success. The second objective involved informal discussions and interviews with various members of the industry who worked for companies that implemented BIM to various extents. The purpose of these discussions was to determine the expectation level of a potential employer would have in terms of a student's exposure to BIM when being hired into an entry level position. These discussions about exposure to BIM were then organized into a list of learning outcomes to use within the curriculum. Lastly, an implementation plan was developed to fit the learning outcomes within the curriculum. The primary focus of this paper is the development of the learning outcomes.

Methods of Implementing BIM into Curriculum

BIM has been slowly introduced to the curriculum of architecture, engineering, and construction degrees, most commonly in a design studio setting or in a digital graphic representation course (Barison and Santos, 2010). A study published in 2011 showed that construction management programs were lagging in adoption as compared to architecture and engineering programs however 87% of those who did currently offer BIM planned to integrate it into their curriculum in some way over the following two years (Becerik-Gerber et.al, 2011). This trend aligns with the increased usage of BIM within the industry through that time period (Finch, 2012).

There are different ways to integrate BIM in the curriculum. These include teaching it as a single-course in one discipline (Gier, 2008; Peterson et.al, 2011), using it in an interdisciplinary setting for collaboration between disciplines (Becerik-Gerber, Ku, and Jazizadeh, 2012), or as a distance collaboration between students at distinct locations (Barison and Santos, 2010). For the time being, BIM implementation is being examined for the CSM discipline as a single domain application, though with its location within the same college as the Department of Architecture there is a potential for a collaborative application of BIM in the future.

Within construction management education there are two common ways to implement BIM into the curriculum. One is as a stand-alone course were all concepts of BIM are integrated into one class while another method is to sprinkle it throughout multiple courses as modules related to the content of each course (Taylor, Liu, and Hein, 2008). Sabongi (2009) reported in a survey that, within a construction management program, only 1 respondent out of 45 taught BIM as a stand-alone course, citing constraints on the curriculum as one of the largest barriers. More commonly, BIM has been showing up in construction management related courses for topical applications, such as in construction documents (Livingston, 2008), materials and methods (Glick et al., 2011), estimating (Sylvester and Dietrich, 2010), mechanical and electrical (Korman & Simonian, 2010), scheduling (Hyatt, 2011), construction project management (Peterson et.al, 2011), or an integrated project/capstone course (Azhar, Sattineni, and Hein, 2010).

Offering a standalone course can have its benefits of allowing for a more in-depth examination of the use of BIM. This can provide a much better understanding of BIM use and how it can link different construction processes. However, there are a few issues with a strictly standalone class in relation to the current CSM curriculum, leaving a standalone course difficult to implement.

In order to work as a standalone class that covers all uses and concepts of BIM, it is best for the students to be previously exposed to the linked concepts. For instance, in order to conduct a quantity take-off with BIM and fully understand a 4-D simulation, it is best for the students to first have taken scheduling and estimating. The course can still cover these aspects of BIM use and walk the students through the processes in a generic fashion, but it is not until the students are formally exposed to these topics and understand what a schedule and estimate represent that they will understand what they are doing with BIM. So with this thinking, the students would first need to be exposed to scheduling and estimating. In the CSM curriculum, these courses take place during the junior year. This would automatically push a designated BIM course to the second semester of the junior year or to the senior year of the program or require the concepts of scheduling and estimating to be introduced at an earlier time, which would require some rewriting of the curriculum. Leaving a designated course late in the curriculum of the program would not allow much practice of BIM in relation to concepts taught throughout the curriculum.

