BIM Undergraduate Capstone Thesis: Student Perceptions and Lessons Learned

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The purpose of this paper is to summarize perceptions of students in an ACCE accredited construction program who completed a BIM centered capstone thesis at the culmination of their undergraduate degree. Eight recent graduates completed an online survey regarding their BIM special thesis project experiences. Although much of their time was spent learning the software, all of the surveyed students believed that completing a BIM thesis was a valuable learning experience. Most of the students are now using BIM technology in their current construction jobs, with about half of them assuming company leadership roles associated with BIM. By embedding BIM in special thesis, and reinforcing the BIM skill set along the way, our goal is to keep our students current with the industry. The authors see it as a pilot strategy for possible long term paradigm shift towards BIM integrated curriculum.

Key Words: BIM, Capstone project, Construction thesis, Undergraduate education, Information technology

Introduction

Building Information Modeling (BIM) is an innovative technology that has transformed the way buildings are designed, constructed and managed (Hardin, 2009; Azhar *et al.*, 2009). According to a recent survey by McGraw-Hill Construction (2008), BIM is being broadly adopted across the construction industry and its use is expected to exponentially expand within firms and across the Architecture, Engineering and Construction (AEC) industry in the coming years. BIM offers the opportunity to unify disparate technologies to provide a coherent Information Technology (IT) skill set for construction students to address the range of problems in the life cycle of a building. It provides a framework that combines visualization and parametric modeling in a way that allows students to simultaneously consider the interdependent processes of planning, analysis, design and construction (Casey, 2008; Azhar *et al.*, 2008). During the last few years, many construction schools felt the need to teach BIM technology to their students to familiarize them with state-of-the-art IT technologies used in the construction industry. Based on a survey of Associated Schools of Construction (ASC) schools, Sabongi (2009) reported that BIM technology is currently being taught in approximately 10% of undergraduate programs in three ways: part of existing IT courses (Taylor *et al.*, 2008), part of other construction courses (Woo, 2007) or as a new course (Burr, 2009). The construction program at Auburn University has incorporated BIM in their existing IT courses to expose this technology to all students. Students with good IT skills can also use BIM to complete their undergraduate capstone thesis. This paper focuses on the perceptions of students at Auburn University who completed a BIM centered capstone thesis. It addresses the learning outcomes for both students and faculty, and suggests future directions to incorporate BIM in the academic curriculum.

Background

All undergraduate students in the construction program at Auburn University have to complete a ‘Thesis Project’ in a capstone course during their final semester. The comprehensive project requires students to work with a set of construction drawings for a light-commercial building of minimum ten thousand square feet. Students have to submit the set of drawings that they have obtained from an architect or contractor to the thesis faculty member in the penultimate semester for approval. Each student works on a unique project, and projects used in the last five years are not allowed to be chosen. Projects range in type from school and church additions, branch banks, post offices and libraries, school building additions, pharmacies, small office buildings, etc. Once the project is approved the student has the last semester to complete the thesis project. In the thesis process students simulate developing a construction company, bidding for the job, and documenting all construction management activities necessary to construct the project. The deliverables for the thesis project are comprised of documents that go with these processes. The final thesis project typically is around 250 to 300 pages in length. The documents include financial data for their fictitious company, complete quantity take-off spreadsheets, pricing sheets and final estimate, contracts and sub-contract documents for the project, sub-contractor scope statements, a project schedule, pay applications, a change order, CPM sheets and project closeout documents. Students must also include a structural assessment and job-specific safety plan. At the end of the semester lots are drawn to assign each thesis to a judge (typically a faculty member, sometimes accompanied by an industry representative). The authors will refer to this type of a project as 'traditional thesis' in this manuscript.

Construction students may also propose an alternate thesis idea known as a 'Special Thesis'. This type of thesis project is unique in that it may not contain all of the elements described in the traditional thesis project above. In order to participate, the student must approach a faculty member to be advisor for the project idea. This faculty member will present the student's proposal to the entire faculty for approval. Once approved, the student will work closely with their project advisor to accomplish the project goals. Typically, only students with exemplary academic records are permitted to conduct such a thesis. Over the years special thesis projects have ranged widely in type and scope. Some examples of previous projects are, sustainable building investigations, bridge projects, demolition projects, historical studies, adaptive reuse, specialty contracting studies, and study abroad projects.

