Evaluation of Building Information Modeling (BIM) Estimating Methods in Construction Education

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Estimating in construction education has remained relatively unchanged despite continual technological advances. Currently, students conduct time consuming quantifications and take-offs from construction documents. This traditional estimating process is disconnected from the physical building leading to greater differences between estimated and actual construction costs. To remedy this condition, significant technological advances in building information modeling have occurred and now allow professionals to link components of three-dimensional computer models to costs databases eliminating human error and reducing time. Accepting that estimates are projections for future construction costs and thus profits, this comparison study seeks to understand how the visual processes of BIM estimating improves our ability to accurately assess building construction costs beyond mere speculation. Overall, this comparison study examines the ability of BIM estimating procedures for integration within construction education and its ability to improve student's understanding of the estimating process.

Key Words: Building Information Modeling, Estimating, Construction Education

Introduction

The ability to estimate is the most required skill for construction professionals. Estimating is a process that involves the science of technical computing processes and the art of creative problem solving to create reliable detailed estimates that quantify material, labor and equipment needs and associates these items with their related costs (Miller & Mills, 2002).

Within the classroom, estimating is taught using varying instructional methods causing a high degree of variation in student estimates and their ability to understand estimating (Adcox, 2004). This condition is also compounded by the industry experience of students and their ability to recall prior course content. Not only do estimates vary greatly in student work, but significant time is spent interpreting construction documents. While construction documents are the same for all students in a classroom, interpretation of construction documents account for the greatest variability in the detailed estimates created by students. To reduce this variance, estimating using building information modeling (BIM) methods relates our understanding of building materials contained within the model to the construction methods used to put them in place. More importantly, BIM estimating methods help estimators visualize real world conditions through a virtual three-dimensional construction of the building. This approach provides a definitive method for learning estimating that currently does not exist. Likewise, students as well as practitioners are able to spend the bulk of their time validating the quantities and cost contained within their estimates rather than simply creating the estimate. This paper presents an assessment of BIM estimating in comparison to traditional teaching methods of estimating. Acknowledging the development of on screen take off methods, spreadsheet software, estimating software and digitizing tablets when using electronic bid document, this paper focuses on the use of three-dimensional visualization techniques of BIM to quantify and cost the material, labor and equipment of a select building. This paper assumes that the use of BIM estimating procedures can be taught to undergraduate students with increased reliability and effectiveness over traditional methods.

According to the *National Building Information Modeling Standard* (National Institute of Building Sciences, 2007), BIM is defined as a digital representation of physical building characteristics that allow for reliable decision making throughout the life of a project. As a logical extension of three-dimensional modeling, BIM models can be expanded to factor detailed construction costs and scheduled activities. However, not all BIM software have the same

functionality and in all cases BIM software require third party software to conduct specialized activities related to detailed cost estimating. Thus, accuracy of the BIM estimate is dependent upon 1) the detail of the BIM model, 2) our understanding of construction assemblies and 3) how building assemblies are represent in cost databases.

Construction Visualization

As planners and creators of the built environment, construction practice and education heavily relies on visual or active learning styles, in addition to written or spoken information. Because, students majoring in construction are more likely to be visual learners (Kolb, 1981), construction education has broadly implemented construction laboratories to improve teaching effectiveness and overall student performance. Thus, it is the stance of this study that virtual construction of three dimensional models ensures more complete comprehension buildings given the physical limitations of traditional construction laboratories and the two dimensional construction documents.

Specifically, computer visual analysis techniques include 1) digital prototyping (Economist, 1994) (Porter, 1994) and 2) Virtual Reality Modeling Language (VRML) (Campbell, 2000). Digital prototyping has been proven successful in manufacturing of precise aircraft components and in creating and testing variations in engine design (Economist, 1994) (Porter, 1994). VRML, a tool that provides interactive navigation of three-dimensional information, has been explored on an experimental basis to understand the built environment before construction (Campbell, 2000). In all cases, three-dimensional models are requisite to computer aided processes and have revealed the ability to significantly aid the construction of buildings throughout the construction process (Cole et al., 1994) (Pilgrim & Sylvester, 2003) (Back, et al., 2000). Consequently, we now explore building construction using digital standards such as building information modeling (BIM). It is when competencies of visual analysis become routine that digital models will transform the construction industry (Holness, 2008).

Construction visualization, which allows visual analysis of technical data, has been heavily researched in the past twenty years. Improved and more accessible CAD software have received greater acceptance by the construction industry over the past decade. Three-dimensional digital models and their time and cost savings capabilities have been recognized by design, industrial plant, and heavy highway industries (Anderson, 1995). Currently, CAD software is expanding to building information modeling concepts of design, estimating, scheduling and three-dimensional models (Collier and Fischer, 1995).

