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Building Information Modeling Applications in Construction Management - A case study for modeling information and outcomes

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ABSTRACT
This study has aimed to utilize BIM in construction management in terms of elements for threefold purpose-orientated integration. Firstly, an apartment complex on campus housing was used as an example project, whose BIM model has been built streamlining construction information for time, cost, and project monitoring. Next, construction information requirements and BIM model integration as well as utilization have been depicted in detail among modeling processes and construction management modules. The applications of BIM in construction management have been exemplified for construction management modules including scheduling, cost estimating, and performance monitoring. The project BIM model was built in compliance with construction management requirements by assigning as-planned parameters to each element. A project schedule containing activities and sequences has been arranged hierarchically supporting the integration of BIM into construction management modules. Both sorts of structural elements and architectural elements were modeled so as to resemble the variety of activities during project construction. These elements were associated with project activities through quantity reasoning processes which determining dependable element quantities while evaluating productivity unit factors at a time. Activity durations would be derived in accordance with the relationship between quantity and productivity of elements resulting the updated project schedule. Cost data were referenced and consolidated into the element hierarchy of project schedule by element information. Three key project performance measures would therefore be imposed emulating project evaluation while augmenting the hierarchy of project schedule by element information.
KEYWORDS *building information modeling, construction management, information and outcomes*

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I. INTRODUCTION

Construction industry can be regarded as fundamental as for nation development, since efficiency, safety, and quality housing and facilities significantly support individual and economic growth. With the even increasing population rise with the ageing of work force in the industry, there is a considerable need for more job-efficient and cost-effective application of scientific knowledge for practical purposes in construction industry to plan, control, monitor, and value these structures. This is an urgent push for developing and utilizing innovative techniques as well as polishing and refining the widely-spread standardized construction management systems in the construction industry, which has been seen a downward trend in competition comparing to other industries for decades.

BIM has been prevalently used in the building industry in most recent decades, while industry and academy are attempting to adopt BIM focusing on any potentially feasible practice. However, there has sparsely been a comprehensive review of the effort specifically targeted at bringing CPM up to date for its standardized project procedure. Indeed, there have been other literature reviews of BIM highlighting rehabilitation of existing buildings, management of BIM, BIM as a platform for collaboration and data management, transportation infrastructure, and BIM and the internet of things integration. These research illustrate an overall picture of how BIM would be employed in their respected areas, but an comprehensive review of BIM for CPM application, such as schedule planning, cost control, resource planning, safety and health have still been scant. Therefore, the vision of this study is to present an in-depth, contemporary literature review of the application and practice of BIM for construction project management.

The objective of this paper is to present an analytical interpretation of the reviewed articles, including most recent topics and techniques, application and uses, emerging technologies, benefits, research gaps, and future directions. In addition, the study aligns future work and collaboration by means of utilizing intelligent technologies with current approaches in the construction industry. Consequently, the paper bridges the gaps among current research, emerging technologies, and further development in terms of efficiency and cost-effectiveness vital to refine, update, and augment the construction industry.

II. RECENT BIM WORKS IN CONSTRUCTION MANAGEMENT

Although BIM for the overall construction industry has been developing and implementing for recent decades in academia and industry, there is still a need to conduct a throughout literature review to dive into its real construction management applications. Reviewing comprehensive literature is vital to keep the research and development in efficacy. The scope of this literature review is concerned with publication pertaining to BIM for construction management. One publication that has topics relating construction management would be collected in this review. A clear limitation is the review only includes research and application directly applies to construction management from actual case application to latent application. That is to say the review body focus on works that have been validated for the use of BIM in construction management modules.

Time Scheduling

Project scheduling is essential to any project for successful timely accomplishment especially for modern complex cases. The implemented BIM extended both time management and model visualization to a new horizon, four-dimension space (4D), by integrating time dimension into physical three-dimension measurement. This area has been one of the most concentrated topics in BIM application and still improving the industry with the development of new technology continuously. Project scheduling benefits from the strength of quantity takeoffs (QTOs) in BIM shed a light on the industry in BIM early developments. 4D QTOs and operation simulation has been proposed by integrating BIM with construction process for simulation purposes as well as for project scheduling support (Wang *et al.*, 2014). Construction process as well as work breakdown structure (WBS) has been detailly analyzed for 4D process simulation. Liu proposed a BIM integrated method for detailed project scheduling with resource constraints with regards to resource utilization for WBS (Liu *et al.*, 2015). Spatial enabled BIM feature therefore brought workspace conflict analysis together into scheduling issues. A series of research concerning workspace conflict and scheduling has been published, one targeted on the overlap level of parallel schedules and workspaces interference while the other utilized BIM object in conflict visualization and simulation for work schedule (Moon *et al.*, 2014 and Moon *et al.*, 2014). These triggered a possibility in virtual design collaborating mechanical, electrical, and plumbing (MEP) service providers transformed from early BIM application in utility clash-detection into 4D visualization system in project planning (Ivson *et al.*, 2018).

