

BIM-based Integrated Framework for Detailed Cost Estimation and Schedule Planning of Construction Projects

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Abstract -

With the increasing popularity of Building Information Modeling (BIM), several research studies have focused on its application in the construction industry, and advancements such as developments of BIM-based tools for construction scheduling and cost estimating have been carried out. Nevertheless, these tools are each developed only for one particular aspect of construction management, such as scheduling or cost estimating. As such, most are still limited to the product element level, rather than the construction operation level. This paper thus presents a BIM-based integrated framework for detailed cost estimation and schedule planning of construction projects. In the proposed framework, a BIM product model developed in Autodesk Revit, is integrated with a construction process model retrieved from RS Means, with the objective of generating detailed cost estimation and a workforce construction schedule simultaneously. In this paper, the literature pertaining to BIM, cost estimating and scheduling is surveyed; then, the proposed framework is presented, and a simple building project is used as a case study to facilitate understanding of and verify the applicability of the integrated framework. Finally, findings from the implementation of the proposed framework are summarized.

Keywords -

Building Information Modeling; Integrated Framework; Detailed Cost Estimation; Construction Scheduling.

1 Introduction

Detailed cost estimating is generally referred to as the process of predicting the project cost at the workforce level based on detailed design drawings/documents and specified construction methods/specifications. During this process, defining the scope of the construction project and establishing its work breakdown structure

(WBS) are the first steps. Then, the quantity takeoff is surveyed according to the detailed design drawings or building information modeling (BIM) model. The following task is to find applicable unit cost items from a unit cost database in accordance with the specified construction method. Furthermore, direct cost is obtained by multiplying quantities with unit cost; other costs, such as indirect costs, are calculated by taking a percentage of the direct cost. Finally, project cost is calculated by summing up direct cost with the other costs mentioned above. Similarly, detailed schedule planning is the processes - including identification of WBS for construction schedule, quantity survey, assessment of productivity, calculation of activity duration, and determination of construction sequencing logic and project duration—by which to plan the construction schedule at the operation level. Due to the fact that both detailed cost estimation and schedule are at the workforce level, they pertain not only to construction planning in the planning phase, but also can be utilized to monitor and control construction progress during the project execution phase. Hence, detailed cost estimating and schedule planning are two critical tasks of construction management which directly contribute to the success of construction projects.

Currently, cost estimation and construction scheduling usually are performed separately by construction practitioners, due to the lack of a well-developed integrated framework or system for both cost estimating and project scheduling. In fact, given that cost estimation and schedule planning share some common processes, such as quantity takeoff, it is possible to combine these two processes to develop a single integrated information framework for detailed cost estimation and project scheduling. Such a framework reduces workload at the planning phase and also benefits construction management during the later execution phase. In addition, BIM, which can be defined as a digital representation of a facility in which all facility information is represented and visualized in the model, is gaining momentum within the construction industry. BIM contains enriched information pertinent

to the facility, and facilitates the exchange and interoperability of information, making it capable of supporting many kinds of analysis, including cost and schedule analysis. Consequently, the development of BIM technology provides solid support for the integrated framework of cost estimation and schedule planning.

Although many BIM-based tools for cost estimation and schedule planning have been developed, they are each developed for only one aspect of construction management, such as scheduling or cost estimation. Moreover, most of these tools are limited in their application to determining quantities of product elements (e.g., number of doors, windows, and walls) from the BIM model as inputs. Detailed construction information (e.g., construction method, crew information), which would be necessary in order to generate detailed estimation and schedule at the construction operation level, is not taken into consideration. This paper thus proposes a BIM-based integrated framework for detailed cost estimation and schedule planning of construction projects. In the proposed framework, a BIM product model in Autodesk Revit is integrated with a construction process model retrieved from RS Means so to combine construction method knowledge with 3D product model, thereby facilitating cost estimation and schedule planning.

The paper begins with a review of state-of-the-art research with respect to detailed cost estimation, project scheduling, and BIM technology. Second, detailed explanations pertaining to the proposed framework are presented, and a simple building project is used as a test-bed to verify the integrated framework. Finally, findings from the implementation of the proposed framework are summarized, particularly as they pertain to potential future research.