Yet, BIM software falls into two categories. Some applications support more comprehensive authoring of three dimensions data and multi-attribute information regarding buildings and their components. Others primarily support the creation of three-dimensional data. It is important to note that state-of-the-art BIM Estimating processes can require several software packages to create viable and usable results. Likewise, BIM software can vary greatly based on its target audience, such as design, preconstruction, and facility management professionals.
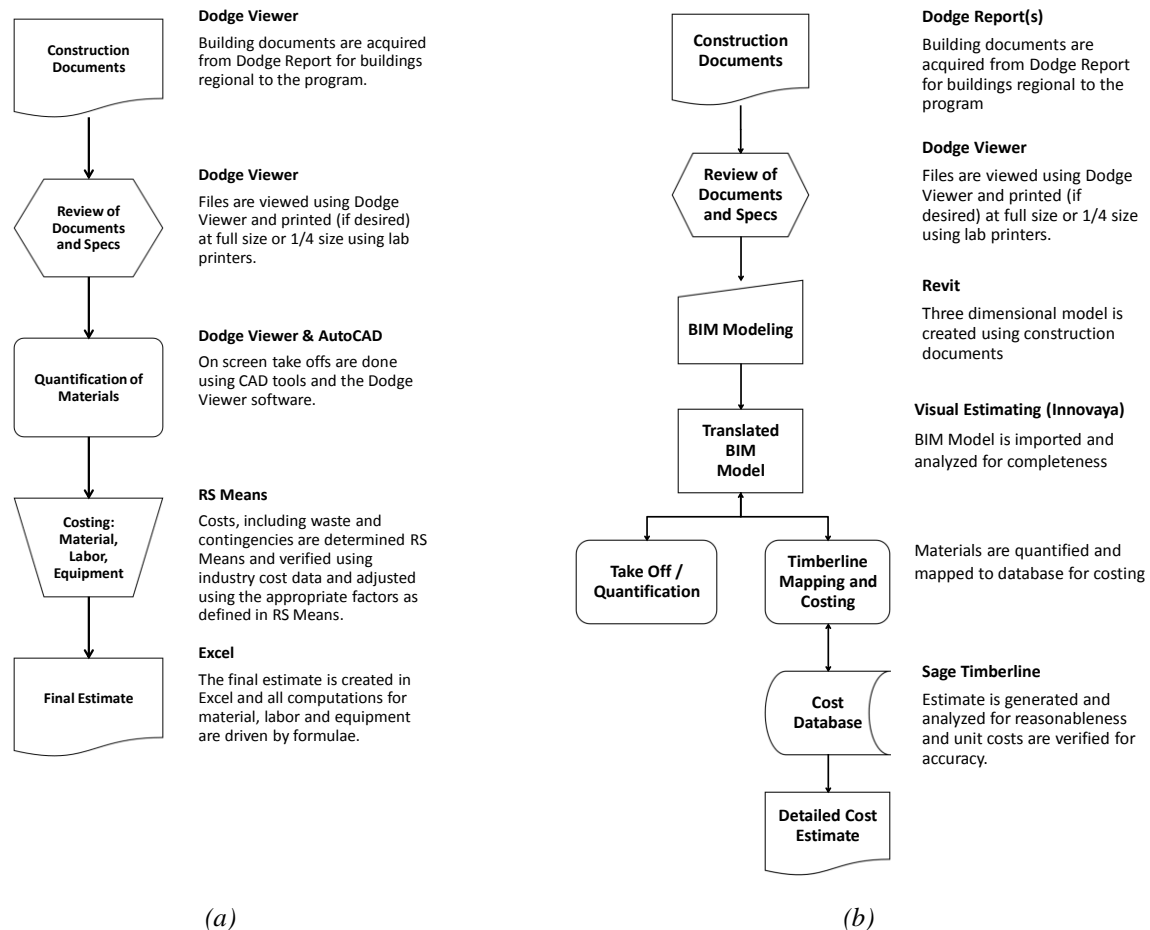
Traditional estimating method (a):

Construction Documents

Dodge Viewer
Building documents are acquired from Dodge Report for buildings regional to the program.

Review of Documents and Specs

Dodge Viewer
Files are viewed using Dodge Viewer and printed (if desired) at full size or 1/4 size using lab printers.

Quantification of Materials

Dodge Viewer & AutoCAD
On screen take offs are done using CAD tools and the Dodge Viewer software.