Another issue with the standalone class would be handling university and accrediting body restrictions on the curriculum. Currently, the university will not allow expanding the curriculum to require an additional three credit course in order to allow students a “reasonable” credit load to finish in four years or eight semesters, similar to the challenge listed by 66.7 % of the respondents in the Sabongi (2009) survey. This means that another requirement would need to be dropped in order to create a BIM course. Because of the general education requirements within the university, there are only four free elective courses within the CSM curriculum. Many students use these electives to obtain a business minor so removing a free elective would increase the possibility of a student staying longer in order to obtain the minor. The core curriculum courses are designed to fulfill the current ACCE accreditation requirements, so these courses are required and cannot easily be dropped. The only way to open up a three credit window would be to rewrite the curriculum in a way that would still fulfill the general education and ACCE requirements through a combining of classes and rethinking the entire curriculum, a task that currently cannot easily be done because of resource and time restrictions. In the future, as accreditation requirements change, this may open up other opportunities for course restructuring and changes to the CSM curriculum that would allow for a three credit standalone BIM course, but at this time BIM implementation is being explored using the current curriculum constraints.

These identified constraints have lead to the conclusion that the most feasible method for immediately implementing BIM into the curriculum, so all students can have exposure to it, is at a course by course level using learning modules. The BIM-based learning modules are developed in lines with the learning outcomes of existing classes. This method of implementation can be beneficial to reinforce more abstract concepts with practical exercises and defined applications of BIM while allowing students to practice and gradually grow their technical skills and conceptual understanding of BIM use over multiple courses throughout their experience at Clemson University.

Learning Module Development

In order to decide what modules to include in the curriculum, existing learning outcomes of classes were linked to potential uses of BIM that support those outcomes. This allowed for determining what areas of BIM application and use are possible for including in existing classes to support the material being learned in those classes. For instance, producing a quantity take-off from a model can support the existing learning outcomes of an estimating class. The selection of areas of BIM exposure that would have the most impact on the students’ future careers was important. Since BIM has so many potential uses within the construction industry it is impossible to explore every one in enough detail to give the students adequate exposure. Instead, the key areas of exposure were identified to give the CSM students the building blocks they will need to succeed in their new careers.

The key areas of exposure were determined through a series of industry interviews. Interviews were conducted with personnel of companies that utilize BIM in their daily work practices. These companies were identified through their relationship with the Department and their history of hiring CSM graduates. Eleven interviews with individuals from nine medium to very large construction companies, ranging from $400 million to $5.8 billion of annual revenue, were conducted as a starting point in identifying the areas of exposure to include in the curriculum. Future interviews may be performed when needed to further develop each module. During the interviews, the participants were asked to focus mainly on what a new hire to an entry level position on track to become a project manager or superintendent would be expected to perform during their work day in terms of using BIM.

The interview questions aligned with the subject material in the curriculum. The following questions were asked, targeting what types of information might be incorporated to the corresponding classes.

1. What general exposure to BIM would you expect a new hire to have? (CSM 2040 – Contract Documents)
2. What exposure to BIM with respect to Structures? (CSM 2010/2020 – Structures)
3. What exposure to BIM with respect to Materials and Methods of Construction? (CSM 2030/2050)
4. What exposure to BIM with respect to MEP Systems? (CSM 3040/3050 – Environmental Systems)
5. What exposure to BIM with respect to Estimating? (CSM 3510/3530 – Construction Estimating)
6. What exposure to BIM with respect to Scheduling? (CSM 3520 – Construction Scheduling)
7. What exposure to BIM with respect to Project and Field Management? (CSM 4530 – Const. Proj. Mgmt)
8. What exposure to BIM with respect to an integrated (Capstone) project? (CSM 4540 – Const. Capstone)

Learning Outcomes

Interview responses from each of the question were compiled to form learning outcomes. The modules will then be designed around the learning outcomes. The learning outcomes with the highest level of agreement from across the interviews are listed on top. The learning outcomes and a brief description of BIM uses that can be incorporated into each course are listed below. Learning outcomes are listed as either a "technical objective" or a "conceptual objective". The technical objectives consist of students interacting with a BIM platform to perform tasks while the conceptual objectives require an understanding of how BIM influences the management of the project and may not require direct interaction with BIM software. For courses that have two levels, the learning outcomes are listed for the second level of the course. This will give the students an opportunity to learn the basic fundamentals of the course content in the lower level of the course and then apply BIM to the more advanced or complete concepts in the upper level of the course.

