Integrating BIM in Construction Takeoff and Estimating: A Case Study of an Advanced Cost Estimating Course for Construction Management

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Abstract: As Building Information Modeling (BIM) is becoming the standard practice for design, engineering, and fabrication in the construction industry, Construction Management (CM) programs have started to introduce BIM for cost estimating in their curriculum. Many CM programs consider model-based quantity takeoff merely as an alternative approach to the traditional plan-based quantity takeoff. The disconnection between automated quantity takeoff and cost estimating, however, still exists. In addition, without fully understanding the role of BIM in preconstruction, students will only use BIM models as 3D representation of the plans without realizing the benefits that the BIM process brings to the project lifecycle. 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 course is structured based on the UniFormat divisional system and uses RSMeans building assemblies for bid pricing. The course streamlines the connection between model-based quantity takeoff and cost estimating with the help of the latest construction software programs. 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. Student survey at the end of 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. This paper provides an empirical case study with valuable insights on how to integrate BIM in a cost estimating course in a CM program.

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.

Based on the latest technologies, 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 Advanced Cost Estimating 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 (2010), 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. (2012), 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 (2018) 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 (Taylor et al., 2008; Barison and Santos, 2010). These courses often focus on the specific skills of 3D modeling in Autodesk Revit or Trimble SketchUp (Sacks and Barak, 2010; Sacks and Pikas, 2013).

Some CM programs introduce BIM by allowing students to take cross-discipline courses from other programs such as civil engineering workshops and architecture studios (Lee and Hollar, 2013). 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 (Ghosh et al., 2015). 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 (Lee and Dossick, 2012). 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 (Sacks and Pikas, 2013).

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. (2018) compared students' uses of Autodesk Revit and Autodesk Navisworks for quantity takeoff in an estimating course. Elliot et al. (2019) 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 BIM 360 and access the model from the cloud service. 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.

Table 1. List of BIM software programs for quantity takeoff

Developer	Takeoff Program	Module/ Version	Model Source
Autodesk	Assemble		BIM 360/ Navisworks
Beck Technology	DESTINI Estimator		BIM 360/ Navisworks
Autodesk	Navisworks Manage	Quantification	AutoCAD/ 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

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 the technology advancement in recent years, a handful estimating programs are 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 Innovaya 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. Some 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 further connecting with Sage Estimating while the RSMeans cost database is integrated with Sage Estimating. Sigma Estimates allows the RSMeans cost database to be directly imported to the program for cost estimating. In other programs, a customized cost database needs to be created before estimating, such as DESTINI Estimator and Vico Office.

Table 2. List of BIM software programs for cost estimating

Developer	Estimating Program	Takeoff Source	Cost Database
eTakeoff	Bridge	Assemble/ Navisworks	Sage + RSMeans
Beck Technology	DESTINI Estimator	Native	Custom
Sigma	Sigma Estimates	Native	RSMeans/ Custom
Trimble	Vico Office	Native	Custom
Innovaya	Visual Estimating	Visual Quantity Takeoff	Sage + RSMeans

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 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 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 is summarized in Table 3. According to the course goals, Sage Estimating and the RSMeans cost database are required for CM 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.

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

Model Source	Takeoff Program	Estimating Program	Cost Database
BIM 360/ Navisworks	Assemble	eTakeoff Bridge	Sage + RSMeans
AutoCAD/ Navisworks / Revit	Navisworks Manage	eTakeoff Bridge	Sage + RSMeans
BIM 360/ Revit	Sigma Estimates	Native	RSMeans
AutoCAD/ Revit/ Tekla	Visual Quantity Takeoff	Visual Estimating	Sage + RSMeans

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 (Anderson et al., 2001). As shown in Table 4, 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" and Objective 5 "Create a comprehensive construction cost estimate with a computer-based RSMeans cost database" aims higher-level cognitive learning process "evaluate" and "create."

Table 4. Course objectives associated with Bloom's taxonomy

Course Objectives	Bloom's Taxonomy
1. Describe different construction cost estimating types and methods	Remember and understand
2. Compare the MasterFormat and UniFormat divisional systems	Understand and apply
3. Explain the BIM process and its relevant concepts	Understand and apply
4. Demonstrate model-based quantity takeoff with a BIM program	Apply and analyze
5. Create a comprehensive construction cost estimate with a computer-based RSMeans cost database	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, as detailed in Table 5. The first two weeks focus on introducing different types of conceptual estimating, refresh unit price estimating, which was covered in

the prerequisite Cost Estimating course, and compare 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 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 by UniFormat divisions or assemblies. The final task as the course project 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 with class time for students to complete.

Table 5. Course topics associated with objectives and schedule

Course Objectives	Course Topics	Course Schedule
1. Describe different construction cost estimating types and methods	Conceptual Estimating	Week 1
	Unit Price Estimating	Week 2
	Assembly Estimating	
2. Compare the MasterFormat and UniFormat divisional systems	Unit Price Estimating	Week 2
	Assembly Estimating	
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	Strip Footings	Week 5
	Spread Footings	
	Slab on Grade	Week 6
	Concrete Columns & Beams	
	Concrete Walls	Week 7
	Slab over Metal Decking	
	CMU & Brick	Week 8
	Steel Columns	Week 9
	Steel Beams	
	Steel Joists, Girders & Trusses	Week 10
	Cold Formed Framing	
	Dampproofing & Waterproofing	Week 11
	Building Insulation	
	Metal Studs & Drywall	Week 12
	Wood Framing & Drywall	
5. Create a comprehensive construction cost estimate with a computer-based RSMeans cost database	Estimate Summary	Week 13
	Project Work Day 1	
	Project Work Day 2	Week 14

3.4. Course Assessment

The course uses a weighted grading system with six categories including participation (10%), seven assignments (25%), fifteen 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 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.

Each course objective is assessed against the assessment criteria presented in Table 6 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 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.

Table 6. Assessment methods and criteria for each course objective and course topics

Course Objectives	Course Topics	Assessment Methods	Assessment Criteria
1. Describe different cost estimating types and methods	Conceptual Estimating Unit Price Estimating Assembly Estimating	Assignments, exams	Ability to select a correct method for any given project information
2. Compare MasterFormat and UniFormat divisional systems	Unit Price Estimating Assembly Estimating	Assignments, exams	Ability to locate cost information in different divisional systems
3. Explain the BIM process and its relevant concepts	Federated Model Level of Development Intro to Navisworks	Assignments, labs, exams	Ability to identify LOD levels and navigate in a federated model
4. Demonstrate model-based takeoff with BIM program	17 different assemblies	Assignments, labs, exams	Ability to perform quantity takeoff with Navisworks
5. Create a cost estimate with a computer-based RSMeans cost database	Estimate Summary Project Work Days	Project	Ability to create a Sage cost estimate report with RSMeans database

3.5. Course Evaluation

Since this course has only been offered for the first time, inadequate information on student performance and feedback were collected to evaluate the course. Nevertheless, student survey at the end of 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 student 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 Building Information Modeling (BIM) is becoming the standard practice for design, engineering, and fabrication in the construction industry, model-based quantity takeoff and cost estimating has 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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