Recently, the department has introduced BIM software into one of its Construction Information Technology (CIT) courses. In response to this exposure, an increased number of students have approached the faculty to do a special thesis using BIM tools. In the course of this project, students were able to meet the majority of the traditional thesis requirements, while incorporating BIM tools. Some portions of the thesis were removed, such as project closeout documents and company financial information. Students were required to draw the architectural, structural and mechanical models using various BIM tools. They used these models to create a project estimate and schedule, later associating it with the building information models. They were therefore able to simulate the construction sequence in a virtual environment using the building information models.

The students are required to model the following elements in the process of working with various BIM tools:

a. It is highly recommended to obtain drawings in electronic format (PDF, CAD) and import into various BIM software applications to complete the thesis.
b. Model architectural components using appropriate BIM software, including but not limited to interior and exterior skin, roof, doors, windows, and stairs. Exclude Landscaping, site utilities, demolition.
c. Model all structural components; including foundation elements, elevated slabs, beams, and columns.
d. Mechanical system should also be modeled using appropriate BIM tools.
e. All thesis documents are submitted electronically in an integrated format with hyperlinked table of contents. Results, including lessons learned, are to be presented to faculty in a 20 minute PowerPoint presentation.

The students are required to submit the following information with regards to the estimate:

a. Project Estimate
    - Specifications take-off
    - Complete Quantity take-off & Pricing
    - Job Overhead
    - Recap w/Alternates
    - Bid Calculation
b. Project estimate will be generated directly from the model, by exporting quantities to spreadsheet or to other estimating software tools.
c. All project quantities must be accounted for, whether or not they are included in the BIM model.
d. Provide an example of the use of hand approximation to check computer generated quantities for one CSI division (e.g. Concrete).

The students are required to submit the following information associated with the schedule and collision detection:

a. Pay Requests with Change Order.
b. Project Schedule
c. Phasing Plan – using Navisworks™ or other appropriate software application
d. Collision Log & Resolution
e. Automatic collision detection should be employed using appropriate software (e.g. Autodesk's Navisworks™) to find and resolve collisions among architectural, structural, and MEP components. A log of all collisions and conflict resolutions should be produced.

Additional information that students are required to submit include the following:

a. Project Photos if possible
b. Model Renderings such as building overview, structural and MEP components, building sections
c. Structural Assessment
d. Site Specific Safety Plan
e. Summary of Lessons Learned
f. PowerPoint Presentation
g. Time Log of student effort on various parts of Thesis
h. Additional Work – e.g. Energy Assessment

To date, eight students have completed this type of special thesis. During their CIT courses, these students demonstrated an expert level of proficiency with visualization software, including BIM. In addition, they were highly motivated to attempt the new special BIM thesis. Furthermore, most of these students began their thesis project prior to the start of the semester. The building projects they chose were more interesting and challenging designs than the typical light commercial buildings investigated in a traditional thesis. Faculty members believe that their above average to excellent performances on thesis was a direct result of this preparation and motivation.

Objectives and Scope

As stated earlier, the main purpose of this research was to analyze the perceptions of students who completed a BIM centered capstone thesis, evaluate its effectiveness for students' learning, and develop strategies for the future. All eight students, who have participated in this special thesis project, have since graduated. The faculty who directed these projects recently contacted these students and had them fill out a questionnaire about their thesis projects.

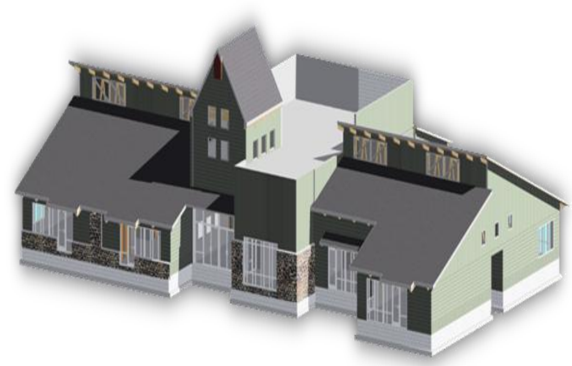
Of the eight students, five used Autodesk Revit™ products for modeling, two used Vico™ products and one student used Bentley™ products. The students using Vico™ products used 'Vico Estimator™' for cost estimation, used 'Vico Control™' for construction scheduling and used 'Vico 5D Presenter™' for construction simulation. All other students used 'Microsoft Excel™' for cost estimation, 'Primavera Suretrack™' for construction scheduling and 'Autodesk Navisworks™' for construction simulation. All students used 'Autodesk Navisworks™' for collision detection between the various models.