Costing: Material, Labor, Equipment

RS Means
Costs, including waste and contingencies are determined RS Means and verified using industry cost data and adjusted using the appropriate factors as defined in RS Means.

Final Estimate

Excel
The final estimate is created in Excel and all computations for material, labor and equipment are driven by formulae.

(a)

BIM estimating method (b):

Construction Documents

Dodge Report(s)
Building documents are acquired from Dodge Report for buildings regional to the program

Review of Documents and Specs

Dodge Viewer
Files are viewed using Dodge Viewer and printed (if desired) at full size or 1/4 size using lab printers.

BIM Modeling

Revit
Three dimensional model is created using construction documents

Translated BIM Model

Visual Estimating (Innovaya)
BIM Model is imported and analyzed for completeness

Take Off / Quantification

Timberline Mapping and Costing

Materials are quantified and mapped to database for costing

Cost Database

Sage Timberline
Estimate is generated and analyzed for reasonableness and unit costs are verified for accuracy.

Detailed Cost Estimate

(b)

Figure 1: Traditional vs. BIM estimating method.

BIM Estimating

It is not the intent of this paper to review existing software. Rather, this paper presents a select state-of the-art BIM estimating method that has been researched and tested. When using the term Visual Estimating or BIM-enabled estimating, this paper is referring to a process that uses Innovaya Visual Estimating software to bridge modeling and project data from Revit software to building construction cost data within Sage Timberline software.

Estimating using Building Information Modeling (BIM) software, in conjunction with cost data, is a comprehensive process that maps components of three-dimensional building models to material, labor and equipment cost data. However, the reliability of BIM estimates is dependent on the accuracy and completeness of the three-dimensional model which is often simplified with minimal construction or assembly information. These models are often not constructed from the viewpoint of the constructor. As a result, assumptions made during this new estimating process vary from those made traditionally and can significantly affect the estimates value.

BIM-enabled estimating is an interfacing process that allows the user to generate object quantities from an imported BIM model and that allows the user to perform cost estimating by linking quantities to cost data. While efficiency is significantly improved, to achieve maximum efficiencies a detailed BIM model and comprehensive and updated cost database is required. Associations are automatically recorded between object types and cost database for current and future uses. As new associations are defined, the efficiency of subsequent BIM estimates increases. With interconnected object quantities and estimate items, estimates are easily updated with each reloading of the modified

three-dimensional model from the BIM software. Overall, BIM estimating greatly improves accuracy of an estimate giving the estimator a better understanding of what is being estimated.

Methods

As comparison study, this work defines BIM-enabled estimating methods, identifies opportunities for implementation of BIM-enabled method in construction estimating practices, and conducts a comparison of student Class estimates using traditional methods as compared to a BIM-enable construction estimate. To accomplish these objectives, a comparison of real world data, student classroom construction estimates and a corresponding BIM estimate were created and compared to a select commercial building built in 1999. While, the control group of the class estimate was 60 students, the BIM-enabled estimate was created as a group project by three undergraduate students as an independent study.

The select building is a Type IV construction with two stories and approximately 29,000 square feet of heated space. The building has a steel-framed, web joist structure with brick cladding, all supported by a typical foundation beam system with interconnected and isolated footings.

In the study, the data were categorized by CSI division and compared. The actual building costs were used and adjusted for present worth. For the Class estimate, costs included detailed data for concrete, masonry and metals only. An undergraduate student researcher created the BIM estimate during the following semester. These activities included modeling, identification of software, software acquisition and maintenance, and updating of the cost database to current values. The visual estimating software was used to link the three-dimensional model of the select building to the material, labor and equipment costs. The estimated construction costs of the BIM process were then compared to documented construction costs of the select building and traditional classroom estimates

Procedures

For the Class estimate, Microsoft Excel and AutoCAD were used to quantify materials and *RS Means Building Construction Cost Data* was used to estimate costs. During the first portion of the semester, lectures and weekly estimating assignments were given. For the second portion of the semester, a detailed cost estimate was performed for the select building. Due to time limitations of the course, only three systems, metals, concrete, and masonry are analyzed to create the class estimate. As shown in Figure 1a, the project was acquired from the Dodge Construction Project database managed by McGraw Hill Construction. Following file downloads, drawings are viewed using Dodge Viewer and printed. On screen take offs were also created using the Dodge Viewer, in addition to CAD software. Material quantities were imported into Excel to create the Class estimate, including waste and contingencies. Construction costs were then determined using *RS Means Building Construction Cost Data*, verified using industry cost data, and adjusted for profit and location.