2 Literature Review

2.1 Overview

Cost estimation and project scheduling have been of interest to scholars for decades, and numerous efforts within these domains have been conducted in recent decades. Conventionally, previous studies in these areas have concentrated on purposes such as schedule optimization, cost estimation models, and time-cost trade off, and have aimed to produce more accurate and optimized project schedule and estimated cost. However, with the recent emergence of BIM, BIM-based applications in the construction industry have been another focus for many researchers. Several BIM-based applications and tools for cost estimation and scheduling planning have been developed to improve the efficiency of construction practitioners. Given the

objective of this research, this literature survey focuses on BIM-based quantity takeoff, BIM-based cost estimation, BIM-based project scheduling, and cost and schedule integration.

2.2 BIM-based Quantity Takeoff

Quantity takeoff is the foundation of other tasks in construction management, such as cost estimation and schedule planning, and its accuracy can directly affect downstream analyses and decisions. Traditionally, quantity takeoff is a manual process during which quantities of design elements are measured based on the design drawings or the 3D model, and this manual quantification is highly error-prone [12]. Thus, various automated approaches to extracting quantity information from 2D drawings or 3D models have been explored in the past, such as generating quantities using AutoCAD drawings [14]. Among these, BIM offers the best automatic approach by which to generate accurate quantity takeoff directly from 3D product models [13]. Also, BIM-based quantity takeoff is currently the most widely used BIM-based application in the construction industry. Most BIM tools are able to support the quantity takeoff feature, including the “Schedules” function of Autodesk Revit. Nevertheless, BIM-based quantity takeoff may not provide all the necessary data about the product model in the case in which the BIM model is not designed with sufficient detail. To facilitate automatic quantity takeoff to a sufficient level of detail, the BIM model must be “redesigned”, which requires even more effort than performing manual takeoff. As such, some studies have sought to explore an automatic approach to designing the BIM model in performing a quantity takeoff. Monteiro et al. [12] developed an add-on for ArchiCAD, which can automatically generate the formwork model based on the structural model of the building. Kim et al. [6] explored an automated modeling method by which to model a building’s interior. Once the detailed information can be represented in the BIM, the thorough quantity takeoff can be generated by the routine in the BIM tools. All these efforts pertaining to automatic modeling could, on the other hand, improve the efficiency of quantity takeoff.

2.3 BIM-based Cost Estimation

As previously described, quantity takeoff is part of the cost estimation process. Most research regarding BIM-based quantity takeoff has actually been conducted to serve the purpose of cost estimating. Besides quantity takeoff, however, another challenge entailing a considerable amount of manual work in estimating is to find and apply appropriate cost data to the takeoff.

Without exploring an automatic solution to this challenge, Ma et al. [11] introduced a semi-automatic way to conduct cost estimation for tendering of building projects based on the use of a design model through an open Industry Foundation Classes (IFC) standard. In fact, the use of ontology technology could help reduce or eliminate manual involvement and automate the process of searching for the most appropriate cost items. By formalizing ontology to represent the cost-driving features of building product models, practitioners can generate cost estimation more expeditiously [14, 15]. In this context, Lee et al. [8] have illustrated the ontology and BIM-based approach for building cost estimation, but with the limitation of only focusing on tiling work.

2.4 BIM-based Schedule Planning

In terms of scheduling, research efforts in the last decade have evolved from traditional 3D CAD model-supported construction planning [16] to BIM models with enriched information-based scheduling [9]. However, most of these have only been able to produce construction schedules at the product component level, not at the construction operation level. Today, with the discrete event simulation-based schedule approach being increasingly utilized to support the generation of construction schedule at the on-site operation level, researchers are exploring potential means by which to

integrate this approach with BIM. One example is an interface system developed by Wang et al. [17] to generate the on-site operation level schedule. However, their research was limited to reinforced concrete (RC) construction projects and did not have flexibility in considering different construction methods.