The types of projects included multistory residential complex, healthcare facility, small office buildings and school additions. Figure 1 shows building information models of some of these projects.

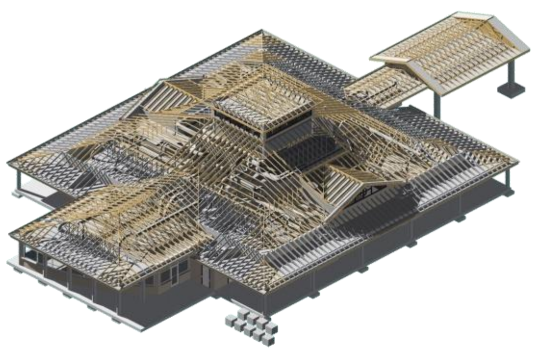
Research Design

The questionnaire was distributed via a web-based service called Zoomerang™ (http://www.zoomerang.com). All eight students completed the survey, yielding a 100 % response rate. This small sample size represents the entire population eligible to participate in this study. Hence, the authors believe that although the results may not be considered statistically significant they are sufficient to draw meaningful conclusions.

(a) Health Care Facility



(b) Montessori School Building



(c) Academy of Early Education Buiding

(d) Multistory Residential Complex

Figure 1: Building Information Models of Projects Chosen and Completed by Students

The questionnaire was comprised of twenty questions and was divided into six sections as follows:

1. General information and students' motivation about BIM
2. Students' prior knowledge of BIM tools
3. Learning BIM software tools during thesis
4. Student's perceptions upon completion of BIM thesis
5. Overall experience of BIM thesis
6. Comments and suggestions for BIM thesis

The results of this survey are discussed in the following section.

Results and Discussion

The mean, median and standard deviation for the responses to selected questions are presented below.

Section 1: Students' Motivation about BIM

Students were asked about their motivation for doing a special thesis involving BIM tools. The students' responses are presented in Table 1. The results indicate that all students picked the special thesis since BIM is a new technology. Students also thought that BIM provides a better understanding of construction processes. Only three students indicated that they decided to do BIM thesis either because it provided better job prospects for them or because it provided an advantage among their fellow students. Students were also asked to comment on this question if there were other reasons they chose the BIM thesis. The comments indicate that students chose this topic because of the challenge it presented and its future potential for transforming the construction industry.

Table 1: *Motivation for doing a BIM special thesis*

	BIM is a new Technology	BIM provides better understanding of construction processes	BIM provided better job prospects	Gives me a competitive advantage over other students
Mean	1.00	0.75	0.38	0.38
Median	1.00	1.00	0.00	0.00
Standard Deviation	0.00	0.46	0.52	0.52

0 = Unchecked, 1 = Checked

Section 2: Students' Prior Knowledge of BIM Tools

Students were asked to rate their knowledge of BIM software tools prior to doing the thesis project. The results for this question are presented in Table 2. A low numerical response indicated very little knowledge about the tools and a high numerical response indicated a good understanding of the BIM tools. The results in Table 2 indicate that students had some prior knowledge of architectural and structural modeling but had little or no knowledge of mechanical modeling, creating an estimate and schedule with the model data or performing collision detection using the various building information models. The high standard deviation for architectural modeling and collision detection indicates the variance in students' knowledge about these tools prior to doing this thesis.

Table 2: *Students' prior knowledge of BIM tools*

	Architecture	Structure	Mechanical	Estimating	Scheduling	Collision Detection
Mean	2.75	2.13	1.75	1.63	1.71	2.00
Median	2.50	2.50	1.00	1.00	2.00	1.50
Standard Deviation	1.28	0.99	1.16	0.92	0.76	1.31

1= Never Used, 2= Some Knowledge, 3= Fair Knowledge, 4= Good Knowledge, 5= Expert

Students were also asked about the proportion of time spent in various ways to learn the BIM software tools. The results to this question are presented in Table 3. The results presented below indicate that they learned some of these tools in a classroom setting but more than half of it was self-taught. Only one student indicated learning some of these tools during an internship.