CSM 2040 – Contract Documents

Within this course, the introduction of BIM would be as a natural continuation of plan reading, exposing the students to all aspects of BIM use. Beyond an introduction to BIM use, students would also learn how to navigate the model, learn how the model objects are organized, extract information, and begin to perform small tasks with BIM software. CSM 2040 would serve as the base course for BIM introduction and provide students with a breath of knowledge of applications of BIM and how a virtual building model is managed. The later subject matter courses would expand on this breath of knowledge and allow the students opportunities to practice specific applications of BIM throughout the curriculum at both a conceptual and technical level depending on the course and learning objectives. The CSM 2040 learning outcomes are for students to:

- Develop the ability to navigate around a model for visualization purposes in performance of constructability reviews, looking at details, and producing meaningful detail views of the models to better understand the buildings construction. (technical objective)
- Demonstrate an understanding of how the model is created with different model elements and levels. (technical objective)
- Demonstrate an understanding of how a federated model of component model parts received from different trades is managed within a model viewer (technical and conceptual objective).
- Extract basic information from the model to create spreadsheets of information while demonstrating an understanding of what the information represents and where it comes from. (technical objective)
- Export information in needed file formats. (technical objective)
- Extract equipment information that may be needed for submittals, etc. during the construction process (technical objective)
- Discuss, at a concept level, how BIM can be applied throughout the construction process and what its benefits of use are. (conceptual objective)

CSM 2040 will also expose students to concepts related to BIM, such as Level of Development/Detail (LOD) and what goes into a BIM Execution Plan and how it is used to manage the use of BIM throughout the construction phase of a facility's lifecycle.

CSM 2020 – Structure II

With respect to topics covered in the structures, the learning outcomes closely matched those developed within the Environmental Systems course dealing with model coordination and thus are included in the class that comes later in the curriculum. At the point of conducting a model coordination exercise between structural and mechanical systems within Environmental Systems II, the students would have been exposed to the basics of both systems. Beyond model coordination, the only relevant use of BIM is through structural design analysis. This type of analysis requires a more in-depth understanding of both BIM and structures and is not considered at this time but may be implemented if there is a need for it in the future. At this time, a conceptual objective is to discuss the impacts and applications of this type of model analyses for structural engineering.

CSM 2030/2050 Materials and Methods of Construction I & II

BIM implementation within both CSM 2030 and CSM 2050 would be as a visualization tool. One of the strong points of using a virtual building model is its ability to better convey complex details and assemblies. To this end, BIM can be used as a visualization tool to aid in students understandings of different materials and assemblies discussed in these courses.

CSM 3050 – Environmental Systems II
BIM implementation in CSM 3040 will allow for conducting a coordination exercise of models from different trades. This coordination would examine clashes between the structural, mechanical, plumbing, and other environmental systems. The objectives to be included within this module would include:

- Demonstrating an understanding of the level of development, or level of detail of files in order to understand how accurate the clash detection is. There is a difference in accuracy and detail of models built for design versus those that are used as “shop drawings” for direct manufacturing. (conceptual objective)
- Perform a clash detection by coordinating models from different trades within a model viewer. This would include students developing an understanding of real “hard” clashes in a model versus clearance issues or soft clashes that would show up but not affect construction. This would also include the students determining if all relevant information is modeled to adequately perform the clash and making sure that each sub-model is using the same reference point. (technical and conceptual objective)

CSM 3530 – Construction Estimating II
For estimating, the logical use of a model is to support quantity take-off. The main issues with using any model for quantity take-off is accepting whether the model is accurate or not. Some of the objectives that would need to be built into this module would include:

- Determining level of accuracy for the model to determine if a quantity take-off can accurately be done. (technical and conceptual objective)
- Understand the quantities taken from the model and how to manipulate them in helping to produce an estimate. For instance, objects in a model can represent more than one material, the students would need to be able to determine which quantity represented by each family of objects would be most appropriate in determining each quantity of material to be used. (technical objective)

Since this is a preconstruction objective and not many companies implement this use of BIM in their current practices it may be kept as a conceptual objective. Another difficulty with using BIM for an actual estimate was noted as a lack of clearly defined work flow. Companies are using models to aid in estimation in different ways and those methods will be discussed as part of the learning outcomes.