2.5 Cost and Schedule Integration

To date, various models and systems through which to integrate cost and schedule have been developed, including an integrated cost and schedule model for repetitive construction processes [2], a schedule and cost management system for steel structural construction [7], and an integrated database framework for cost, schedule, and performance data [1]. Nevertheless, these efforts have sought mainly to manage and control the construction process during the project execution stage, whereas detailed cost estimation and construction schedule planning, as two main concerns for construction project management [5], demand a large amount of effort during the planning phase. In this regard, an integrated system with the support of BIM for detailed cost estimation and schedule planning would improve project planning efficiency during the planning phase and benefit all the stakeholders involved.

3 Integrated Framework

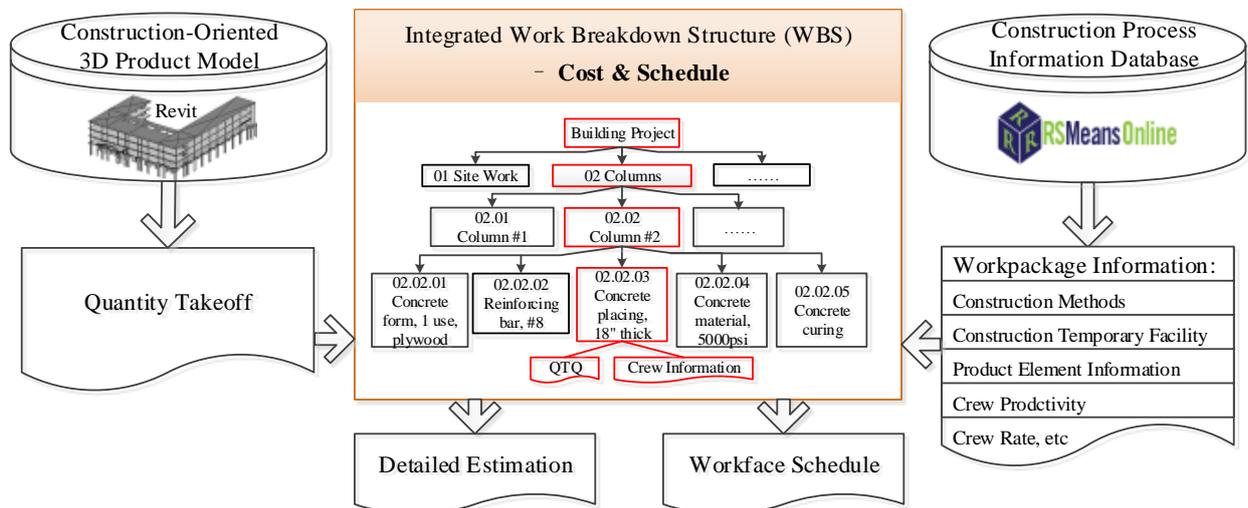


Figure 1. Proposed integrated framework for detailed cost estimation and schedule planning

The proposed integrated framework for detailed cost estimation and schedule planning is presented in Figure 1. It mainly consists of three components, a

construction-oriented 3D product model, an integrated work breakdown structure, and a construction process information database. The construction-oriented 3D

product model, developed in Autodesk Revit, is a building product information database from which quantity takeoff is extracted for cost estimation and schedule planning, whereas the construction process information database from RSMeans stores the construction process/work package information, such as the crew rate and productivity information of each work package. Both quantity takeoff and work package information are organized based on an integrated work breakdown structure (WBS) which, as the core of this framework, combines cost breakdown structure and WBS for construction scheduling in consideration of specific construction methods (e.g., requirements of temporary structures and crews), thereby facilitating the generation of detailed cost estimation and construction schedule. In the following sections, detailed explanations are given.

3.1 Integration of Cost and Schedule

Integration models for cost and schedule can be categorized into three groups, including a WBS-based model, faceted classification model, and work-packaging model [1]. In the present research, a new WBS-based model drawing on the advantages of both the WBS-based model proposed by Eldin [3] and a work-packaging model, is proposed to achieve the integration of detailed cost estimation and construction scheduling. More specifically, the new WBS-based model constitutes a single, integrated work breakdown structure linking and combining cost breakdown structure (CBS) items with WBS items. Additionally, CBS items in the proposed WBS should be designed corresponding to cost records customized for specific construction methods in the construction process information database, such as RSMeans. Moreover, the integrated WBS is established following a consistent format based on all construction activities involved in constructing the final product; resources (cost) or time or both are incurred in the activities.

