Implementing BIM for Performing Detailed Construction Estimates in the Classroom

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Abstract

Building Information Modeling (BIM) is becoming an integral part of the Architecture, Engineering, and Construction (AEC) industry as a requirement for complete Construction Documents (CD's). As a generation of new practitioners are trained the understanding of BIM is an integral part of the overall educational parameters for CE/CM. The purpose of this study is to present techniques used for assembling detailed construction estimates incorporating BIM. Various estimating process are examined determining the key aspects necessary to develop a detailed estimate. In determining the capabilities of the BIM drawing, the Level of Development (LOD) is presented as a control of the accuracy of the drawings and ultimately the estimate. This study further examines the student's ability to work with BIM modeling. At the conclusion of the course a student survey instrument was provided to the students to examine their skills and confidence.

Keywords
BIM, Estimating, LOD, Schedule, 3D

1. Introduction

As technology advances at an exponential rate, the construction industry is constantly evolving to incorporate technological advances that provide benefit to the end cost (Armstrong & Gilge, 2016). The construction industry has progressed from using rudimentary documents to CAD drawings and word processing and Building Information Modeling (BIM) (AutoDesk, 2018). The introduction of BIM provides a powerful platform to evaluate the entire project through intuitive software. BIM provides the ability to assemble an accurate model of a structure as part of the construction documents (Messner, John, 2017).

The accuracy of the model is dictated by standard BIM protocols published by the American Institute of Architects (AIA) (AIA, 2017). BIM provides, through various computer programs, the ability to create various schedules containing the attributes and numerical quantities pertaining to the structure. These attributes are assembled for developing detailed estimates. The accuracy of the estimate is partially dependent upon the detail of the model. The model allows the students to view as orthographic sheets or a 3-Dimensitonal (3D) rotational representation. These attributes provide the detail for compiling accurate estimates (Messner, John, 2017).

BIM provides a platform to complete conceptual estimates that are provided to the owner as the project develops to keep the owner and designer on budget. Budget analysis allows for making cost decisions on the design to regulate the project's cost and reduce scope creep. The important aspect is that time spent estimating can be reduced allowing for bidding on additional projects, increasing the opportunity for a successful bid. Value engineering is enhanced with BIM, examining the details of the structure for alternative materials and construction procedures (Messner, John, 2017). Design Options are useful for examining differing alternatives both in constructability and cost (AutoDesk, 2018).

2. Class Case Studies

The Construction Management curriculum at Norwich University has two required estimating classes for CM students Specifications and Estimating and Advanced Project Estimating. Prior to taking the estimating courses students' have been introduced to basic construction techniques and *Autodesk* Revit. Revit is the program of choice at Norwich University for creating and maintaining the interrelated data that comprise the database in a BIM (Pluralsight, 2013). Specifications and Estimating is the first of the estimating courses, the course is offered to first semester sophomores. The course covers the obvious, estimating and specifications, but the course content covers the details of reading construction documents, constructability and materials. On-screen viewing of the construction prints in CAD and PDF formats is incorporated in Estimating and Scheduling for presenting the project documents. In the second required course, Advanced Project Estimating, the use of Revit as an estimating, scheduling and electronic estimating tool are incorporated in the course. Revit drawings and accompanying data are exclusively used in Advanced Project Estimating.

The preliminary project examines a simple two car garage (Figure 1). A garage is used for its simplicity and that most students will have an understanding of a similar structure and if not there are similar structures on campus as examples. After completing the initial estimate and have acquired new skills, their attention is directed to a commercial project that has a higher level of difficulty within the project itself and that the students have separate files for architecture, MEP and structural models that are then linked or used independently.

