

Streamlining Takeoff and Estimating with BIM: A Case Study of a Construction Cost Estimating Course

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Abstract: Since the construction industry has been adopting Building Information Modeling (BIM) as the standard practice for design, engineering, and fabrication in the recent decade, many Construction Management (CM) programs at U.S. universities have started to introduce BIM for cost estimating in their curriculum. Although considered as the fifth dimension beyond 3D and schedule, BIM for cost estimating in many cases is still used merely as an alternative model-based quantity takeoff method to the traditional plan-based approach. The disconnection between automated quantity takeoff and cost estimating, however, still exists, and the benefits of the BIM process in a project life cycle can not be fully understood by CM students without realizing its impact in the preconstruction phase. To bridge these gaps in a CM curriculum, an Advanced Cost Estimating course for CM programs has been developed that focuses on integrating BIM in both the takeoff and estimating process. The new course streamlines the connection between model-based quantity takeoff and cost estimating with the help of a combination of multiple construction software programs. Through the integration between the software, quantity data from a BIM model can be seamlessly transferred to a construction cost database for bid pricing and reporting. This paper presents the development of the new Advanced Cost Estimating course as a case study, including its objectives, layout, and assessment methods, and provides empirical and valuable insights on how to integrate BIM in a cost estimating course for a CM curriculum.

Key words: Quantity takeoff, cost estimating, BIM, CM, education.

1. Introduction

As the construction industry has adopted Building Information Modeling (BIM) as the standard practice for design, engineering, and fabrication, Construction Management (CM) programs in the U.S. have been actively introducing BIM in their curriculum for various construction-related topics, including cost estimating. Many, however, consider model-based quantity takeoff merely as an alternative approach to the traditional plan-based quantity takeoff, and there is still a disconnection between model-based quantity takeoff and automated cost estimating. With the advancement of construction software programs in recent years, this connection has been established and new approaches have emerged for cost estimating with BIM.

Using the latest technologies as instructional tools,

this paper presents a newly developed Advanced Cost Estimating course for CM programs that focuses on integrating BIM in both the takeoff and estimating process. The objectives of developing the new course are to: (1) introduce BIM for cost estimating in a CM program; (2) connect model-based quantity takeoff to automated cost estimating; (3) practice assembly takeoff and estimating with a computer-based cost database; and (4) prepare CM students for a comprehensive cost estimate in the capstone course. By applying a combination of three different computer programs, quantity data from a BIM model can be seamlessly transferred to a construction cost database for bid pricing and reporting. This paper provides an empirical case study with valuable insights on how to integrate BIM in a cost estimating course in a CM program.

2. Background

2.1 BIM in CM Education

According to a survey by Pavelko and Chasey [1],

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out of 59 ACCE-accredited Associated Schools of Construction member programs, 70% already had included BIM contents in 2010, of which about a third had taught BIM for cost estimating. In a similar survey by Joannides et al. [2], out of 35 ACCE-accredited construction programs, 83% had covered BIM contents in 2012, of which one fifth had BIM-related cost estimating topics. Huang [3] summarized the different approaches the various CM programs had adopted to incorporate BIM in their curriculum, including standalone courses. cross-discipline courses, capstone/project courses, and integration into existing courses.

Introducing BIM in standalone courses is an effective approach to quickly cover BIM components. Many CM programs introduce BIM in a standalone course to replace an existing lower level CAD course, such as Digital Graphical Representation, Graphical Communication, and Construction Information Technology [4, 5]. These courses often focus on the specific skills of 3D modeling in Autodesk Revit or Trimble SketchUp [6, 7]. Some CM programs introduce BIM by allowing students to take cross-discipline courses from other programs such as civil engineering workshops and architecture studios [8]. While this approach is efficient at some extent and takes the maximal use of existing resources, these cross-discipline courses often focus towards design and away from CM topics. Implementing BIM in a capstone project allows students to learn the BIM process in various CM subjects throughout the project cycle [9]. However, teaching BIM within a one- or even two-semester capstone project limits the use of BIM in each CM discipline to only a couple of weeks due to time constraint. As a result, students get only a basic understanding of the BIM process and their BIM skills fall short of the expectation to become fluent. Integrating BIM into existing courses is considered the most practical way to offer BIM [10]. This strategy typically divides BIM contents into smaller and manageable topics, and thus can provide CM

students with a rich and rigorous learning environment and consequently better quality of education [7].

2.2 BIM in Quantity Takeoff

BIM models have made the quantity takeoff process significantly easier over 2D drawings because the 3D objects have contained dimension and material information. Depending on its Level of Development, a BIM model can be used for quantity takeoff at various stages of a project for different accuracy levels. Many BIM programs have the capability of performing model-based quantity takeoff. Eberhardt et al. [11] compared students' uses of Autodesk Revit and Autodesk Navisworks for quantity takeoff in an estimating course. Elliot et al. [12] examined student perceptions of using Autodesk Revit for quantity takeoff in an estimating course. Both studies, however, focused only on model-based quantity takeoff and did not connect with cost estimating despite describing the tasks as model-based estimating.