3.1.1 Integrated work breakdown structure

As indicated in the example provided in Figure 1, the integrated WBS is organized into three levels. The first level is designed for types of building component, with the second level for specific individual components. By setting the second level, the proposed WBS addresses one main limitation of traditional CBS with no support of BIM – *that it does not involve specific (e.g. spatial) information of individual building components*. For instance, “02 Columns” in Figure 1 is further separated into “02.01 Column #1” and “02.02 Column #2”, etc., in order to consider work packages for individual components.

With detailed construction data available, the third level is divided into activities. As shown in the figure, “02.02 Columns #2” is divided into “Concrete form”, “Reinforcing bar”, “Concrete material”, “Concrete placing”, and “Concrete curing” at the third level. Among these items, “Concrete form”, “Reinforcing bar”, and “Concrete placing” will incur construction cost and time, and be taken into consideration for cost estimation and schedule planning. However, “Concrete material” is the only item considered for the purpose of estimating the material cost of concrete, and “Concrete curing” only incurs time during construction. As a result, the integration of cost and schedule is achieved at this level by combining cost and schedule activities.

3.2 Integration of Product and Process Models

In fact, the three-level hierarchical WBS not only achieves the integration of cost and schedule, but also integrates the product model with the construction process model. The reason lies in the fact that the product model is decomposed into individual building components which are listed at the second level in the integrated WBS, whereas the third level WBS consists of detailed construction processes constructing the corresponding individual component. Thus, by linking the third level to the second level of WBS, we essentially complete the match from the construction process model to the product model.

Additionally, the quantity takeoff from Revit and the construction process information from RSMeans should be generated or selected to match the lower-level (third level) WBS. In fact, data from RSMeans is construction-oriented and is formulated based on detailed construction process information (e.g., construction method). Aside from this, RSMeans utilizes a MasterFormat-based 12-digital-index system, known as the most adopted industry standard for organizing construction data, to organize cost items. Thus, RSMeans data can be easily mapped to detailed WBS manually. However, the product model in Revit is an assembly of building components and does not embrace any construction information used to generate the takeoff for construction activities. Therefore, we have to integrate Revit and RSMeans systematically to address this issue.

Fortunately, Autodesk Revit provides several powerful mechanisms by which to integrate data into Revit families (product model components), including “project parameters”. In general, project parameters are customized properties that can be added to elements by end-users and are able to hold the user-defined information. Consequently, the integration of Revit and

RSMeanS can be realized by defining construction process information as project parameters for Revit elements. Moreover, to facilitate the implementation of the integration, one Revit add-on, as shown in Figure 2, is developed. The add-on automatically identifies and lists all types of building elements in the project model, as well as construction information items in the Microsoft (MS) Excel file (exported from RSMeanS Online). Practitioners can then add the selected construction items as type parameters into the building elements belonging to the checked element type by clicking “Attach Parameters”, and can also define names for the parameters through the middle Textbox in the interface. Figure 2 shows one example of mapping construction information to building element for a concrete masonry unit (CMU) wall. The resulting properties of the CMU wall are presented in Figure 3. As indicated in the figure, five construction items from RS Means are stored under the “Construction” category in Type Parameter of CMU Wall.

With regard to quantity takeoff for each work package under each building element, the schedule feature of Revit can be utilized to perform the task. However, it should be noted that Schedule in Revit not only can produce the physical volume or area of a building element as quantity takeoff, but also is capable of allowing users to embed user-defined equations for the derived quantity, which makes Revit able to produce construction activity-oriented quantity takeoff. For instance, the quantity for grouting in CMU walls is defined as one quarter of the area of CMU walls in

<Wall Schedule>

A	B	C	D	E	F
Family and Type	ID	Work Package #1	Quantity_WP#1	Work Package #2	Quantity_WP#2
Basic Wall: Exterior-Brick on CMU 12" 500	01	42210280650 Concrete block,	997 SF	040516300350 Grout,	249 SF
Basic Wall: Exterior-Brick on CMU 12" 500	02	42210280650 Concrete block,	680 SF	040516300350 Grout,	170 SF
Basic Wall: Exterior-Brick on CMU 12" 500	03	42210280650 Concrete block,	997 SF	040516300350 Grout,	249 SF
Basic Wall: Exterior-Brick on CMU 12" 500	04	42210280650 Concrete block,	680 SF	040516300350 Grout,	170 SF

