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A FRAMEWORK FOR COST ESTIMATION USING BIM OBJECT PARAMETERS

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Abstract: This paper proposes a framework to conduct a quantity take-off (QTO) and cost estimate using a Building Information Modeling (BIM) Environment. The framework addresses the cost uncertainty associated with the detailed information that defines the BIM element properties. This cost uncertainty is due to the lack of available tools that address detailed QTO and cost estimation using solely a BIM platform. In addition, cost estimators have little experience in leveraging and managing information within semantic-rich BIM models. Unmanaged BIM element parameters are considered a source of uncertainty in a model-based cost estimate, therefore they should be identified and quantified as work items. A model-based system, which assists the estimators to conduct a QTO and cost estimate within the BIM environment, is developed. This system harnesses BIM element parameters to drive work items associated with the parameter's host element. The system also captures the cost of scope not modeled in the design team's BIM models. The system consists of three modules 1) establishing estimate requirements; 2) planning and structuring the estimate; 3) quantification and costing. This framework is supported by a computation engine built within an existing virtual design and construction (VDC) model review software. The Framework's quantification and costing module was compared to existing methods in a case study. The outcome demonstrated improved cost estimate accuracy in comparison to existing BIM QTO computation platforms. This system provided a workflow for conducting a detailed cost estimate within the BIM model environment, instead of extracting geometric parameters to a spreadsheet.

1 INTRODUCTION

BIM is a computer-based process of communicating design intent (Sacks, et al. 2018). VDC is the use of models provided by different project stakeholders to pursue construction objectives. It's important to note that VDC is a verb, meaning it is the act of employing information in project-related decision making. Successful VDC involves visualization and analysis of the combined model to produce decisions (Stanford Engineering 2018). The zenith of BIM and VDC is the return of the master builder concept. Not to an individual, but to one locus of control for the entire project. The BIM model presents elements that spatially organize the project's information. This information is used to plan and execute construction operations using VDC. Proper implementation of BIM and VDC entails that the project's suite of information is wholly accessible within the BIM model. One major pillar in a project is the cost estimate information. The BIM model environment can become the locus of control for a project's cost information.

Many project variables, including the project's estimated cost, are dependent on the parameters stored in BIM elements. The core principle guiding the proposed model-based cost estimating framework is "No cost estimate information should exist that is inaccessible from, or blind to, the project's BIM models." When this principle is followed, all the cost estimate quantities should be driven by the model elements. Any design changes to the model element's parameters should automatically be available to the estimate work items.

This paper presents the outline of a framework to complete a model-based cost estimate. The literature review examines the current BIM and cost estimation body of knowledge to develop the seven identified limitations. The methodology section presents an outline of the framework. The case study section presents an evaluation of a single module within the proposed framework. Conclusions and future recommendations are presented based on the findings in this paper.

2 LITERATURE REVIEW

2.1 BIM and VDC

In BIM, data is associated with specific digital elements contained in the model. A BIM model is wholly comprised of elements. They are discrete objects, each of which has a unique identifier known as an Element Id. These are unique addresses that allow BIM users to clearly specify the parameters associated with that object. Element Id's are also a tool for referencing relationships to other objects. Parameters of model elements store data. These parameters allow stakeholders to communicate information beyond the model geometry. So aside from length, width, and height, a BIM element can store its installed phase, manufacturer's website, and structural properties (Wu and Zhang 2018). BIM is in effect a form of spatial organization for information.

Producing construction decisions based on BIM is VDC. It requires a product-organization-process model (Stanford Engineering 2018). BIM is one of the three sub-models employed in the product-organization-process model. It represents the finished product as intended by the design team. It is the contractor who takes this intent and applies means and methods to physically produce the model. VDC is what the contractor does to digitally communicate the organization and process components of a project. VDC synthesizes the information produced by a designer's BIM with the people and processes required to complete the project (Chen, John and Cox 2018).

An organizational model identifies various stakeholders in an organizational breakdown structure (OBS). This is effectively a list of all parties who may be interested in a decision. The process model is the work breakdown structure (WBS), or the sequential activities required to complete the work (Stanford Engineering 2018). Since BIM elements can hold additional parameters, they can store data regarding the element's relationship to the OBS and WBS. Both breakdown structure models are presently stored external to the BIM model (Sacks, et al. 2018).