Table 3: *Learning about BIM software tools*

	Learned in IT classes within the curriculum	Self Taught	Learned during an internship
Mean	43%	51%	6%
Median	40%	55%	0%
Standard Deviation	18%	20%	14%

Students were told that their totals must add up to 100%

Section 3: Learning BIM Software Tools during Thesis

In this section, students were asked to indicate the amount of time they spent learning the BIM software tools while doing their thesis project. The results presented below in Table 4 show that students spent about thirty hours to learn about structural and architectural modeling. The median and the standard deviation for time spent learning architectural and structural modeling indicates that there was some variance in the amount of time spent by students in learning these tools. Students indicated that they spent more than thirty hours learning to model the mechanical drawings for the project. Students spent upwards of ten hours learning to create an estimate with the model data and to create a schedule for the models. Students spent upwards of ten hours learning to perform collision detection between the various building information models. The data shows some variance in the amount of time spent learning the various BIM tools except the mechanical modeling, where all students seemed to spend considerable time.

Table 4: *Time spent learning BIM tools*

	Architecture	Structure	Mechanical	Estimating	Scheduling	Collision Detection
Mean	4.13	3.71	4.38	2.50	2.43	2.13
Median	5.00	4.00	5.00	2.50	2.00	2.00
Standard Deviation	1.36	1.38	0.92	1.20	1.27	1.13

1= 5 or less hrs, 2= Up to 10 hrs, 3= Up to 20 hrs, 4= Up to 30 hrs, 5= 40 or more hrs

Section 4: Student's Perceptions upon Completion of BIM Thesis

First of all, students were asked to rate the difficulty in creating the various models using BIM software tools. The responses presented in Table 5 indicate that the mechanical modeling was significantly more difficult compared to structural and architectural modeling. The standard deviation for mechanical modeling is relatively low compared to architectural modeling, indicating that there is a greater variance in the architectural modeling than mechanical modeling. It is important to note that most students had 'some to fair' knowledge of architectural and structural modeling (see Table 2) as compared to mechanical modeling (i.e. 'never used' to 'some' knowledge), and that might be a contributing factor about their perception of mechanical modeling as 'difficult to very difficult'.

Table 5: *Difficulty in creating various building information models*

	Architectural Modeling	Structural Modeling	Mechanical Modeling
Mean	3	2.71	4.43
Median	2	2.00	5.00
Standard Deviation	1.29	0.95	0.79

1= Very Easy, 2= Easy, 3= Neither Easy nor Difficult, 4= Difficult, 5= Very Difficult

Next, students were asked to rate the accuracy of creating the various models for their thesis project. Their responses to this question are presented in Table 6. The students seemed to think that architectural and structural modeling was more accurate than MEP modeling. The low standard deviation for all responses seems to indicate agreement among students' answers. Again, one possible reason behind this response could be the students' low-knowledge about mechanical modeling.

Table 6: *Accuracy of BIM modeling*

	Architectural Modeling	Structural Modeling	MEP Modeling
Mean	1.71	2.14	3.33
Median	2.00	2.00	3.00
Standard Deviation	0.76	0.38	0.82

1= Very Accurate, 2= Accurate, 3= Neither Accurate nor Inaccurate, 4= Inaccurate, 5= Very Inaccurate

Students were asked about the difficulty of performing various construction specific tasks using the building information models data. The results of this question are presented in Table 7. Students were also asked to rate the difficulty in performing a quantity take-off, pricing and creating a final estimate. The responses seem to indicate that creating this information was neither difficult nor easy. The same rating was given for students' ability to combine the schedule with a building information model for construction simulation. The students found that collision detection between the various models created was relatively easy.

Table 7: *Difficulty in working with various BIM models for construction issues*

	Performing Quantity Take-off, Pricing and Creating Final Estimate	Combining the Schedule with BIM Model for Construction Simulation	Performing Collision Detection using the various BIM Model
Mean	2.93	2.83	1.71
Median	3.00	3.00	2.00
Standard Deviation	0.72	0.75	0.76

1= Very Easy, 2= Easy, 3= Neither Easy nor Difficult, 4= Difficult, 5= Very Difficult

Section 5: Overall Experience of BIM Thesis

In this section, students were asked a few concluding questions about their experience in doing the BIM thesis. They were provided with a few statements to which they had to choose an answer ranging from 'strongly agree' to 'strongly disagree'. The results of this question are presented in Table 8. The results indicate that the students valued doing a BIM capstone thesis. It also seemed to help them in finding a job. Several of them are also using their skills in their current jobs. Interestingly students did not want to recommend using BIM special thesis for all students but rather to only those students who are good at information technology.