Figure 4. One example of quantity takeoff

4 Case Study

In this section, the procedures to implement the integrated framework are illustrated by using a simple building project as a case study. The project is a one-storey reinforced unit masonry building designed for use as a parking garage, with the dimensions of 60 ft. (width) x 90 ft. (length) x 12 ft. (height). The exterior load bearing walls are made of 12-in.-thick, 5000 psi CMU blocks, vertically reinforced by #6 bars in every second block, with reinforcing cores fully grouted. To enhance the structural integrity, all rebar extends 3 ft.

RSMeanS, provided that only one quarter of CMU cores are fully grouted. In this case, the quantity of grouting for CMU walls can be produced by embedding “Area*0.25” in Revit Schedule. Figure 4 presents one example of quantity takeoff for CMU walls. Subsequently, the takeoff can be easily combined with unit cost and productivity data in order to perform detailed cost estimation and schedule planning.

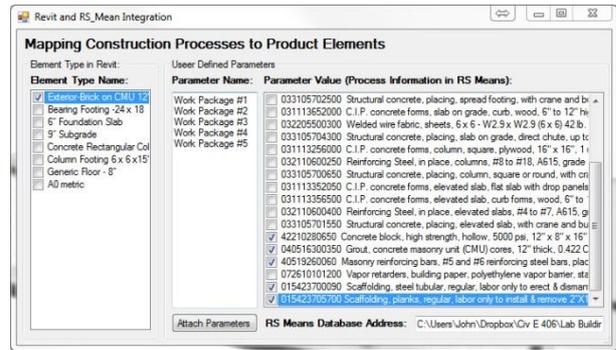


Figure 2. Interface by which to map construction processes to product elements

Construction	
Structure	Do not wrap
Wrapping at Inserts	None
Wrapping at Ends	None
Width	1' 0"
Function	Exterior
Work Package #1	42210280650 Concrete block, high strength, hollow, 5000 psi, 12" x 8" x 16", includes mortar and horizo
Work Package #2	040516300350 Grout, concrete masonry unit (CMU) cores, 12" thick, 0.422 C.F./S.F., pumped, exclude
Work Package #3	40519260060 Masonry reinforcing bars, #5 and #6 reinforcing steel bars, placed vertically, ASTM A615
Work Package #4	015423700090 Scaffolding, steel tubular, regular, labor only to erect & dismantle building exterior, wall f
Work Package #5	015423705700 Scaffolding, planks, regular, labor only to install & remove 2'x10'x16", up to 50' high

Figure 3. User-defined properties of CMU wall

above the top of the wall and is bent into the roof slab. The continuous wall footing is 24 in. (width) x 18 in. (depth) with 2 #6 bars, continuous, and #4 bars, 18 in. on-center, across the footing. The footings are formed on the sides, using fine-graded earth as the soffit. All concrete in the structure is 5000 psi, and is placed by crane and bucket. The slab-on-grade (SOG) is 6 in.-thick, with 6 x 6 6/6 welded wire fabric reinforcement. The subgrade consists of 6 in. of gravel, 3 in. of sand, with a 0.010 in.-thick polyethylene vapor barrier. Three interior reinforced concrete columns are placed down the center line of the building. All columns are 16 in. x 16 in. and are constructed using 1-use plywood forms and 4 #8 vertical reinforcing bars. Column footings are

6 ft. square and are constructed using 1-use plywood forms, 15 in. deep, with 6 #6 bars each way in the bottom of the footing. Footings are formed on all sides, with fine-graded earth as the soffit. The roof slab is an 8 in.-deep flat slab constructed using 2-use plywood forms, with #8 rebar 24 in. on-center each way. Rebar is placed in the bottom of the roof slab. #4 bars, 12 in. on-center each way, are located in the top of the slab in an 8 ft. square area over each column. 1-use wood curb forms are installed for the construction of the slab-on-grade and the roof slab.