2.2 Cost Estimation

A cost estimate is an establishment of the most probable cost for a project. To complete an estimate, the project must have a defined scope. In construction, this scope is typically delineated by the drawings and specifications (AACE RP, 2015). It is important to note that the construction cost estimate is a linear static representation of a non-linear dynamic system, the construction project. Managing a cost estimate means managing the influences on the dynamic system (Alzraiee 2013). Current practices do not effectively manage the dynamic change in a cost estimate once the estimate is finalized and construction is underway. The process of producing a cost estimate is outlined by the AACE. It includes 7 steps of direct effort (Hollmann, et al. 2003). The scope of this framework is limited to the first three steps to produce the initial cost estimate.

As part of the case study, interviews of the construction team were conducted. One interview revealed an instance of tribal knowledge that would be lost due to current estimating practices. The project's geometry had a large perimeter to surface area ratio. It also was in a geographic location with lower labor skill and availability than where the company typically operated. This led to under-estimation of the floor to floor cycle times for column and suspended slab construction. The project team does not know how the important estimating lesson from this cost and schedule overrun will be communicated within the company aside from word of mouth (Tuttle 2018).

2.3 Existing BIM QTO Computation Systems

This section examines the BIM QTO body of knowledge and current computation systems. Two of the most popular systems include Autodesk Assemble and Navisworks (Lawrence, et al. 2014) lack the ability to produce a model-based cost estimate. The models supplied to the contractor lack “consistent quality”. Up to half of the data for QTO may be absent from the BIM model (Olsen and Taylor 2017). The current BIM QTO systems attempt to map designer’s objects straight into an estimate ledger. This mapping process is inconsistent since “Error-free classification is beyond state of the art” (Wu and Zhang 2018). In model-based cost estimation, there is a reliable and repeatable method for producing a cost estimate directly from a BIM model. The current systems are not reliable or repeatable. They employ quantity extraction which diminishes the spatial context provided within BIM (Borhani, et al. 2017).

Ontology in BIM is the formal and explicit specification of model elements. A successful ontology requires a singular library of model elements which is accessible to all who use the software (Sabol 2008). An ontology also requires that modifications to a model element do not change its definition. Currently, any stakeholder who has access to a model can produce a model element or modify the parameters and the resulting meaning of a model element. This introduces uncertainty in the definitions of model elements. An ontology is meant to eliminate subjectivity in the process of estimating (Lee, Kim and Uy 2014). However, since subjective input has not been sufficiently documented in the past it must be documented to build a more powerful understanding of what subjective parameters influence cost.

BIM cannot be compressed into an ontology in current practice (Chen, John and Cox 2018). Without an ontology, the model based estimating process must involve manual categorization of model elements. The categorization process cannot be automated since the designers do not intend to communicate cost directly (Monteiro and Martins 2013). Under the current BIM domain, a second hierarchy must be produced exclusively for cost estimating. Since classes defined in different domains cannot share parameters, the cost estimate class must be produced by manual manipulation (Niknam and Karshenas 2015).

2.4 The Traditional Method of Cost Estimation

The traditional method of cost estimation method is defined in this paper as the use of digital 2D drawings to complete a QTO and spreadsheet-based applications for producing the cost estimate. This is the most common procedure used to produce “bid-tender” or detailed cost estimates (Brook 2017).

In the traditional method, step 1 of the AACE cost estimating process consists of mostly of communication external to the estimate that is recorded in a basis of estimate. Communication between estimators and designers guide the requirements of the estimate. Some of this information is not attached to the contract documents. In step 2, the contractor should review the plans and specifications to define the entire SOW. This is the time the estimators spend to visualize projects requirements. Once visualized, the estimator can categorize each requirement by the WBS and OBS (Brook 2017). During step 3, the estimators measure quantities and categorize them in the WBS subjectively. The measurements are made by drawing shapes on the 2D plans to capture lengths, areas, and volumes of the work-in-place (Pickett, et al. 2014). Figure 5 shows a finished 2D PDF QTO used in the case study. The estimator manually asserted where each condition occurred, and there is no direct link between the quantity and the corresponding specification section, detail, or communication that led the estimator to establish this condition. This link would ideally serve as an audit trail (Chen, et al, 2015).