Progress monitoring

Progress monitoring topic has drawn a significant attention for integration between BIM with updating video records. 4D as-planned modeling and as-built scanning reconstruction has been proposed for automation in progress monitoring and updating by using daily project photographs with IFC-BIM planning (Golparvar-Fard *et al.*, 2014 and Hamledari *et al.*, 2017). Clearly, on-site reinforced concrete (RC) structures have seen a certain level of difficulty in scheduling as well as progress monitory to a hundred percent satisfactory management due to a lack of comprehensive knowledge and experience in constructability. Sigalov and König then proposed a knowledge-based scheduling which is a 4D schedule process pattern recognition into BIM-based construction schedules (Sigalov and König *et al.*, 2017). Alternatively, prefabricated construction becomes a fascinating area in project scheduling. Sensors, such as RFID, setup on prefabricated building components enable BIM to mitigate uncertainties and to improve scheduling performance; moreover, an Internet-of-Things (IoT) platform modeling 4D date flow in BIM project has been proposed for on-site assembly prefabricated house construction (PHC) (Li *et al.*, 2017 and 2018). This type of construction could benefit from IoT platform development and also from cloud asset BIM management for potential project information sharing among stakeholders. Lean construction philosophy therefore brought back into theme in construction management. Xu *et al.* proposed a cloud-enable platform integrating asset management to lean perfricated construction exemplifying a framework of Lean Construction for PHC (Xu *et al.*, 2018). In addition, a recent study proposed and simulated their design of work packages dedicate to prefabrication housing production (PHP) by integrating BIM to prefabricated residential activities (Li *et al.*, 2019).

Cost Estimation

Cost estimation plays an integral role in successful construction project achievement. The emerging of BIM has seen a dramatic transformation in cost estimation for construction management. Before this, project cost estimating used to be performed on an activity basis among projects. It is the accuracy and precision of BIM yields QTOs that fascinates recent researchers contributing significant efforts in innovation of cost control based on elements through the timeline of project. 5D QTOs, combing 4D model with cost items, enable visualization the effect of construction progress which usually represented in project earned value analysis and progress curves in CM. Wang *et al.* proposed a method of applying BIM with project cost and schedule for visualizing construction progress curve using BIM model QTOs output as a protocol implementing project earned value analysis into BIM application (Wang *et al.*, 2014, Wang *et al.*, 2016, Alrashed and Kantamaneni, 2018), while similar methodology has been applied and demonstrated in varied project types from liquefied natural gas (LNG) plant, office building, to flats and mid-terrace houses.

There have been developing and evolving a wide variety of interests and studies applying BIM in construction management in recent decades, including both industry and academia works. In some cases, specific businesses in the industry tend to work with academia to develop various applications of BIM by means of bridging gaps in-between, while most academics applying the strengths of BIM especially in parametric and spatial relationship as supplements to their profession as well as bringing considerable insights to the whole community of AECO. By reviewing recent publications, research objectives were identified so as to improve BIM model utilization alongside applications in construction management. Streamlining information and applications via a case study BIM model would be targeted to support key construction management modules. The BIM model, especially those elements modeled served as information repository supporting reliable construction information and applications. On top of that, the project case study would be steppingstones examining the satisfaction of BIM applications within the research scope.