4.1 Development of 3D BIM Model

According to the design description, the BIM model is developed in Autodesk Revit in detail. All the product information is modeled in Revit, including various types of rebar, in order to facilitate the generation of the comprehensive quantity takeoff. In order to design rebar in detail and build the 3D model for rebar, one Revit extension provided by Autodesk, “Reinforcement”, is employed. The extension is developed based on an object parametric modeling approach. It requires only a few parameters from users in order to generate the 3D model of rebar, and improves the efficiency of modeling. Figure 5 shows the 3D view of the building project.

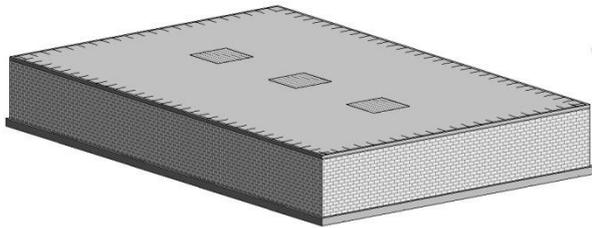


Figure 5. 3D view of the building project

4.2 Construction Information Database

Construction information, including cost or productivity for each work package, is extracted from RSMeans Online. During this process, construction practitioners must be involved in selecting appropriate items corresponding to the construction methods specified in the design description and to match the RSMeans items with the integrated WBS. Taking the formwork for concrete wall footings as an example, RSMeans provides a variety of items for formwork which are differentiated by the material of the formwork, number of uses, and type of building component, etc. However, only one item can be considered the most appropriate item for the designed wall footing, based on the conditions of “continuous wall footing”, “plywood” and “1-use”. In this regard, practitioners eventually

should select item with a line number “031113450020”. Similarly, other items for the project can be selected in the same manner. Once all cost items are identified from RSMeans, they are exported into MS Excel for the subsequent estimation and scheduling. One aspect to be pointed out at this juncture is that the bare cost, rather than overhead and profit (O&P) cost, is used in the estimation; the indirect cost, meanwhile, including overhead, is estimated by taking a percentage of direct cost. The cost listed in Table 1 is the bare cost for labor, material, equipment.

4.3 WBS and Quantity Takeoff

The WBS for the building project is presented in Table 1. During the establishment of WBS, it is assumed that: (1) excavation and earth moving work will be performed by subcontractors, and not included in the WBS; (2) demobilization is also ignored in the WBS. It should also be noted that in the interest of brevity only two wall and two wall footings, and one column and one column footing are presented in Table 1, since the same quantities and cost and productivity information will apply for the remaining wall footings, columns, and column footings.

Then, following the steps illustrated in the previous section, the RSMeans construction data is assigned to each type of building component in Revit. The quantity takeoff is generated and exported into MS Excel through Revit’s Schedule feature. Table 1 tabulates the generated quantity takeoff. As described above, Schedule in Revit allows users to define equations in order to produce derived quantities, and this feature is especially instrumental in performing quantity takeoff for temporary facilities which are not represented in the 3D product model. In the case study, quantities for formwork and scaffolding are surveyed as such. For instance, the formwork quantity for each continuous wall footing is expressed as Equation (1); and scaffolding quantities are estimated separately by Equation (2) for steel tubular and by Equation (3) for planks. All the equations are inputted into Revit when the quantity schedules are created.

$$Q_i^F = \frac{V_i}{W_i} \times 2 \quad (1)$$

$$Q_i^{ST} = A_i \quad (2)$$

$$Q_i^{SP} = \frac{L_i^W}{L_i^P} \times 2 \quad (3)$$

Where i is the identification number of the building element; Q^F is the formwork quantity for wall footing; V denotes the volume of the wall footing in Revit; W