Estimators who collaborate must manually coordinate scopes through communication methods detached from the estimate i.e. email or physical meetings. Upon completion, the estimators must manually review each other’s work to confirm the entire SOW is captured exactly once (Brook 2017).

Seven key limitations within the existing body of knowledge were identified in a comprehensive literature review. Based on these limitations, a framework is developed. The complete list of limitations includes 1) ease of use, 2) documentation of the estimator's subjective input in the estimate, 3) the contractual warranted accuracy of the design team's BIM models, 4) parametric estimating, 5) documentation of means and methods, 6) flexible data mapping, and 7) software interoperability.

3 METHODOLOGY

3.1 Overview

The methodology initially focused on the system's input and output. Input in this context is any information or model that a stakeholder produces to define the construction work. This information flows into the framework in a BIM model, CAD, or text format. So, this information is either stored within a BIM model or external to it. The desired output is any cost estimate information and an audit trail for quality control. That information is presented in a suite of reports which are provided for different purposes to different stakeholders. These reports are designed to be queryable, meaning the stakeholder can seek answers to specific questions.

Given the input and output requirements, the Structured Query Language (SQL) was selected for the database implementation. This language supports queries, an audit trail, and interoperability with the specified BIM authoring and VDC review software. This database exists parallel to the BIM models. Using an add-in built into Navisworks, data transactions are made that send BIM parameters to and return cost information from the database. The framework's skeleton is presented in Figure 1.

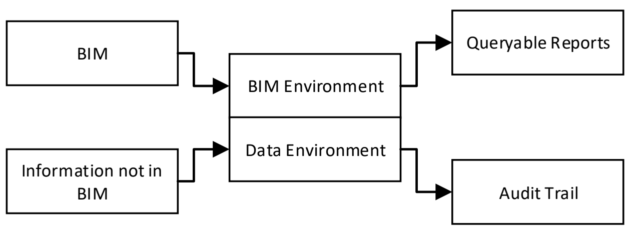

Figure 1 Skeleton of the Framework's Input, Environment, and Output

3.2 Establish Estimate Requirements

This module includes stipulations for refinement of construction contracts. There is currently risk associated with both the quality and quantity of information presented in the designer's BIM models. The quality and quality of BIM provided to the contractor should be contractually warranted to employ the framework. The two BIM platforms used are Revit for BIM authoring and Navisworks for VDC. These are the two most popular BIM/VDC platforms (Olsen and Taylor 2017). This feature promotes ease of use by limiting the number of platforms that the estimators must train to use. This is also the simplest solution to ensure interoperability for the project team. Flexible mapping is intended to reduce the menial tasks that estimators perform and decrease the cost of estimating design changes. The flexible map allows parameters stored in BIM elements produced by the design team to flow through to the proper cost estimate work items. This module prepares the model for conditioning.

3.3 Plan and Structure the Estimate

This module conditions the BIM model(s) for cost estimation and prepares many forms of information for association with BIM elements. Two important forms of information are tribal knowledge and assumptions regarding construction tactics and temporary structures required to complete the work (means and methods). As demonstrated in section 2.2, the documentation of an estimator's subjective opinion and tribal knowledge is not sufficiently supported by current cost estimating practices. The cost estimators make decisions about what means and methods the construction team will employ to produce the work in place. A ladder, man lift, or scaffolding are all examples of means and methods that can be employed to work on a building's exterior. So, documenting the decision in the model allows the cost of alternatives to be easily evaluated as well as communicated to other estimate stakeholders. In this phase, a separate model is authored to host parameters for the contractor's means and methods of construction. The complete set of designer and estimator authored BIM elements serve as the hosts for all cost estimate information. Figure 2 presents a designer's BIM model (Blue) and the contractor's means and methods model (Green)