CSM 3520 – Construction Scheduling
Using BIM for scheduling in construction has widely been connected to 4D simulation. 4D simulation is the practice of tying modeled objects to a schedule to allow for a visualization of the project at different stages of construction. There are mixed reviews from the industry as to what the actual benefit of a 4D simulation is since it is time consuming to do at a very high level of detail. This leaves most of the respondents to the survey stating they use 4D simulation in very limited situations. This leaves the following learning outcomes for this module:

- Demonstrate an understanding of how the model can be linked to the schedule, how the schedule can be updated, and how the model would need to be broken down to properly represent the schedule. (conceptual objective)
- Create a 4D simulation of a simple model and schedule to understand the linking process. (technical objective)
- Demonstrate an understanding of when 4D simulation is most beneficial, such as for “big-picture” scheduling or trade coordination. An example application would be visualizing the breakdown of concrete pours on a job and how this would affect other work on site because of cure times, etc. Most applications of 4D simulation are related to pre-construction planning more so than actual production throughout the project. (conceptual objective)

CSM 4530 – Construction Project Management
For project management the main focus of integrating BIM into the curriculum would be in the sense of using it to management the construction process. In this way, it becomes a project management tool. The learning objectives associated with Construction Project Management include:

- Being able to explain the purpose of and create a BIM execution plan to manage the process of using BIM throughout the project. This would include managing the models from the subs as well as developing uses for BIM, levels of development needed, and defining compatible file formats. They will also need to be able to develop a plan on how to manage the process in order to fulfill deliverable requirements in respect to BIM to the owner. (conceptual objective)
- Demonstrate an understanding of how BIM can be utilized in the field. This includes the use of tablets that are linked to BIM within the field and how to manage documents, RFIs, and other submittals electronically. (conceptual objective)

CSM 4540 – Construction Capstone
The idea behind the capstone project is the students are given basic project requirements and information and they need to develop a plan as to how they would complete the project. The entire idea of developing modules to use throughout the curriculum was so that the students can practice and implement what they learned into the construction capstone course. In this course, the students will be required to integrate different aspects of BIM while developing their projects. They will be expected to be able to develop an appropriate BIM execution plan and explain how they will use BIM on the project. Other aspects of the project may include using BIM to simulate a site laydown or a macro-scale schedule to coordinate trades.

Challenges of Teaching BIM in the Classroom

One of the challenges for implementing BIM throughout the curriculum is the level of technical expertise by all members of the faculty. Do to different backgrounds, research interests, and teaching subject matter not all faculty are technically savvy in the realm of BIM. This has been one of the reasons for BIMs limited use in the past. It is a challenge with respect to the technical objectives listed in the learning outcomes more than the conceptual. The conceptual objectives would be easier for someone to study and learn. Most of the faculty members already have a general understanding of its applications and uses. The technical objectives and technical use of BIM software, and understanding it enough to be able to teach it to students, would generally require much more time and computer knowledge. So the question becomes, who is going to teach BIM in all the courses? And how will it be taught? Though there is no defined answer yet, there are a few possibilities.

One option is to train the faculty who teach those courses on the technical aspects of BIM required to teach that material. Though this is time consuming for the faculty, it would distribute the load of teaching the modules evenly. The conceptual concepts, as mentioned earlier, are not the issue as much as the technical objectives. This would require a predetermined will and want to learn the software to the extent that they can effectively teach it to the students as many BIM applications are not very “user friendly” and have multiple facets to them. With the current demand on faculty within the CSM department it is understandable that there may be resistance to this time consuming method.