| Specifications	
Footings	**Roof - Ceiling**
12x24	5/12 Roof Slope
No rebar	2x4 Trusses 16" OC
3000 PSI Concrete	5/8" CDX Plywood Sheathing
Foundation Wall	Underlaymennt
12" Block	Shiingles
8" Block Top Brick Ledger Course	Ridge Vent
No rebar	
Block Grout Filled	**Finsihes**
Horazontal Truss Reinforcement Every Course	Sealant around doors and Windows
Back Fill a Stipulated on Print	Boxing
Slab	Fiber Cement Board (FCB)
3000 PSI Concrete	2 Coats of paint
6x6 10x10 Reinforcement Wire	Boxing Vents - Continuous
Top 4" of Back Fill is Sand	Door Lock
Trowel Finish	Interior Ceiling 1/2" OSB
Wall	
9'-0" Ceiling Height	**Electrical**
Brick Vineer	Floresent Lights
Brick Wall ties	2 - Exterior Recepticals
1" Air Space	Interior Utiliyt Recepticals
Rolock Window Sills	
House Wrap	
1/2" OSB - Exterior Sheathing	
2x6 Wall Framing	**Note:**
6" Insulation	The top of these courses of brick are used as
1/2" OSB - Interior Sheathing	form work around the perimeter of the
Single 2x6 Shoe Plate	
Double 2x6 Top Plate	
Window and Door Framing	**Note:**
Windows	All inspections on this job stop work until
Door	completed and passed
Garage Doors	
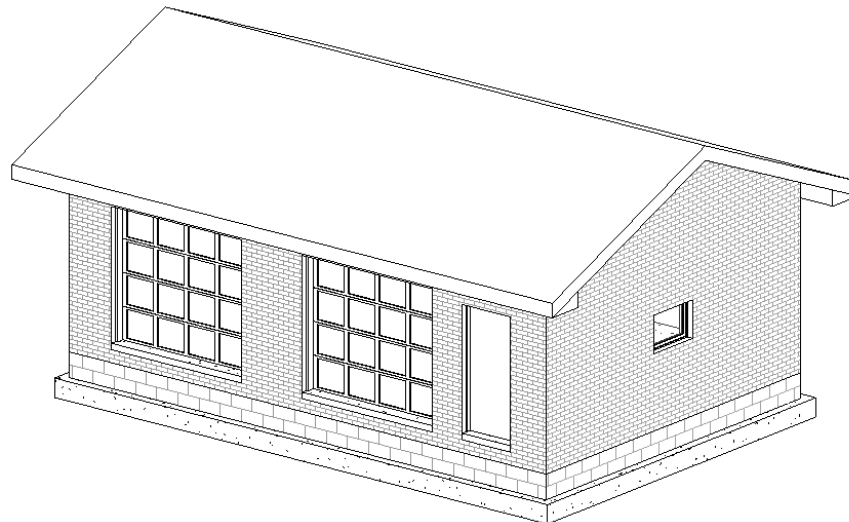
Figure 1: Garage Project

3. Level of Development (LOD)

The first and important step in performing a detailed estimate the structure is to determine the Level of Development (LOD) (Bedrick, 2008). The LOD, published by the BIM Forum, is represented by major contributors to the construction industry (AIA, AGC, and others), to set standards developed to evaluate the BIM for its level of detail. The BIM Forum originally developed an evaluation system enveloped in five

basic levels: 100 - Conceptual; 200 - Approximate Geometry; 300 - Precision Geometry; 400 - Fabrication; 500 - As-Build (Bedrick, 2008)