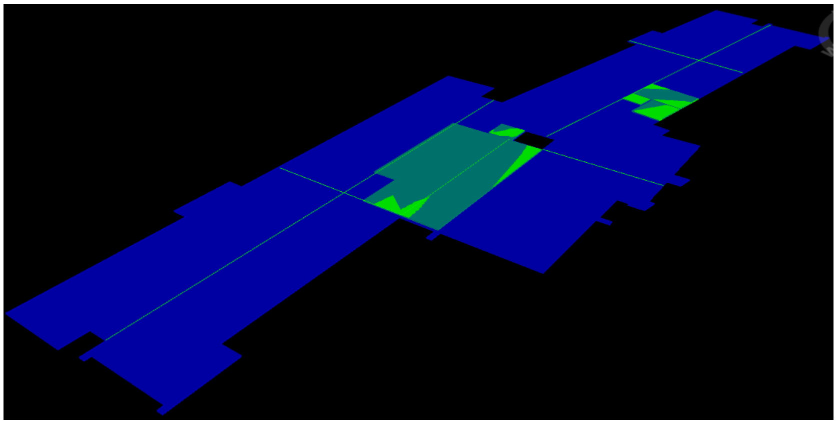

Figure 2 Conditioned Navisworks File for Completing a Model-Based Cost Estimate of a SOG.

3.4 Quantification and Costing

Parametric cost estimating is addressed in the quantification and costing module. It involves driving the parameters of estimator created work items with the BIM parameters of the element that is hosting the work item. Parametric estimating is intended to replace manual QTO of specific geometric parameters. It is the process of linking multiple work items to a single BIM model element and interlinking multiple parameters to a single work item. The key advantages are these work items do not need to be authored in BIM and the parameter mappings can be evaluated once actual project cost data are available. Addressing this limitation provides cost estimate specific information without demanding additional BIM authoring since current models are not intended to store primarily cost estimate information. This module employs an automatic QTO of each BIM element and all available parameters within that element. However, only the parameters that are used to drive the cost of work items will be delivered into the estimate report.

This module is the only module where estimators produce new cost information in the context of the conditioned model. This step produces the model-based cost estimate. It amalgamates information within BIM, and is a departure from the existing practices. This methodology amalgamates the product (BIM models), organization (OBS), and process (WBS) models of the construction project alongside cost estimate data. In BIM, this data is spatially organized by the 3D BIM model elements that host the amalgamated data. Current computation systems employ quantity extractions from BIM. Meanwhile, this system completes the entire quantification and costing process within BIM. This means that while using the model-based system, cost estimators must produce new parameters when the designers' models are insufficient to describe a work item. This feature is actually what enables the cost estimators to author the means and methods of construction as BIM elements within their own linked BIM model.

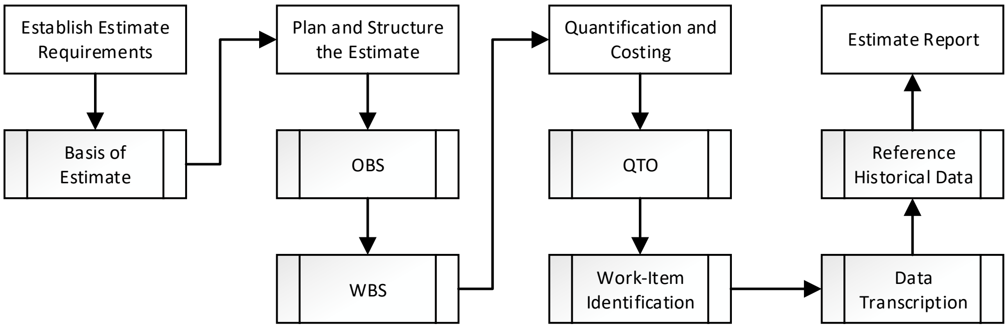

Figure 3 Outline of the Framework's 3 Modules and their Corresponding Processes

3.5 Data Structure and Software Linking

The structure for completing this model-based cost estimate is built in a Structured Query Language (SQL) database. This database has 36 entities or tables that are inter-related. Figure 4 presents an example of three entities from within this database. PK (primary key) indicates that the attribute forms the entity's unique identifier. FK (foreign key) indicates that the attribute is referencing the primary key of another (foreign) entity. Using this data structure, creating a crew, adding members to it, and even defining new members are all activities that the estimator can complete within the Navisworks add-in environment. The estimator does not have to learn SQL.