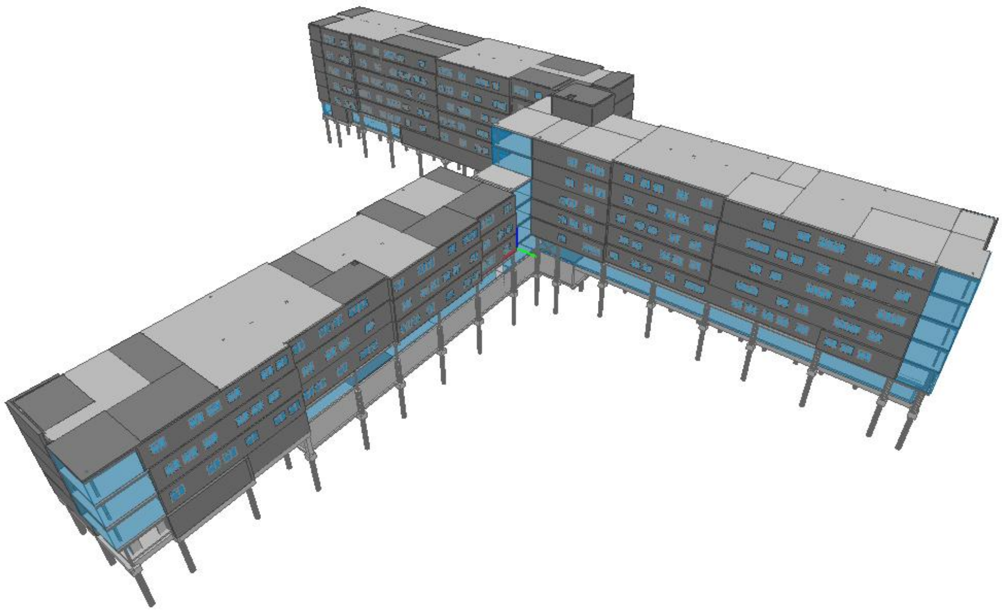

Figure 1 Case Study BIM Model

III. PROJECT DESCRIPTION

The case study of this research is a student apartment complex on campus (Figure 1), housing six hundred sophomore students. Not only reserved for students living on campus, it also serves classrooms and lounges for educational programs and social connecting. It is designed as an energy efficient building while earned a Gold rating under the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system. With these considerable dedicated design features, the project could be seen as an ideal model for research purposes.

Modeling Preparation

Structural drawings and architectural drawing were collected in accordance with BIM modeling for construction management purposes. A list of them has been summarized clarifying where each of BIM elements/information were coming from (Table 1). For example, structure drawing 101 has a title of

"BASEMENT – AREA A AND C FOUNDATION PLAN AND LEVEL 1 – AREA A FOUNDATION PLAN", and it is therefore required for modeling elements such as "Foundation slab, Foundation wall, Grade beam, Pile, Column, Beam, Wall, Precast slab, Door, and Slab shaft", and thus acquiring information content such as "Basement GB level, Basement level, Level 1, Grid lines 1 to 10.7, Grid lines C to H, Element quantity, Element material, Element parameter". Identifying such information flow was important because BIM model in this study was mostly depicted from raster PDF design drawings rather than a BIM design model.

Table 1 Drawing Element Information Summary

Drawing	Drawing title	BIM element modeling	Information
S101 to S109	BASEMENT – AREA A AND C FOUNDATION PLAN AND LEVEL 1 – AREA A FOUNDATION PLAN	Foundation slab, Foundation wall, Grade beam, Pile, Column, Beam, Wall, Precast slab, Door, and Slab shaft	Basement GB level, Basement level, Level 1, Grid lines 1 to 10.7, Grid lines C to H, Element quantity, Element material, Element parameter
S110	LEVEL 6 AND 7 – AREA A FRAMING PLANS	Column, Beam, Wall, Precast slab, Door, and Slab shaft	Level 6, Level 7 Roof Area A, Level 8 Penthouse, Grid lines 1 to 9.4, Grid lines D.9 to G, Element quantity, Element material, Element parameter
S503 to S507	BRACE FRAME ELEVATIONS AND DETAILS	Bracing	Bracing span, Bracing type, Bracing intersection center
A0301 to A0305	EXTERIOR ELEVATIONS	Wall shaft, Window	Building east elevation (Scale 1/16" = 1' - 0), Building west elevation (Scale 1/16" = 1' - 0), Shaft location, Shaft elevation, Shaft quantity, Shaft parameter, Window quantity, Window material
A0601 to A0605	INTERIOR ELEVATION	Interior wall, Interior wall shaft, Interior door	Space layout, Wall level, Wall quantity, Wall parameter, Door level, Door quantity, Door parameter