Each LOD has an integral part in possessing data necessary for the completion of the detailed estimate. Level 350, an intermediate level, is used for greater construction detail, and coordination between trades providing order and construction quality (Jizba, 2014). Level 400 provides the greatest detail (Figure 2). A Level 400 development provides extreme detail; shop drawings is an example (BIM-Forum, 2016).
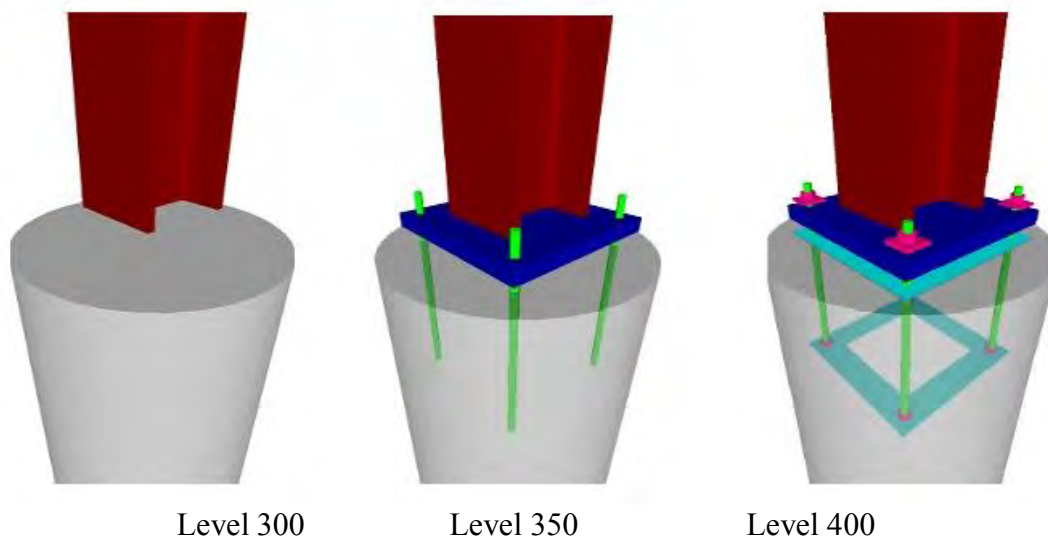

Level 300   Level 350   Level 400

Figure 2: Column Connections – BIM Forum 2016 (BIM-Forum, 2016)

When performing a detailed estimate using Revit, a minimum LOD of Level 300 is required for performing a detailed estimate, with a Level 350 or greater is preferred (Bedrick, 2008). The higher the level the greater the amount of data presented in the model. Figure 3 displays a limited selection of the LOD categories that contribute to the accuracy of the estimate and method employed.

UniFormat Levels 100 and 200 provide minimal amount of information that is beneficial for the client to track the developing costs and the feasibility of the project. These projects are being developed during the conceptual phase, modeled using masses. Level 300 is the beginning of the detail necessary for basic estimating. At Level 300 one would be relying on notes and inserted detail clips drawn in CAD. Starting at Level 350 enough detail is provided for a complete estimate, with Level 400 the desired level. The as-built drawing and actual cost is detailed in Level 500 (Bedrick, 2008). The 2015 Element Attributes Tables provides a comprehensive evaluation tool for determining the LOD.

Figure 3: Example of the LOD 2015 Element Attributes Tables 2015-10-30 (BIM-Forum, 2016)

4. Problem Statement

As the construction industry embraces BIM, educators need to ensure that they are providing training for students in the use of a Building Information Modeling system. CM curriculums need to examine every opportunity to employ BIM, adding to the body of knowledge presented for the student's training and practice. This study is designed for students to examine the differing methodologies used to assist in producing a detailed estimate. Most students, at this point in their educational career, have a wide range of experience in the basics of BIM through the application of Revit (Pluralsight, 2013). This research examines the effectiveness of Revit as an estimating tool and that using Revit adds to the students' broader knowledge of not only the use of Revit, but that of the constructability of the structure and their estimating skills. As part of this study two separate projects are examined in the class and techniques used. A survey was administered to the Advanced Project Estimating class at the conclusion of the semester. The survey is to measure the student's capacity to use Revit as an estimating tool. The survey instrument, administered to students upon completion of Advance Project Estimating, employs a ten point Likert scale to numerically evaluate the student's responses.

5. Estimating Procedures

This article is presenting methods for performing a detailed estimate based on the a LOD of no less than Level 300, Level 350 is preferred (Bedrick, 2008). The higher the level the greater the amount of data presented in the model. Figure 4 displays a limited selection of the LOD categories that contribute to the accuracy of the estimate and method employed. Uniformat Levels 100 and 200 provide minimal amount of information that is beneficial for the client to track the developing costs and the feasibility of the project. Level 300 is the beginning of the detail necessary for basic estimating. At Level 300 one would be relying on notes and inserted detail clips drawn in CAD. Starting at Level 350 enough detail is provided for a complete estimate, with Level 400 the desired level. The as-built drawing and actual cost is detailed in Level 500 (Bedrick, 2008).