In addition to Revit and Navisworks, Table 1 lists other available BIM software programs for quantity takeoff along with the required module or version. These programs can either open a local model in AutoCAD, Revit, Navisworks, or Tekla file type, or connect to Autodesk's cloud service BIM 360 and access the model from the cloud. The programs also work differently when performing model-based quantity takeoff. Some programs simply take off everything within the model and present a master spreadsheet, such as Assemble and Revit, while others allow individual object takeoff, such as Navisworks, Vico Office, and Innovaya Visual Quantity Takeoff.

2.3 BIM in Cost Estimating

Connecting model-based quantity takeoff to a construction cost database is required to perform cost estimating and generate cost reports, which used to be a challenge for model-based estimating due to the lack of available software programs. With new

technologies, programs are now able to connect a takeoff source to a cost database, which bridges the gap and enables the workflow of model-based takeoff and estimating.

Table 2 presents a list of available software programs that are able to perform model-based cost estimating. Some programs contain the quantity takeoff module within itself as a full package, such as DESTINI Estimator, Sigma Estimates, and Vico Office, while others need to connect to a quantity takeoff program as the data source. eTakeoff Bridge can connect to either Assemble or Navisworks while Innovava Visual Estimating needs to access quantity data from its own Visual Quantity Takeoff. Once the quantity data is ready, the estimating program will access a cost database to apply a unit price to the quantity of each cost item in the takeoff. All programs can access the RSMeans cost database as a standard construction cost database. eTakeoff Bridge and Innovaya Visual Estimating access the RSMeans cost database by first connecting with Sage Estimating while the RSMeans cost database is integrated with Sage Estimating. DESTINI Estimator, Sigma Estimates, and Vico Office allow the RSMeans cost database to be directly imported to the program for cost estimating, or simply use a customized cost database created before estimating within the program.

Based on the available BIM software programs for quantity takeoff and cost estimating and how they interact with each other, the available workflow of integrated model-based takeoff and estimating methods using industry standardized RSMeans data is summarized in Table 3.

3. Case Study: Advanced Cost Estimating

3.1 Course Overview

The Advanced Cost Estimating course aims to focus on additional quantity takeoff and cost estimating skills beyond the basic Cost Estimating course that students already took as a prerequisite. These new skills include using BIM models for quantity takeoff, streamlining model-based takeoff and cost estimating with Sage Estimating, applying RSMeans Assembly cost database, and creating a summary-level cost estimate with Sage Estimating. Eventually, the Advanced Cost Estimating course prepares CM students for the capstone course where they will be required to create a bid package including a comprehensive cost estimate. Based on the course goals, Sage Estimating and the RSMeans cost database are required for CM

Developer	Model-based takeoff program	Module/version	BIM model source
Autodesk	Assemble		BIM 360/Navisworks
Beck Technology	DESTINI Estimator		BIM 360/Navisworks
Autodesk	Navisworks Manage	Quantification	AutoCAD/BIM 360/Navisworks/Revit
Autodesk	Revit	Schedule	Revit
Sigma	Sigma Estimates	Enterprise	BIM 360/Revit
Trimble	Vico Office	Cost Planner	Revit/Tekla
Innovaya	Visual Quantity Takeoff		AutoCAD/Revit/Tekla

 Table 1
 List of available BIM software programs for quantity takeoff.

Table 2	List of	f available	BIM	software	programs	for	cost	estimating
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Developer	Model-based estimating program	Takeoff source	Cost database
eTakeoff	Bridge	Assemble/Navisworks	Sage + RSMeans
Beck Technology	DESTINI Estimator	Native	RSMeans/Custom
Sigma	Sigma Estimates	Native	RSMeans/Custom
Trimble	Vico Office	Native	RSMeans/Custom
Innovaya	Visual Estimating	Visual Quantity Takeoff	Sage + RSMeans

students. Due to the popularity of Navisworks in the CM field and eTakeoff Bridge being bundled with Sage Estimating, the workflow of Navisworks model + Navisworks Manage + eTakeoff Bridge + Sage Estimating with RSMeans database was selected as the software programs for the Advanced Cost Estimating course, as shown in the red path within the available workflow combinations in Fig. 1.

3.2 Course Objectives

Five course objectives were developed to match the course goals and in the meanwhile align with the six levels of cognitive learning process in Bloom's Taxonomy, which are "remember, understand, apply, analyze, evaluate, and create" from lower- to higher-order thinking skills [13]. As shown in Fig. 2, Objective 1 "Describe different construction cost estimating types and methods" belongs to lower-level

cognitive learning process "remember" and "understand", and Objective 2 "Compare the MasterFormat and UniFormat divisional systems" and Objective 3 "Explain the BIM process and its relevant concepts" align with lower- to mid-level cognitive learning process "understand" and "apply." Objective 4 "Demonstrate model-based quantity takeoff with a BIM program" covers mid-level cognitive learning process "apply" and "analyze" while Objective 5 "Create a comprehensive construction cost estimate with a computer-based RSMeans cost database" aims at higher-level cognitive learning process "evaluate" and "create."