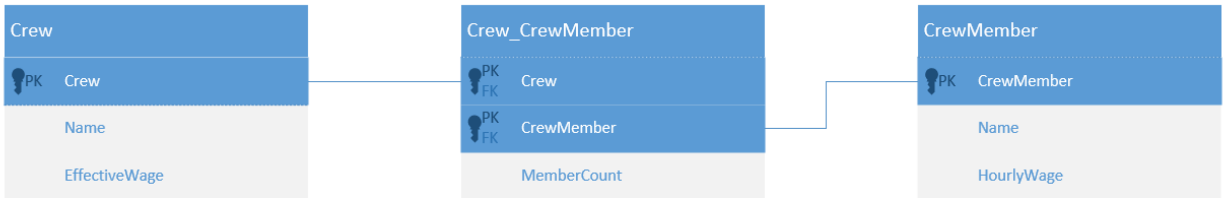

Figure 4 SQL Data Structure for Building Crews from Individual Members with Pre-defined Hourly Wages

4 CASE STUDY

4.1 Overview

A case study was completed to compare traditional and model-based estimating methods. The scope of the case study is the structural slab on grade (SOG) of building 4E in the Yakʔitʸutʸu student housing project at California Polytechnic State University in San Luis Obispo. A traditional QTO and estimate, BIM QTO and estimate, and a model-based cost estimate were completed in order. The SOG was selected for this study since it is a single BIM element with multiple attached work items. Only the process and results of the quantification and costing module are presented in this paper.

The quantification and costing module consisted of 1) a QTO using the structural foundation 2D electronic plan and corresponding details; 2) identification of the required work-items based on the QTO parameters; the OBS, and the WBS; 3) transcription of the QTO parameters to the Excel environment; and 4) references to historical labor, material, and equipment data regarding prices and production rates.

4.2 Traditional Method of Cost Estimation

The traditional method cost estimate was complete first in the study. The results of the 2D electronic plan based QTO is presented in figure 5. Time to create QTO conditions or understand the plans is not included in the study. Only the time to complete the physical measurement process is reported (4.5 minutes).

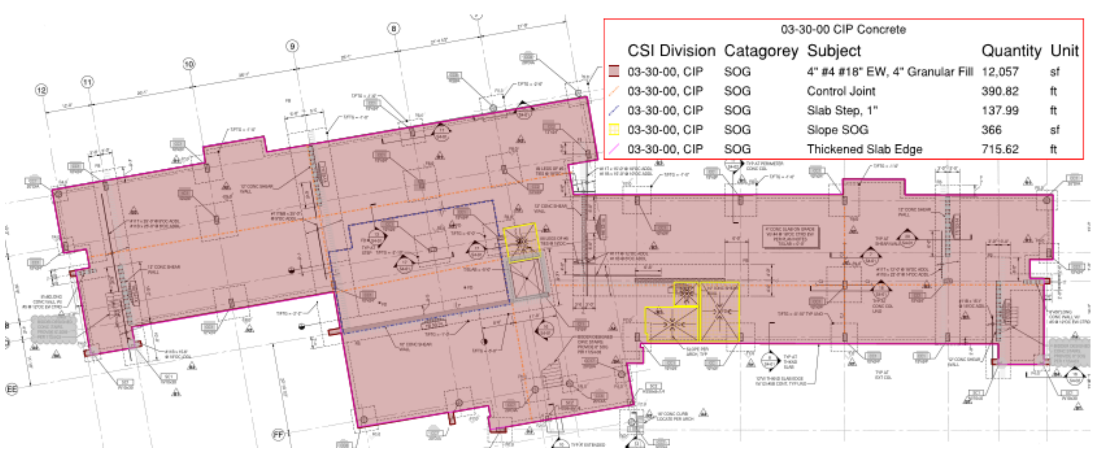

Figure 5 Traditional QTO of SOG Completed using Bluebeam Revu

Bluebeam Revu was used to perform the QTO. The QTO values closely match the BIM parameters since Revu has a feature to snap to Autodesk Objects. The software was reading the 2D geometry that is spatially driven by the BIM element's property, but it was not able to access that property directly.

The spreadsheet estimate (Figure 6) was completed following the traditional QTO. In the spreadsheet format, each workbook row is an activity. Each activity has a placeholder for material, labor, and equipment work items. This means a single line item can contain as many as three work-items. The orange highlighted cells are all transcribed from the QTO report. These were added in "one to one" relationship, meaning that one and only one activity has the QTO value. All tan highlighted cells were based on a relationship to a QTO parameter. These are "one-to-many" references, meaning a single parameter drives multiple quantities. The database references define the cost and production rate of a work item. The quantities used in these cells are created from a "one-to-many" relationship, the value in each tan cell is driven through an equation linked to the value in an orange cell. The complete estimate process was completed in 17 minutes.