Table 8: *Student impressions of doing a BIM Special Thesis*

	Mean	Median	Standard Deviation
BIM thesis provided me the best value time spent	1.50	1.00	0.76
Doing BIM thesis helped me to find a job	2.00	1.00	1.53
I am using the BIM thesis experience in my current job	1.63	1.00	1.06
I recommend BIM thesis for ALL BSCI students	3.50	3.50	1.20
I recommend BIM thesis for THOSE BSCI students who are good in IT	1.75	1.50	0.89

1= Strongly Agree, 2= Agree, 3= Neither Agree nor Disagree, 4= Disagree, 5= Strongly Disagree

Section 6: Comments and Suggestions for BIM Thesis

In this section, two open-ended questions were asked to gather students' comments and suggestions for the BIM thesis. Students were also asked to write some comments about their current job responsibilities if they included BIM. A summary of the responses for both questions is presented below along with some representative quotes.

Several students felt that the requirements provided for doing a BIM thesis were not detailed enough. *"A specialized outline on the requirements of a BIM thesis would help with overall organization."* However comments also indicate that not having strict guidelines enabled them the flexibility of exploring the software tools. *"…the best approach is to create guidelines, but keep them somewhat broad; even a little ambiguous. I enjoyed the freedom to create my own schedule and organization"*

Students had suggestions to align the thesis project more in lines with the current BIM practices within the construction industry. *"It would be helpful to have the thesis requirements to reflect what the industry is currently using BIM for, from a standpoint of a general contractor."* Students suggested that the instructors should stay in regular touch with the industry in order to create guidelines that reflected the industry practices. *"Keep in touch with industry and keep adjusting the thesis as necessary."* Students that used Vico software indicated that they thought the software was very powerful but the lack of proper help for the software is a hindrance. *"While not completely writing Vico off as a loss, I would say that I spent more time trying to wade through the quirkiness of the software than I did gaining knowledge on how to successfully and efficiently use the program."*

Five of the eight students mentioned that they are engaged in BIM activities within their company on a full time basis. Some are working on the jobsite using it on specific projects, while others are working at implementing BIM on a company wide basis. One student indicated being self-employed as a residential contractor and using BIM for presenting ideas to potential clients and using it for performing take offs.

This information points out that six out of eight students are using BIM in their current jobs. This indicates that the BIM thesis experience substantially helped them in their current job responsibilities.

Concluding Remarks

The results of the survey from the eight students who completed the BIM thesis indicate that they all learned from doing a thesis with BIM tools. Most of them chose this format for the thesis in order to learn the latest technology in the construction industry. Based on the student's comments, they did not know all aspects of the technology when they started the process but improved their skills of the technology as a result of the BIM project. Students found it difficult to model the mechanical aspects of the projects. The students did not explicitly mention this but the authors believe that students had trouble understanding the mechanical drawings. This may reflect insufficient time spent on this aspect within the curriculum at Auburn University. There is currently only one course that covers the topics 'Mechanical, Electrical and Plumbing'. Students were able to quickly pick up the details of learning the BIM tools necessary for collision detection. This knowledge is very significant since the author's interaction with industry leaders using BIM tools suggests that this is an invaluable tool for contractors. It is interesting to note that these eight students did not think it appropriate for all construction students to do a BIM thesis. They indicated that this form of thesis may work best with students that have an aptitude for information technology.

As is the case with any spoken language, the key to mastery of BIM is engagement and reinforcement. By introducing BIM to students early in the curriculum, reinforcing the BIM skill set along the way, and making BIM a pivotal tool of a comprehensive thesis project, it is our goal to keep our students current with the industry. The authors see it as a pilot strategy for the eventual paradigm shift towards a BIM integrated curriculum. The feedback received from these eight students is already being used to refine instructions for future BIM thesis projects. The authors plan to collect these data from all students who will complete the BIM thesis (currently 5 students have signed up for Spring 2010 semester and possibly 15-20 students for the Summer 2010 semester) and constantly improve the BIM thesis guidelines and relevance of the overall thesis experience.

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