IV. QTOS AND PROJECT SCHEDULING

By assigning exactly as-planned parameters to each element in the project, it is workable to conclude project summary via BIM model with respect to element type, material, count, and dimensions. The summary delivers essential element quantities, in this project case, including 456 basic walls, 455 windows, 44 openings, 195 floors, 343 structural columns, 1310 structural framing, 1 structural foundation slabs, 114 isolated foundations, and 67 curtain panels. These quantities are bridges linking BIM elements with project activities within this study scope. It is straightforward and feasible to generate the project summary table concerning reliable element geometry counts using built-in exportation in Revit. Element counts were a single parameter reviewed. However, the counts of element could not sufficiently workable for overall project quantity takeoffs requirements. This means that more parameters must be retrieved from the BIM model in order to satisfy construction management modules. It is then feasible when each BIM model was crafted via a parametric modeling process, say an as-planned BIM model, despite the fact that some flaws may occur by scrutinizing what context in Revit report could generate. Overall, element quantities are able to be retrieved systematically via BIM model, but only accurate quantities would be able to applied for construction management modules, which is purpose-oriented such as activity schedule.

Activity and Sequence

Activity sequencing was the first step of activity schedule in this study. Activities were classified into two general works, structural and architectural (Table 2). Elevation levels were clearly identified among both works, for example, activities lie in sub structure are divided into Grade Beam level (GB) and Basement level (BS), or activities on Ground Floor (GF) in super structure. Due to the scope of this project, activities are considered only on an element basis in order to seamlessly integrating quantity and productivity into an activity with exact QTOs derived from the project BIM model. Activities are structured hierarchically using Microsoft Project. However, task numbers denoting task sequence with preidentified predecessors, were sorted sequentially yet not starting from one. This is because the Project software assigning task numbers not just for tasks but also for hierarchical structure before the first task resulting the first task, numbered 6 yet with no predecessor. Finish-to-Start (FS) is the most common sequential relationship across the table, while Finish-to-Finish (FF) and Start-to-Start (SS) are also used when such relationship is required.

Table 2 Activity and Sequence

No	Task Name	Predecessors
	010100 Foundation	
6	010110 Pile Foundation Formwork/Steel Reinforcement/Concrete Casting GB	
7	010120 Grade Beam Formwork/Reinforcement/Concrete Casting GB	6FF+1 day
8	010130 Column Formwork/Reinforcement/Concrete Casting GB	6FF+1 day
9	010140 Foundation Slab Formwork/Reinforcement/Concrete Casting GB	7
10	010150 Foundation Brace Reinforcement GB	9FF+1 day
11	010160 Exterior Wall Installation basement GB	9SS+1 day
	010200 Basement	
13	010210 Basement Floor Slab	9
14	010220 Column Formwork/Reinforcement/Concrete Casting BS	13SS+1 day
15	010230 Beam Formwork/Reinforcement/Concrete Casting BS	14SS+1 day
16	010240 Basement Brace Reinforcement	15FF+1 day
17	010250 Exterior Wall Installation Basement	16FF+1 day
	Super Structure	
	010300 Ground Floor	
20	010310 Pile Foundation Formwork/Steel Reinforcement/Concrete Casting GF	6SS
21	010320 Grade Beam Formwork/Reinforcement/Concrete Casting GF	20FF+1 day
22	010330 Foundation Slab Formwork/Reinforcement/Concrete Casting GF	21
23	010340 Precast Slab Erection GF	20
24	010350 Ground Floor Brace Reinforcement	22,23FF+1 day
25	010360 Foundation Wall Installation GF	22FF+1 day
	010400 First Floor	
27	010410 Column Installation 1F	14
28	010420 Beam Installation 1F	27SS+1 day
29	010430 Precast Slab Erection 1F	28
30	010440 Brace Reinforcement 1F	29FF
	010500 Second Floor	
32	010520 Beam Installation 2F	28
33	010530 Precast Slab Erection 2F	32
34	010590 Brace Reinforcement 2F	33FF
	010600 Third Floor (Wing A &B) and Roof Deck (Wing C)	
36	010610 Column Installation 3F	27
37	010620 Beam Installation 3F	32
38	010630 Precast Slab Installation 3F	37
39	010640 Brace Reinforcement 3F	38FF
	010700 Forth Floor (Wing A &B)	
41	010710 Column Installation 4F	36FF
42	010720 Beam Installation 4F	37
43	010730 Precast Slab Installation 4F	42
44	010740 Brace Reinforcement 4F	43FF
	020000 Architectural	
	020300 Ground Floor	
56	020310 Exterior Wall Installation GF	23
57	020320 Glazed Curtain Wall Installation GF	56SS+1 day
	020400 First Floor	
61	020410 Exterior Wall Installation 1F	29
62	020420 Glazed Curtain Wall Installation 1F	61SS+1 day
63	020430 Glazed Windows Installation 1F	61FF+1 day
	020500 Second Floor	
67	020510 Exterior Wall Installation 2F	33,61
68	020520 Glazed Curtain Wall Installation 2F	67SS+1 day
69	020530 Glazed Windows Installation 2F	67FF+1 day
	020600 Third Floor (Wing A &B)	
73	020610 Exterior Wall Installation 3F	38,67
74	020620 Glazed Curtain Wall Installation 3F	73SS+1 day
75	020630 Glazed Windows Installation 3F	73FF+1 day
	020700 Forth Floor (Wing A &B)	
79	020710 Exterior Wall Installation 4F	43,73
80	020720 Glazed Curtain Wall Installation 4F	79SS+1 day
81	020730 Glazed Windows Installation 4F	79FF+1 day