Project Name: Building 4E SHS
Date: 1/25/2019
Estimator: Michael Clark

Quantity from Relationship
Quantity from QTO

Total Conc Volume: 177 CY — $820.21/CY
Sales Tax Rate: 7.75%

				LABOR			MATERIAL		EQUIPMENT		TOTAL
#	Description	Quantity	Unit of Measure	Units /HR	Hourly Rate	Total Cost	Unit Cost	Total Cost	Unit Cost	Total Cost	ITEM COST
15	FORMWORK:										
16	slab edge, 12"H (off subgrade)	749	LF	4.0	$ 51.10	$ 9,568	$ 1.19	$ 956		$ -	$ 10,525
17	CJ bulkhead, H=5½"	391	LF	4.3	$ 51.10	$ 4,701	$ 1.25	$ 526		$ -	$ 5,227
18	3/8"x24" smooth dowels @ CJ	196	EA	5.5	$ 51.10	$ 1,816	$ 2.75	$ 579		$ -	$ 2,396
19	hang form @ slab depression, H<12"	138	LF	5.0	$ 102.20	$ 2,821	$ 3.50	$ 520		$ -	$ 3,341
#	hang form @ slab depression, H<12"	2	CSF	6.0	$ 102.20	$ 33	$ 3.50	$ 7		$ -	$ 41
21											
#	CONCRETE WORK:										
#	concrete 4,000psi	177	CY		$ -	$ -	$ 130	$ 24,741	$ 353.3	$ 62,396	$ 87,137
#											
#	FINISH, CURE & MISC:										
#	set screeds	12,060	SF	2,000	$ 244.65	$ 1,475		$ -	$ 0.02	$ 241	$ 1,716
#	place, trowel finish & cure	12,060	SF	1,500	$ 613.35	$ 4,931	$ 0.34	$ 4,418		$ -	$ 9,350
#	1-8' ride-on trowel	1	DAY		$ -	$ -		$ -	$ 395	$ 395	$ 395
#	Sloped Slab	366	SF	220.0	$ 613.35	$ 1,020		$ -		$ -	$ 1,020
	SLAB ON GRADE TOTAL					33,201		43,205		68,467	144,874

Figure 6 Cost Estimate Spreadsheet produced from the Traditional QTO

Figure 6 does not show that the estimator began with a blank spreadsheet template or copied one from a similar project. Each line item was manually added by referencing the drawings, specifications, and recalling tribal knowledge. There was no singular checklist referenced to build out the contents of the estimate. Instead, the estimator had to manage various sources of information and amalgamate them into the spreadsheet. This amalgamation diminishes the audit trail of the estimate. Any stakeholder that reviews the estimate would have to ask the estimator to justify decisions since there is no database storing their justification.

4.3 BIM QTO

In BIM QTO, the take-off parameters are automatically extracted from the BIM model. These parameters are presented in Table 1. They are wholly defined by the design team. Therefore, there is no transcription or measurement error introduced by the estimator when performing this QTO. The estimator can incorrectly map the parameters to work-items, but any errors in the "one-to-one" quantities were from the design team not meeting the warranted model accuracy. So, in Module 1 of the framework, this warranted accuracy should be explicitly specified in the designer's contract. The BIM QTO was completed in a matter of seconds using Autodesk Assemble. This is the fastest QTO of all three methods tested in the case study.

The spreadsheet estimate (Figure 7) was completed with parameters from the BIM QTO (Table 1). In this report, the blue highlighted cells are transcribed data added in "one to one" relationship. One and only one activity has the QTO parameter. This is referred to as the "Primary Quantity". The tan cells follow the same format as Figure 6, they are driven by the Primary Quantity. The red cells represent activities that were not captured in the BIM QTO. There's no BIM Element with a Primary Quantity to describe them and they could not be driven by another Primary Quantity. This results in a $12,901 or 12% discrepancy in the estimated cost versus the traditional method. The estimate took 11 minutes since empty rows were skipped.