Table 1

Average class values as compared to actual costs

Method	Actual ($)	Class($)	% Diff
Metals	276,097	302,944	9.27%
Masonry	214,176	87,250	-84.22%
Concrete	151,189	82,274	-59.04%
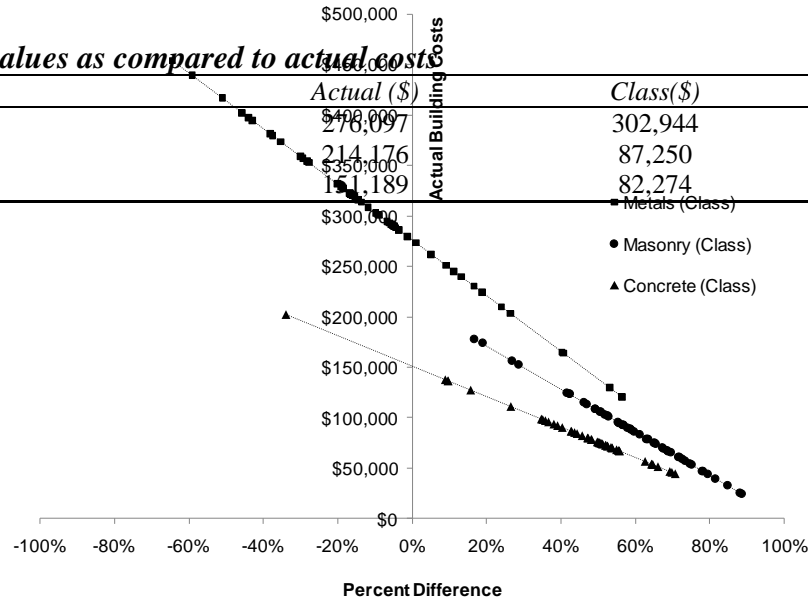
Figure 2: Comparison of student results and actual costs.

As shown in Figure 1b, the estimating process is significantly modified after acquiring documents from the project database. Like before, drawings are viewed using Dodge Viewer and printed. However, this is only a cursory step to prepare files for import into CAD software for modeling. Some initial CAD drafting maybe required. Nonetheless, the three-dimensional model was created from the construction documents in a virtual construction process. Following, the BIM Model is imported into Visual Estimator software and analyzed for completeness. Materials were quantified and mapped to the Sage Timberline database for costing, and the estimate was generated and analyzed for reasonableness. Unit costs are verified for accuracy using *RS Means Building Construction Cost Data*.

Results

The actual construction cost data were acquired from the general contractor and brought to present worth with an escalation rate of 3% over 10 years. Overall, the difference in cost to construct the building in today's value is $673,578. To analyze the student work a scatter plot comparing the actual building cost to the student responses was created for the areas of metals, masonry and concrete. The mean student response for Metals shows greater agreement with the actual cost as compared to Concrete and Masonry (Figure 2 and Table 1). Investigations into this conditions show that while estimating methods used by the students were sound, they often failed to include all construction components related the select tasks. Consistent with this occurrence, related costs for erecting the steel building are often included in the steel material cost item, minimizing the need to define such secondary activities in the estimate. As seen in Table 2, a 9.7% difference exists between the Class estimate for steel and the Actual costs. For Metals and Masonry, the percent difference between the Class estimate and the Actual costs are severe and are not used in the final comparison.
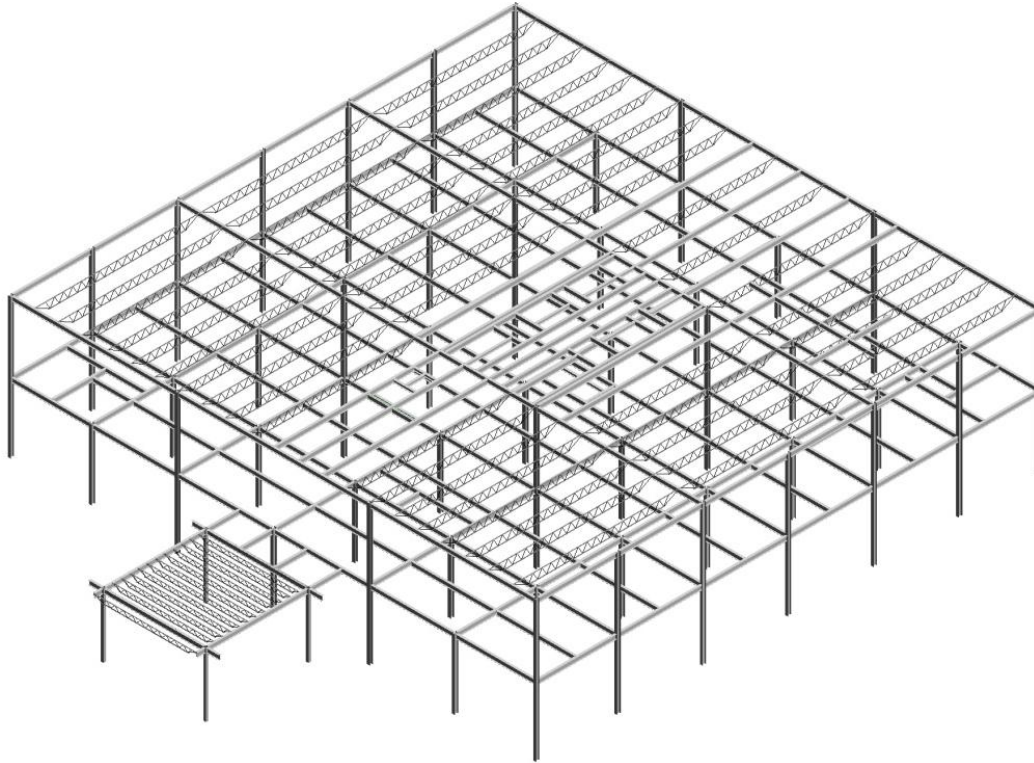
Figure 3: Steel frame used in BIM estimate.