QTOs vs Productivity

One fundamental goal of this study was to integrating project scheduling with BIM elements correspondingly. This requires accurate quantity of each element as well as each level of element for scheduling purposes. Fortunately, it is possible for BIM model to derive such information intensive calculating process from Revit version 2020. Due to certain modeling conditions, level of element may not be precise as what schedule requires, which took a large amount of efforts identifying and refining the extracted results to fit study goals. Moreover, only quantity of accuracy would be able to be referred to external productivity/cost data for further information utilization. QTOs by level of Structural Columns has been summarized to determine rational quantity of accuracy. Element Count has been fully reviewed in former sections. There are still various parameters, Height, Width, Depth, and etc., which are possible quantity candidates. In order to rationally determine which is the most useful one of the topics, project scheduling, productivity must be considered in advance. According to Building Construction Cost Data 2009 published by RSMeans, W10X33, for example, has a generic productivity of 0.102 hours per length in feet (0.102hr/L.F.). It is then clear enough that Length is the critical parameter for determining quantity so as productivity and schedule. A step further is required for matching Length within these quantity candidates say using Height as the Length requirement for scheduling purposes. It is logical to have Height to be the critical parameter from both modeling and construction management perspectives.

Depending on the unit of productivity available, BIM models have the ability to support and extract reliable parameters or dimensions so as to make achieve unit consistency. To better illustrate the concept of most appropriate quantity Q* for construction management modules, a simple formulation must be introduced with regards to parameter and dimensions (equation 1):

$$Q_{ec}^{*} = (C, H, L, A, V) \qquad \text{(equation 1)}$$

where

Q_{ec}^{*}	=	the most appropriate quantity for an element or component,
ec	=	Element component type: column, beam, slab, etc.
C	=	the number of an element,
H	=	the height of an element,
L	=	the length of an element,
A	=	the area of an element,
V	=	the volume of an element.

In general, concrete components would have volume V as the most appropriate quantity Q*, W shape steel columns would have Height H as the Q*, HSS steel bracing components would use the number of elements for Q*, slab components would use element area as Q*, and beam components would have the length L as the most appropriate quantity Q*. The result worksheet of clearly identifying the relationship between Q* and parameters in accordance with activity schedules has been organized as the QTOs of project BIM model.

Activity Duration

Among previous discussions, Q_{ec}^{*} has been determined from BIM model quantity takeoffs, and Productivity P has been referenced through external source. It is then sufficient to yield activity duration with these two criteria mentioned above. In short, duration equals to quantity multiplies productivity for each element component of an activity (equation 2). Since the productivity has given time unit in hour, eight working hours in a day would be used for transforming duration into a daily basis (equation 3). On top of this, element duration De can be calculated from summarizing each component duration Dec of an element type (equation 4). And therefore, task duration could be derived by summarizing each element duration among the task (equation 5).

$$D_{ec}^{hr} = P_{ec} * Q_{ec}^{*} \qquad \text{(equation 2)}$$

$$D_{ec}^{day} = \frac{1}{8} P_{ec} Q_{ec}^{*} \qquad \text{(equation 3)}$$

$$D_e = \sum_{c=1}^{c=m} D_{ec}^{day} \qquad \text{(equation 4)}$$

$$D_t = \sum_{e=1}^{e=n} D_e \qquad \text{(equation 5)}$$

where

D_{ec}^{hr}	=	the duration of element component in hours,
D_{ec}^{day}	=	the duration of element component in days,
D_e	=	the duration of element in days,
D_t	=	the duration of task in days,
P_{ec}	=	the productivity of a task element component, and
Q_{ec}^{*}	=	the quantity of a component.