Another option would be to use tutorials from outside sources as a resource for the faculty and students to learn the material. This would require less time on the part of the faculty as they would need to be able to understand what the tutorial is asking to help students through the process but would not require a deep knowledge of the software. This would still give exposure to the students at a deep enough level to understand the basics, but may limit them in being pushed to explore things further. The personal exploration of the software can be a tremendous learning experience but there is the possibility of many roadblocks that can cause it to be a frustrating endeavor. If the faculty does not have a deep understanding of the technical aspects of the software and uses of BIM it may be difficult for students to overcome these roadblocks, however with the availability of learning materials on YouTube and other websites, it is becoming easier to self-explore BIM software.

The last alternative would require a designated faculty or a few members of the faculty (or an experienced adjunct specifically hired for the job) who have in depth experience with BIM to teach all the modules. This can be done either in person or through a recorded lecture/tutorial setting. The in person method would allow for direct question and feedback for the students, though can seem extremely slow for students who pick up the technology quickly or too quick and frustrating for students who require more time to pick up the understanding of the software. The recorded tutorial can allow students to stop and pause, or rewind, the video and go through it at their own pace, making sure they do not miss anything along the way. As a last resort a paper based tutorial is also possible for use, though may not be as effective as watching it done on the screen and then doing it yourself. One other benefit of the video based module is that once created it can be used multiple times, thus freeing up the time it takes the designated instructor to teach the material. The course can still be administered by different faculty and the videos become a resource. In this way, the designated faculty who created the tutorial can still be brought in for limited in-person interaction with the students but not have this interaction and teaching of the modules take up too much of their time.

Another challenge to the module-based approach of implementing BIM into the curriculum is the opportunity for knowledge loss and simply forgetting how to perform certain tasks if they are not practiced often enough. Care will have to be given when developing the different modules to try and space them in a way to allow for a more "constant" exposure and consistent practice. This can be done by specifically scheduling the modules in the different classes to make sure they are evenly spaced. This can also be accomplished by breaking a module up into smaller modules and spreading them throughout the semester. This will have to be examined as the modules are created to determine what makes the most sense in respect to other course work.

Future Directions

With the learning objectives to be included within the coursework identified, the actual modules are being developed and thought is being given on the best alternative for teaching the information. The modules will include student exercises and activities so they can practice the use of BIM and demonstrate their understanding of the process. The modules will also include methods for evaluation to check the students' retention and understanding of the knowledge. It is expected that after the students complete the modules they will have a well-developed understanding of how BIM can be used. In order to develop the modules and activities, industry professionals have already expressed an interest in helping in both as the role of guest lecturer and in providing models and realistic problems the students can work through.

Since the modules are set up to build upon one another it will take up to three years to fully implement from the sophomore to senior level. In the meantime, modified modules for upper level classes will be used as to not put the junior and senior level students at a disadvantage in their job search. This will at least allow them some exposure, at least at the conceptual level, to BIM during their education, allowing them to have the basic understanding of its application for when they join the workforce.

Conclusion

The implementation of BIM into the course curriculum as discussed in this paper is as a core requirement for all students to be exposed to. The curriculum objects and learning outcomes are designed around input from industry members that support the CSM program and hire the majority of our graduates. Separately, an elective course may be created to delve deeper into the application of BIM throughout the different construction processes. The elective course would promote a more in-depth exploration of BIM concepts and use within the construction processes and give a wider area of exposure. It would also give a continuous linking of concepts throughout the semester instead of leaving a time gap between modules and risking the loss of knowledge.

Since BIM is ever changing in its application and practical use within the construction industry, these modules will need to be revised every few years to ensure their relevance to the most current industry practices. Long term plans for implementation include having continual input from industry professionals as well as alumni who go through the program to identify areas that can use improvement within the implemented modules as well as to identify new learning outcomes to include in new modules that may need to be added in the future.

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