UniFormat Level 1	2	3	4	Use on this project	Description	Relevant Attribute Tables	SD Date LOD	MEA	Notes	DD Date LOD	MEA	Notes	CD Date LOD	MEA	Notes	Estimating Ext. 1 Date LOD	MEA	Notes	Estimating Bid Pkg. Date LOD	MEA	Notes	LEED Cert, Check Date LOD	MEA	Notes	LEED Cert Submittal Date LOD	MEA	Notes
B	20				Exterior Vertical Enclosures																						
B	20	10			Exterior Walls	B – Ext. Wall																					
B	20	10	.10		Exterior Wall Veneer	A, B Masonry																					
B	20	10	.20		Exterior Wall Construction	A, B Cold Formed Metal Framing; A, B Wood																					
B	20	10	.30		Exterior Wall Interior Skin																						
B	20	10	.50		Parapets																						
B	20	10	.60		Equipment Screens																						
B	20	20																									
B	20	20			Exterior Windows	B – Ext. Openings																					
B	20	20	.10		Exterior Operating Windows																						
B	20	20	.20		Exterior Fixed Windows																						
B	20	20	.30		Exterior Window Wall																						
B	20	20	.50		Exterior Special Function Windows																						
B	20	50			Exterior Doors and Grilles	B – Ext. Doors																					
B	20	50	.10		Exterior Entrance Doors																						
B	20	50	.20		Exterior Utility Doors																						
B	20	50	.30		Exterior Oversize Doors																						
B	20	50	.40		Exterior Special Function Doors																						
B	20	50	.60		Exterior Grilles																						
B	20	50	.70		Exterior Gates																						
B	20	50	.90		Exterior Door Supplementary Components																						
B	20	70			Exterior Louvers and Vents	B – Ext. Louvers and Vents																					
B	20	70	.10		Exterior Louvers																						
B	20	70	.50		Exterior Vents																						
B	20	80			Exterior Wall Appurtenances																						
B	20	80	.10		Exterior Fixed Grilles and Screens																						
B	20	80	.30		Exterior Opening Protection Devices																						
B	20	80	.50		Exterior Balcony Walls and Railings																						
B	20	80	.70		Exterior Fabrications																						
B	20	80	.80		Bird Control Devices																						
B	20	90			Exterior Wall Specialties																						

Figure 4 – The LOD 2015 Element Attributes Tables 2015-10-30 (BIM-Forum, 2016)

The student's first project is to perform a detailed takeoff of the Garage Project. The estimate begins by a detailed examination of the construction documents (CD's) this provides the students with an overview of the project. As they examine the prints, check sheets are used as a guide. The check sheets contain accumulated data from previous estimates and the LOD standards.

After becoming conversant with the CD's, the students first main task using Revit as a take-off tool, is to evaluate the prints to determine the LOD of the Revit file. As the model is developed the designers should be following and completing the AIA G202-2013 form to document the Model Development Specification (MDS) (Jizba, 2014). The Element Attributes Tables serve as a tool to verify that the required elements are present in the model. The columns at the far left of the Table define the UniFormat Level or the LOD. After the students determine the LOD Level, the elements of the table can be reordered to reflect the order of construction of the structure, which becomes the outline for their schedule.

With the LOD Element Attributes Tables Check Sheet as a guide the students are able to evaluate the CD's. The change in the headings focuses the students on the elements. Although a Level 100 drawing is not represented in the drawing, but this is used to coordinate the specifications with the drawings. Multiple Uniformat Levels may be indicated, as an example: a simple foundation, the foundation drawing is evaluated to be drawn to Level 350 providing a check in this column and a check in the Level 100 indicating that this is also presented in the specifications. The review will also find those items that are missing and require an RFI for clarification. The drawings may need to revert back to the individual designer for additional clarification and a higher LOD rating. When used as a check sheet, the AIA G202-2013 we incorporate a variation as shown in Figure 5.