Table 1 Cost and schedule information of each activity

1 st WBS	2 nd WBS	3 rd WBS	Quantity	Line Number	Material	Labor	Equip- ment	Daily output	Dura- tion	
01	0101	010101	Fine grading	567 SY	031221601100	0.00	0.68	0.73	1040	0.55d
SW	SW#1	010102	Subgrade 6" gravel 3" sand	138.7 CY	312323171200	50.24	9.45	0.82	200	0.69d
02	0201	020101	use plywood forms, WF	270 FCA	031113450020	8.10	3.60	0.00	375	0.72d
WF	WF	020102	Rebars #4, #6, WF	0.17 Ton	032110600500	1448	573.04	0.00	2.1	0.08d
	#1	020103	Concrete placing, WF	10.03 CY	033105702200	0.00	27.77	11.79	110	0.09d
	(#3)	020104	5000psi concrete	10.03 CY	033105350400	219.89	0.00	0.00	-	-
		020105	Concrete curing	-	-	-	-	-	0.14	7d
	0202	020201	use plywood forms, WF	174 SFCA	031113450020	8.10	3.60	0.00	375	0.46d
	WF	020202	Rebars #4, #6, WF	0.11 Ton	032110600500	1448	573.04	0.00	2.1	0.05d
	#2	020203	Concrete placing, WF	6.47 CY	033105702200	0.00	27.77	11.79	110	0.06d
	(#4)	020204	5000psi concrete	6.47 CY	033105350400	219.89	0.00	0.00	-	-
		020105	Concrete curing	-	-	-	-	-	0.14	7d
03	0301	030101	use plywood forms, CF	90 SFCA	031113455000	2.61	4.42	0.00	305	0.3d
CF	CF	030102	Rebars #6, CF	0.16 Ton	032110600500	1448	573.04	0.00	2.1	0.08d
	#1	030103	Concrete placing, spread	5 CY	033105702500	0.00	67.52	29.08	45	0.11d
	(#2)	030104	5000psi concrete	5 CY	033105350400	219.89	0.00	0.00	-	-
		030105	Concrete curing	-	-	-	-	-	0.14	7d
04	0401	040101	use wood form, curb, sog	146 FCA	031113652000	3.32	6.29	0.00	215	0.68d
SOG	SOG	040102	Welded wire fabric, sheets, 6 x 6 - 6 x 6	51 CSF	032205500300	32.58	20.74	0.00	29	0.18d
	#1	040103	Concrete placing, up to 6"	95 CY	033105704300	0.00	17.59	0.65	55	1.73d
		040104	5000psi concrete	95 CY	033105350400	219.89	0.00	0.00	-	-
		040105	Concrete curing	-	-	-	-	-	0.14	7d
05	0501	050101	use plywood form square	192 SFCA	031113256000	3.49	7.28	0.00	185	1.04d
C	C#1	050102	Rebar #8, column	0.2 Ton	032110600250	1448	524.03	0.00	2.3	0.09d
	(#2)	050103	Concrete placing, column	2.37 CY	033105700650	0.00	54.99	23.69	55	0.04d
		050104	5000psi concrete	2.37 CY	033105350400	219.89	0.00	0.00	-	-
		050105	Concrete curing	-	-	-	-	-	0.14	7d
06	0601	060101	use plywood forms	5104 SF	031113352050	2.91	4.08	0.00	449	11.4d
R	R	060102	use wood curb forms	195 SFCA	031113356500	1.80	7.48	0.00	180	1.08d
	#1	060103	Rebar #4 & #8, slab	7.44 Ton	032110600400	1448	414.70	0.00	2.2	3.38d
		060104	Concrete placing	126 CY	033105701550	0.00	27.77	11.79	110	1.15d
		060105	5000psi concrete	126 CY	033105350400	219.89	0.00	0.00	-	-
		060105	Concrete curing	-	-	-	-	-	0.14	7d
07	0701	070101	5000psi CMU block	1092 SF	042210280650	8.85	6.00	0.00	300	3.60d
MW	MW	070102	Grout cmu core, 12" thick	249 SF	040516300350	3.32	1.95	0.22	640	0.42d
	#1(#3)	070103	Masonry Rebars, #6	767.2 lb	040519260060	0.90	0.53	0.00	650	1.18d
		070104	Scaffolding, tubular	10.95 SF	015423700090	0.00	131.63	0.00	8	1.37d
		070105	Scaffolding, planks	11.55 Ea.	015423705700	0.00	14.58	0.00	72	0.16d
	0702	070201	5000psi concrete block	702 SF	042210280650	8.85	6.00	0.00	300	2.32d
	MW	070202	Grout cmu core, 12" thick	170 SF	040516300350	3.32	1.95	0.22	640	0.27d
	#2	070203	Masonry rebars #6	494.4 lb	040519260060	0.90	0.53	0.00	650	0.76d
	(#4)	070204	Scaffolding, tubular	7.05 CSF	015423700090	0.00	131.63	0.00	8	0.88d
		070205	Scaffolding, planks	7.45 Ea.	015423705700	0.00	14.58	0.00	72	0.10d
08V	0801	080101	0.010" thick Vapor carp	50.14	072610101200	9.66	9.27	0.00	37	1.36d