3.3 Course Layout

Over twenty course topics were developed to meet the needs of the five course objectives during a fourteen-week schedule not including time for exams,

 Table 3 Available workflow of integrated model-based takeoff and estimating methods.



Fig. 1 Selected software programs among available workflow combinations for the advanced cost estimating course.



Fig. 2 Course objectives associated with bloom's taxonomy.

as detailed in Table 4. In the first two weeks, the course introduces different types of conceptual estimating, refreshes unit price estimating, which was covered in the prerequisite Cost Estimating course, and compares it with assembly estimating, which is the primary estimating method in this course. These topics fulfill the needs of Objectives 1 and 2. In the next two weeks, the course switches to BIM-related topics, including the BIM process, the evolvement and management of federated model, and the Level of Development (LOD). Students start to learn the basic navigation of Navisworks, including display options, the selection tree, creating sets, and search features, and get ready for the upcoming model-based quantity takeoff. These topics fulfill the requirements of Objective 3.

The majority of course topics occur between week 5 and week 12 when individual assemblies are introduced, followed by a computer lab session for each topic, which covers 7 divisions from concrete foundation, masonry, steel framing, to insulation and interior finish. Using the UniFormat divisional system, students are instructed to take off selected assemblies within a federated model using Navisworks, locate the same assembly item and complete the required quantity inputs in eTakeoff Bridge, and send the assembly estimate to Sage Estimating. The federated model contains most of the assembly types and is used throughout all the assembly topics. These topics satisfy the requirements of Objective 4. During the last two weeks, students learn to combine all separate estimates created in previous weeks using Sage Estimating and add additional items to the total cost, such as general conditions, profit, and contingency. Students then create different types of cost reports, including detail- or summary-level cost estimates sorted by UniFormat divisions or assemblies. The course project as the final activity is to develop a similar cost estimate report with all the knowledge and skills learned for a different federated model and submit a total price for bidding. The course project is designed as a group project for two to three members per group and is allocated within the class time for students to complete.

3.4 Course Assessment

The course uses a weighted grading system with six categories including participation (10%), seven assignments (25%), fifteen computer labs (25%), midterm exam (10%), final exam (15%), and project (15%). Participation includes five times of random sign-in throughout the semester. Assignments include short answer questions, manual conceptual estimating questions, and model-based takeoff and estimating

Course objectives	Course topics	Course schedule	
1. Describe different construction cost estimating types and methods	Conceptual Estimating	Week 1	
2. Compare the MasterFormat and UniFormat divisional systems	Unit Price Estimating		
	Assembly Estimating	Week 2	
3. Explain the BIM process and its relevant concepts	Federated Model	Week 3	
	Level of Development		
	Introduction to Navisworks	Week 4	
4. Demonstrate model-based quantity takeoff with a BIM program	17 assemblies from 6 divisions:		
	03 Concrete	Week 5-6	
	04 Masonry	Week 7	
	05 Steel	Week 8-9	
	06 Wood	Week 10	
	07 Insulation	Week 11	
	09 Finishes	Week 12	
5. Create a comprehensive construction cost estimate with a	Estimate Summary	Week 13	
computer-based RSMeans cost database	2 Project Work Days	Week 14	

Table 4	Course to	pics associa	ated with c	objectives	and schedule.

questions. Both exams have a close-book multiple-choice and terminology section and an open-book model-based takeoff and estimating section. The project, as described earlier, is a small-group project to be completed within two classes.

Each course objective is assessed against a specific assessment criterion by at least two assessment methods. Objectives 1 and 2 are assessed by two assignments and multiple-choice questions in the exams to evaluate students' ability to select a correct method for any given project information and to locate cost information in different divisional systems, respectively. Objectives 3 and 4 are assessed by five assignments, fifteen lab reports, terminology questions, and model-based takeoff and estimating questions in the exams to evaluate students' ability to identify LOD levels and navigate in a federated model, and to perform quantity takeoff with Navisworks and develop cost estimates with eTakeoff Bridge, respectively. Objective 5 is assessed by the course project to evaluate students' ability to create a Sage cost estimate report with RSMeans database.

3.5 Course Evaluation

Since this course has only been offered for three times and two of them were during the COVID-19

pandemic, the information collected on student performance and feedback was inadequate and inconsistent to statistically evaluate the course. Nevertheless, student surveys at the end of each semester suggested that using BIM models for construction takeoff and estimating with building assemblies can greatly improve student understanding of knowledge and consequently strengthen the learning outcomes. Future research will continue on course evaluation via the following methods:

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

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

improvements, etc. The feedback of questionnaires will be used to improve future course offerings.

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

4. Conclusions

As BIM is becoming the standard practice for and fabrication design, engineering, in the construction industry, model-based quantity takeoff and cost estimating have been a new trend over the traditional plan-based approach. There is, however, a disconnection between automated quantity takeoff and cost estimating in many CM programs in the U.S. This paper presents a newly developed Advanced Cost Estimating course for CM programs that focuses on integrating BIM in both the takeoff and estimating process and provides an empirical case study with valuable insights on how to integrate BIM in a cost estimating course in a CM program.

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