UniFormat Level				Use on this project		Relevant Attribute Tables	100	200	300	350	400
1	2	3	4								
B	20				**Exterior Vertical Enclosures**						
B	20	10			Exterior Walls	B – Ext. Wall					
B	20	10	.10		Exterior Wall Veneer	A, B Masonry					
B	20	10	.20		Exterior Wall Construction	A, B Cold Formed Metal Framing; A, B					
B	20	10	.30		Exterior Wall Interior Skin						
B	20	10	.50		Parapets						
B	20	10	.60		Equipment Screens						
B	20	20									
B	20	20			Exterior Windows	B – Ext. Openings					
B	20	20	.10		Exterior Operating Windows						
B	20	20	.20		Exterior Fixed Windows						
B	20	20	.30		Exterior Window Wall						
B	20	20	.50		Exterior Special Function Windows						
B	20	50			Exterior Doors and Grilles	B – Ext. Doors					
B	20	50	.10		Exterior Entrance Doors						
B	20	50	.20		Exterior Utility Doors						
B	20	50	.30		Exterior Oversize Doors						
B	20	50	.40		Exterior Special Function Doors						
B	20	50	.60		Exterior Grilles						
B	20	50	.70		Exterior Gates						
B	20	50	.90		Exterior Door Supplementary Components						
B	20	70			Exterior Louvers and Vents	B - Ext. Louvers and Vents					
B	20	70	.10		Exterior Louvers						
B	20	70	.50		Exterior Vents						
B	20	80			Exterior Wall Appurtenances						
B	20	80	.10		Exterior Fixed Grilles and Screens						
B	20	80	.30		Exterior Opening Protection Devices						
B	20	80	.50		Exterior Balcony Walls and Railings						
B	20	80	.70		Exterior Fabrications						
B	20	80	.80		Bird Control Devices						
B	20	90			Exterior Wall Specialties						

Figure 5: LOD Element Attributes Tables Check Sheet

With the evaluation phase of the estimate completed the students advance to the second phase, that of extracting data to perform an estimate. The LOD indicates the extent and level of detail available from Revit. Data is presented through a series of schedules, a tablature assembly of data containing the materials and quantities contained in the model. Revit has several categories of schedules that program will assemble. There are six levels of schedules available for different functions. The two main Schedule choices for estimating are Schedule/Quantities and Material Takeoff. The only information that is available for display in a schedule is that that is contained within the designer's database. If additional data is needed, such as the ceiling height, because it is not a provided Field, a column is added that contains a formula that divides the area of the wall by the length to derive the wall height, similar to creating Excel formulas.

\<Wall Schedule\>									
A	B	C	D	E	F	G	H	I	J
Line Number	Family	Type	Area	Length	Width	Unconnected Height	Wall Area	Actual Wall Length	Actual Wall Area
Exterior - Brick and CMU on MTL. Stud									
1	Basic Wall	Exterior - Brick and CMU on MTL. Stud	240 SF	28.84	1.16	8' - 0"	230.75	30' - 0"	240 SF
2	Basic Wall	Exterior - Brick and CMU on MTL. Stud	151 SF	18.84	1.16	8' - 0"	150.75	20' - 0"	160 SF
3	Basic Wall	Exterior - Brick and CMU on MTL. Stud	151 SF	18.84	1.16	8' - 0"	150.75	20' - 0"	160 SF
4	Basic Wall	Exterior - Brick and CMU on MTL. Stud	201 SF	28.84	1.16	8' - 0"	230.75	30' - 0"	240 SF
Exterior - Brick and CMU on MTL. Stud: 4			742 SF	95.38			763		800 SF
Grand total: 4			742 SF	95.38			763		800 SF

Figure 6: Wall Schedule with Formulas

A Multi-Category schedule will produce a document with all the modeled components of the structure (Figure 6). This schedule can be very long. The advantage in this type of schedule is that it provides all the components that can be modeled and separate schedules may be necessary to have the detailed information needed. Have the students evaluate their schedule options with different types of schedules and the fields that you may add. The key to successfully compiling an estimate is dependent on the assembly of the Schedule using the provided data and the estimator's ability to create formulas.