Table 1 BIM QTO Parameters Exported using Assemble

Element Parameter	**Parameter Value**
Element Thickness	0ft 4in
Element Volume	4020.196 ft³
Element Area	12060.589 ft²
Element Perimeter	749ft 1in
Element Level	Level "LEVEL 1", #329
Element Id	1640726
Element Category	Floors
Element Family	Floor
Element Type	4" CONC SLAB ON GRADE

Project Name:	Building 4E SHS		Quantitiy Linked from BIM	Total Slab Area:	12,060 SF	$11.02/SF
Date:	1/25/2019		Quantity not captured in BIM	Total Conc Volume:	177 CY	$752.13/CY
Estimator:	Michael Clark		Quantitiy generated by a relationship	Sales Tax Rate:	7.75%	

				LABOR			MATERIAL		EQUIPMENT		TOTAL
#	Description	Quantity	Unit of Measure	Units /HR	Hourly Rate	Total Cost	Unit Cost	Total Cost	Unit Cost	Total Cost	ITEM COST
15	FORMWORK:										
16	slab edge, 12"H (off subgrade)	749	LF	4.0	$ 51.10	$ 9,568	$ 1.19	$ 956		$ -	$ 10,525
17	CJ bulkhead, H=5½"		LF								
18	3/8"x24" smooth dowels @ CJ		EA								
19	hang form @ slab depression, H<12"		LF								
20	hang form @ slab depression, H<12"		CSF								
21											
22	CONCRETE WORK:										
23	concrete 4,000psi	177	CY		$ -	$ -	$ 130	$ 24,741	$ 353.3	$ 62,396	$ 87,137
24											
25	FINISH, CURE & MISC:										
26	set screeds	12,060	SF	2,000	$ 244.65	$ 1,475		$ -	$ 0.02	$ 241	$ 1,716
27	place, trowel finish & cure	12,060	SF	1,500	$ 613.35	$ 4,931	$ 0.34	$ 4,418		$ -	$ 9,350
28	1-8' ride-on trowel	1	DAY		$ -	$ -		$ -	$ 395	$ 395	$ 395
29	Sloped Slab		SF								
	SLAB ON GRADE TOTAL					22,810		41,572		68,467	132,849

Figure 7 Traditional Cost Estimate Spreadsheet Driven by Quantities from the BIM QTO

4.4 Model-Based Cost Estimate

The Model-Based cost estimate was completed using a purpose-built Navisworks add-in. It facilitates interoperability between Excel, SQL, C#, Revit, and Power BI. The add-in is intended to control the entirety of module three from within Navisworks and Revit. Using the Autodesk switchback feature, the means and methods of construction are authored in Revit and reviewed in Navisworks to condition the model. Figure 2 presents the conditioned BIM model. The blue element is the SOG from the designer's model, as in the BIM QTO method. The green elements were produced in Revit by the estimator. In the means and methods Revit file, the design model was used as a Revit link to prescribe the location of elements. There is possibly error introduced in the authoring process, but that can be visually checked against the 3D model. The authored elements are all within the 3D mass of the designer's model. This is one contractual requirement of the warranted accuracy clause for the proposed framework. The authoring process took 3 minutes.

Figure 8 presents an estimate summary. Unlike the previous two methods, parameters were not transferred to the spreadsheet. Instead, they're fed into a SQL table which is referenced when the estimator attaches work items to the model elements. The parameters in the table are used to drive the work items and subjective input that the estimator assigns. They are selected from a filtered flexible map. The Navisworks add-in reads and writes to this SQL table. The SQL language affords interoperability with Excel and Power BI. The model-based process estimated a similar cost to the traditional method in 2.3 minutes.