BIM estimate

Due to the agreement between the Class steel estimate and the Actual costs, the BIM estimate focused on the steel framed construction for analysis and comparison. The BIM-enabled estimating process included a literature review, defining criteria for software selection, discussions with software vendors, discussions with the industry users, and learning the functionality of the software. Figure 3 shows the three-dimensional model used to create the BIM estimate.

Table 2

Cost comparison for metals by method

Method	$	% Diff
Actual Cost	276,097	-
Classroom Average	302,945	9.72
BIM estimate	256,952	-6.93

Overall, the BIM estimate generated a cost that is 6.93% less than the Actual cost of the steel components of the building. While confounding factors of profit exists, this difference is partially due to the scope of the BIM estimate. That is, the BIM estimate does not include related metal costs such as metal studs, rebar, corrugated metal and other metal accessories that are included within the Actual costs.

Conclusions

This study assumes that the use of BIM to estimate material, labor and equipment costs on projects will provide more accurate estimates by visually linking construction components with their related costs. Furthermore, students who learn BIM-enabled estimating are better prepared for changing practices in a rapidly growing construction industry. Students may possess knowledge of BIM tools, however, formal instruction in required to navigate

complex processes. Too often students are allowed to set technological standards due the rapidly changing state of technology and the effort of faculty to stay current. As we define construction curricula for the 21st Century, students must be able to create and analyze BIM models to meet current and future needs of the construction industry. Likewise, faculty must also engage in continuous professional development to maintain growing technological standards.

When applying this BIM estimating process, students gain associative knowledge of building construction processes and systems, improve their ability to read construction documents with a clear understand the intent of the architect, and gain a valuable 21st century skill. When teaching estimating, students ability to account for all components is directly related to their construction experience and the application of prior knowledge. Since most students do not have significant experience and since their learning is in its infancy, this study shows that teaching BIM methods for quantifying and costing major systems can yield high levels of success. Likewise, as student become more familiar with estimating methods and BIM technology, student success will become more a matter of process, rather than effort.

Additionally, the benefits of BIM are improved accuracy of quantities and the related costs and increased reliability and consistency in student responses when compared to real world data. While general investigations with BIM are easily performed, estimating and scheduling activities are complex and require formal instruction by knowledgeable faculty. It is important to note that faculty cannot only be trained; they must also be knowledgeable of estimating methods and the problem solving processes that are required to engage state-of-the-art estimating building tools.

We are now breaking the limitations of the industry that have prohibited BIM analysis methods from becoming efficient common practices. In order to implement BIM estimating methods, companies must possess adequate hardware and software capable of performing high performance computing. Likewise, related software and hardware to conduct the presented BIM estimating procedure has significant costs and requires experienced individuals competent with BIM software and varying estimating procedures.

Future Work

As comparison study, this work defines BIM-enabled estimating methods, identifies opportunities for implementation of BIM-enabled method in construction estimating practices, and conducts a comparison of student Class estimates using traditional methods as compared to a BIM-enable construction estimating. To measure the effect of BIM-enabled estimating methods on student learning, future work will conduct a controlled experiment comparing student outcomes using the defined traditional and BIM-enabled estimating methods presented in this paper.

Acknowledgements

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