The first step in extracting data from Revit is to create the schedule. Choosing the proper schedule and attributes ensures that the data presented in the schedule is proper and accurate. Creation of schedules can be a simple or complex depending on the manner in which the drawing was prepared. Another

consideration in developing a schedule is the ease of transferring data to WinEst. The required units can dictate whether the dimensions need to be presented in feet and inches or a decimal equivalent. The metric system (not used as a standard in the U.S.A.) would circumvent this dilemma.

Previously a simple Wall Schedule was examined (Figure 6). In the schedule the units were changed for the wall length segments from feet and inches to the decimal equivalent. Students select the column then select Format Unit (Figure 7).
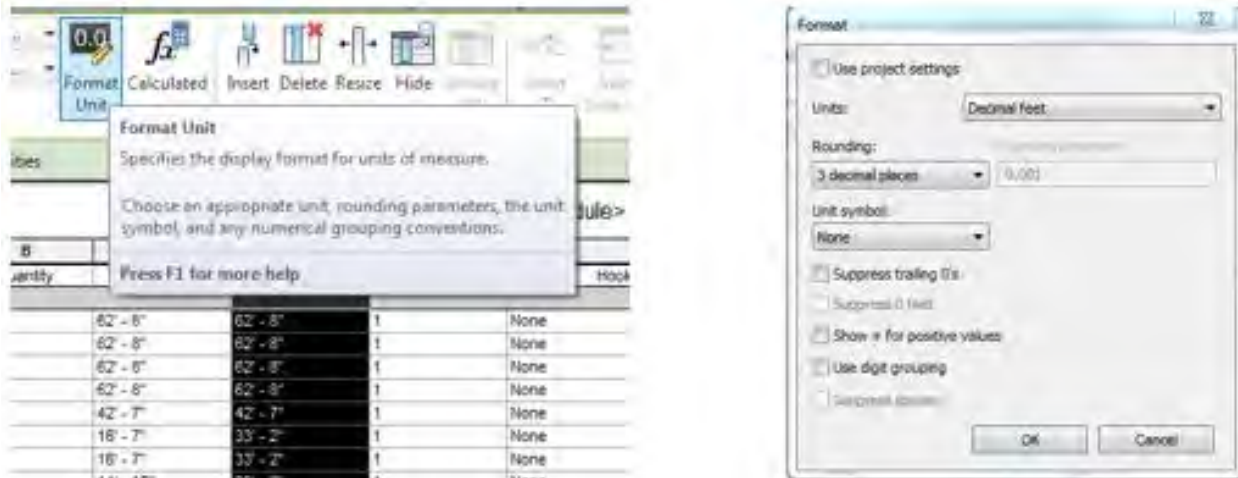

Figure 7: Conversion of Units

Change the units to Decimal feet. To make the Units selection visible you will need to delete the check mark from the Use project settings. By converting to Decimal feet this allows for adding the quantities once the data is exported to an Excel Spreadsheet. The maximum allowable rounding is to 3 decimal places. Selecting Rounding to 3 decimal places to provide a higher level of accuracy to the conversion.

Once the schedule is created and the Units adjusted sorting of the data before exporting is advantageous for clarity. To sort the data in the Properties dialog box, select Sort/Grouping. The Schedule Properties dialog box is now open sort first by Type and check the box for a Blank Line to be added. This places a blank line between the different types of rebar. The students then will export their data to a *Microsoft* Excel spreadsheet and/or manually enter the data in WinEst to complete their estimate

6. Results

At the conclusion of the semester long test course, a survey was completed by the students examining their knowledge of BIM, comparing their skill level at the beginning of the semester to that at the end of the semester, and if Revit assisted in compiling their estimates. The five questions below were part of the completed survey. Each of the questions were evaluated by the use of a ten point Likert scale. The questions and statistical analysis of the student's responses is presented in Table 1.