Note: SW: site work; WF: wall footing; CF: column footing; SOG: slab on grade; C: column; R: roof; MW: masonry wall; V: vapor. Under "Material", "Labor", and "Equipment" is bare unit cost (\$/unit); d in Duration is day.

Table 2. Cost estimation of the building project

Description	Amount (\$)	Total(\$)	Rate	Cost Basis
Labor	70,297			
Material	137,652			
Equipment	2,861			
Other				
	210,810	210,810		
Engineering Fees	14,757		7%	Current Total
GST	6,883		5%	Material
Permits	7,000			Lump Sum
Payroll Burden	18,980		27%	Labor
	47,619	258,429		
Insurance	517		\$2/1000	Current Total
	517	258,946		
Corporate Overheads and Profit	46,610		18%	Current Total
		305,556		
Surety Bonds	10,399			Bond
Base Estimate				\$315,955.21

represents the width of the wall footing; Q^{ST} denotes quantities for steel tubular scaffolding; A represents the vertical area of the wall; Q^{SP} is the quantity of scaffolding planks; L^w is the length of wall; and L^p is the length of scaffolding planks

4.4 Cost and Schedule Determination

Direct costs in the estimation are grouped into three categories - namely, labor, material, equipment, and are calculated separately, following Equation (4).

$$Cost_i = \sum_{j=1}^n R_{ij} \times Q_{ij} \quad (4)$$

Where i denotes the category of cost, (labor, material, or equipment); j represents the index of cost item; n is the number of cost items, R is the bare rate from RSMMeans; and Q denotes the quantity from the BIM model. Other costs, such as indirect cost, are calculated by taking a percentage of the basis. The assumptions pertaining to various types of indirect costs considered in the project and the cost results are presented in Table 2.

In terms of schedule, the duration for each activity is obtained by dividing its quantity by its daily output as shown in Table 1, and the construction sequencing logic of the schedule is determined manually based on authors' experience. For instance, "020202 rebar for wall footing" must be finished before "020203 concrete placing for wall footing" can be started. Finally, the project duration is determined as 53 calendar days (or 35 working days.)

5 Summary

In the presented research, a BIM-based integrated framework for detailed cost estimation and scheduling planning has been proposed, and has been explained and verified through a case study of building project. As the core of the proposed framework, the integrated WBS achieves cost and schedule integration as well as the integration between the product model and the construction process model. However, it is developed manually based on construction knowledge of a building project. Future research efforts are needed with respect to the automatic generation of WBS. Some other challenges regarding full automation of BIM-based detailed cost estimation and schedule planning are summarized as follows:

1. Temporary facilities such as formwork and scaffolding are missing from the 3D model. Consequently, quantities for formwork and scaffolding cannot be directly extracted from the BIM model without manual involvements.
2. Modeling of the temporary facilities in a BIM environment is difficult to achieve without the required construction knowledge. For instance, in the case study, CMU walls can be constructed concurrently by establishing multiple sets of scaffolds around the building; or they can be built sequentially by installing and moving only one set of scaffolds. In this case, the BIM program needs to have "intelligence" embedded in order to automatically build a 3D model of the temporary facility.

3. Incompatibility between the BIM-based quantity takeoff and downstream analyses, such as estimation, with respect to the definition of quantities also impedes the integration of the product and process models. For example, RSMean defines the grout quantity for CMU as the area of the grouted wall, rather than the physical volume, area or perimeter of grouted core provided by Revit.

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