		(blue)	Quantitiy Linked from BIM	Total Slab Area:	12,060 SF	$12.03/SF
Project Name:	Building 4E SHS	(green)	Quantity Linked Means & Methods	Total Conc Volume:	177 CY	$821.24/CY
Date:	1/25/2019	(yellow)	Quantitiy generated by a relationship	Sales Tax Rate:	7.75%	
Estimator:	Michael Clark					

#	Description	Quantity	Unit of Measure	LABOR Units /HR	LABOR Hourly Rate	LABOR Total Cost	MATERIAL Unit Cost	MATERIAL Total Cost	EQUIPMENT Unit Cost	EQUIPMENT Total Cost	TOTAL ITEM COST
15	FORMWORK:				$ -	$ -		$ -		$ -	$ -
16	slab edge, 12"H (off subgrade)	749	LF	4.0	$ 51.10	$ 9,568	$ 1.19	$ 956		$ -	$ 10,525
17	CJ bulkhead, H=5½"	401	LF	4.3	$ 51.10	$ 4,821	$ 1.25	$ 539		$ -	$ 5,361
18	3/8"x24" smooth dowels @ CJ	201	EA	5.5	$ 51.10	$ 1,863	$ 2.75	$ 594		$ -	$ 2,457
19	hang form @ slab depression, H<12"	142	LF	5.0	$ 102.20	$ 2,902	$ 3.50	$ 536		$ -	$ 3,438
20	hang form @ slab depression, H<12"	3	CSF	6.0	$ 102.20	$ 48	$ 3.50	$ 11		$ -	$ 59
21					$ -	$ -		$ -		$ -	$ -
22	CONCRETE WORK:				$ -	$ -		$ -		$ -	$ -
23	concrete 4,000psi	177	CY		$ -	$ -	$ 130	$ 24,741	$ 353.3	$ 62,396	$ 87,137
24					$ -	$ -		$ -		$ -	$ -
25	FINISH, CURE & MISC:				$ -	$ -		$ -		$ -	$ -
26	set screeds	12,060	SF	2,000	$ 244.65	$ 1,475		$ -	$ 0.02	$ 241	$ 1,716
27	place, trowel finish & cure	12,060	SF	1,500	$ 613.35	$ 4,931	$ 0.34	$ 4,418		$ -	$ 9,350
28	1-8' ride-on trowel	1	DAY		$ -	$ -		$ -	$ 395	$ 395	$ 395
29	Sloped Slab	320	SF	220.0	$ 613.35	$ 892		$ -		$ -	$ 892
30					$ -	$ -		$ -		$ -	$ -
31					$ -	$ -		$ -		$ -	$ -
	SLAB ON GRADE TOTAL					33,337		43,252		68,467	145,056

Figure 8 Model-Based Cost Estimate Presented in a Spreadsheet Format for Comparison.

4.5 Discussion

The results indicate that the model-based method was the quickest (5.3 minutes) while it also achieved the same estimated cost as the traditional method. It attained this accuracy with additional BIM element parameters that were not available to the BIM QTO system. The BIM QTO method developed a bill of materials in one operation. However, the estimate still employed manual methods (11 minutes). The bill of materials low detail led to the omission of 12% of the total estimated cost captured in the other methods. The traditional method was the slowest of the three tested in the case study (21.5 minutes). Though it did not require the estimator to undergo any advanced computer programming skills or BIM-based training. In practice, the proposed framework would require at least one estimator to champion the programming, while every estimator would require training on Revit, Navisworks, and the developed add-in.

The results exclude the preparations made for each method. In the model-based method, these preparations included seeding a database of SOG work items (1.5 hours), creating Revit Families for the means and methods, control joint and sloped SOG (10 minutes), and mapping the BIM hierarchy to potential work-items (30 minutes). These activities would be completed in module two (plan and structure the estimate) and can be recycled for subsequent estimates of a SOG.

5 CONCLUSION

The authors presented a system that addressed the limitations identified in the literature review. A case study evaluation of three cost estimating methods was completed. The case study exemplified the speed and completeness of a succinct model-based framework that utilized BIM element parameters to drive work items hosted by the BIM elements. The data structure of this method increases interoperability and improves the speed with flexible mapping to the BIM elements. The system is a cost estimate platform that allows all cost information to be associated with specific BIM elements. All cost estimate information can be accessed through BIM viewing and manipulated by modifying the BIM models or attached work items. In this framework, no cost estimate information is blind to the BIM model.

This case study did not elaborately discuss the overhead time and cost of preparing to complete the model-based estimate. This represents a high barrier to entry that requires the time of a skilled computer programmer and database administrator. This estimate system does lend itself to a potential form of highly detailed cost reporting. Future research should integrate this framework with construction phase data collection and subsequent data mining.

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