Table 1: Survey Questions and Survey Statistical Results

No.	Survey Question	Mean	Median	Mode

1	At the beginning of the spring 2017 semester how would you rate your proficiency with using Revit?	2.57	2	0
2	At the end of the spring 2017 semester how would you rate your proficiency with Revit.	6.48	6	6
3	Compared to manual estimating methods used in Estimating I, did using Revit improve your estimate, verses using AutoCAD prints?	7.30	7	7
4	Traditionally estimators are supplied with orthographic prints and specifications to complete their estimate. Revit drawings offer Building Information Modeling (BIM) 3D imaging, orthographic views and the database associated with the structure. Did the Revit files and aid in compiling your estimate?	7.52	8	7
5	How well did Revit drawings and accompanying data add to your understanding of the project, verses traditional orthographic drawings.	8.09	8	9

7. Discussion

When examining the student's responses interesting results are presented. The student's prior knowledge of Revit, before attending the class, is very limited as indicated in Question 1. With an average response of 2.57, and a mode of zero, the students had a low understanding of Revit at the beginning of the semester. In contrast Question 2 is examining the student's capabilities at the end of the semester of using Revit as an estimating tool, indicating a substantial increase in their understanding of Revit at an average of 6.48. In comparison to the first question the students increase of knowledge of using Revit has increased 2.52 times when comparing the means.

Questions 3, 4 and 5 examine the application of Revit as an estimating tool in comparison to previous estimating experiences in the Specifications and Estimating class. In each instance the students provided favorable responses of, 7.50, 7.52 and 8.09, respective to the questions number. In Specifications and Estimating the students use orthographic drawings provided electronically in AutoCAD or PDF format. Using Revit, a program that that they had a low understanding of at the beginning of the semester, has drastically increased the student's ability to use Revit as a BIM tool, it has similarly improved their understanding of the project and their estimates.

8. Conclusions

The results of this research has validated that the techniques used in Advanced Project Estimating employing BIM (Revit) as an estimating tool, not only has their Revit skills improved, but the accuracy of their estimates has improved. BIM provides the opportunity for students to examine the project in 3D or in orthographic style assists students to visualize the project thus a better understanding of the project's requirements. The inclusion of BIM in an estimating program has numerous benefits beyond as an estimating tool. The estimate will follow this structures beyond the completion of the project when as-built documents are compiled. The information contained in a BIM provides students with the necessary data for completion of a detailed estimate, aided the students with their understanding of the project and processes required to construct the structure.

9. References

AIA. (2017, November 06). *AIA Document G202™ – 2013*. Retrieved from Project Building Information Modeling Protocol Form: http://aiad8.prod.acquia-sites.com/sites/default/files/2016-09/AIA-G202-2013-Free-Sample-Preview.pdf

Armstrong, G., & Gilge, C. (2016). *Building a Technology Advantage*. (KPMG International) Retrieved November 16, 2017, from https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2016/09/global-construction-survey-2016.pdf

AutoDesk. (2018). *Revit*. San Francisco: AutoDesk.

Bedrick, J. (2008). *Organizing the Development of a Building Information Model*. California: Webcor Builders.

BIM-Forum. (2016). *Level of Development Specification*. Minneapolis, MN: BIM Forum.

Jizba, A. (2014, August 29). *AIA Technology in Architectual Practice*. Retrieved from network.aia.org: https://network.aia.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=6a27a32c-93e0-4ebc-8ec1-f31c52cf71a4

Messner, John. (2017, October 21). *Cost Estimation (Quantity Take-off)*. Retrieved from Penn State - Computer Intergrated Construction: http://bim.psu.edu/Uses/Cost_Estimation.aspx

Microsoft. (2016). Excel [Computer Proigram]. Redmond, Washington: Microsaoft.

Pluralsight. (2013, November 14). *Pluralsight*. Retrieved from What Is BIM? It's More Than Revit: https://www.pluralsight.com/blog/architecture/what-is-bim-revit

Revit (2018). Autodesk Revit [Computer software]. San Rafael, California: Autodesk