It is certainly true that an activity completion means its sub jobs, or task components are functionally put in place completely. By integrating BIM QTOs and productivity data, it is workable to redefine the activity duration sheet in a bottom-up method, or on an element basis. Although summing up the working time of each component in a task for populating job duration is feasible from a single activity work flow since in reality these works regarding components must be done for finishing a job. It is not responsible for further adding up total task time so as for yielding project duration in advance, which works against project scheduling module expecting shortest duration with parallel activities working at a time.

Project Schedule

It is a must to recall the Activity and Sequence. Given such sequence, and project activity duration has just been discussed and completed, it is adequate to plan project schedule for the BIM model. Supporting data among previous discussions are sufficient and ready for demonstrating the result of integrating BIM into project scheduling using Microsoft Project for both durations, start time, finish time, and Gantt Chart. Starting from duration assignment, given the results of task duration Dt (highlighted) from Table 3 which have a direct linkage with coded activities such as 010110 Pile Foundation Formwork/Steel Reinforcement/Concrete Casting GB, then the task duration 32 days would be assigned to the task. Since task 010110 is the first task of the project, its start day assumed to be the first working day, November 2nd, 2009 corresponding to project start day as mentioned. And it takes 32 working days for task 010110 to complete, finishing on December 15th, 2009. Following the procedure of assigning task durations with Activity Tasks of the project, it is straightforward to generate overall project schedule (Table 3) with strictly identified task duration retrieved from BIM model QTOs.

Table 3 Project Schedule

No	Task Name	Duration	Predecessors
	BIM Project Schedule	474 days	
	Construction Phase	474 days	
	010000 Structural	327 days	
	Sub Structure	135 days	
	010100 Foundation	95 days	
6	010110 Pile Foundation Formwork//Concrete Casting GB	32 days	
7	010120 Grade Beam Formwork/Concrete Casting GB	11 days	6FF+1 day
8	010130 Column Formwork/Reinforcement/Concrete Casting GB	16 days	6FF+1 day
9	010140 Foundation Slab Formwork/Concrete Casting GB	45 days	7
10	010150 Foundation Brace Reinforcement GB	2 days	9FF+1 day
11	010160 Exterior Wall Installation basement GB	61 days	9SS+1 day
	010200 Basement	57 days	
13	010210 Basement Floor Slab	2 days	9
14	010220 Column Formwork/Reinforcement/Concrete Casting BS	41 days	13SS+1 day
15	010230 Beam Formwork/Reinforcement/Concrete Casting BS	53 days	14SS+1 day
16	010240 Basement Brace Reinforcement	5 days	15FF+1 day
17	010250 Exterior Wall Installation Basement	2 days	16FF+1 day
	Super Structure	327 days	
	010300 Ground Floor	184 days	
20	010310 Pile Foundation Formwork//Concrete Casting GF	68 days	6SS
21	010320 Grade Beam Formwork/Concrete Casting GF	31 days	20FF+1 day
22	010330 Foundation Slab Formwork/Concrete Casting GF	100 days	21
23	010340 Precast Slab Erection GF	115 days	20
24	010350 Ground Floor Brace Reinforcement	5 days	22,23FF+1 day
25	010360 Foundation Wall Installation GF	5 days	22FF+1 day
	010400 First Floor	148 days	
27	010410 Column Installation 1F	34 days	14
28	010420 Beam Installation 1F	29 days	27SS+1 day
29	010430 Precast Slab Erection 1F	118 days	28
30	010440 Brace Reinforcement 1F	5 days	29FF
	010500 Second Floor	148 days	
32	010520 Beam Installation 2F	31 days	28
33	010530 Precast Slab Erection 2F	117 days	32
34	010590 Brace Reinforcement 2F	5 days	33FF
	010600 Third Floor (Wing A &B) and Roof Deck (Wing C)	171 days	
36	010610 Column Installation 3F	20 days	27
37	010620 Beam Installation 3F	29 days	32
38	010630 Precast Slab Installation 3F	115 days	37
39	010640 Brace Reinforcement 3F	4 days	38FF
	010700 Forth Floor (Wing A &B)	138 days	
41	010710 Column Installation 4F	1 day	36FF
42	010720 Beam Installation 4F	23 days	37
43	010730 Precast Slab Installation 4F	78 days	42
44	010740 Brace Reinforcement 4F	4 days	43FF
	020000 Architectural	291 days	

	020300 Ground Floor	291 days	
56	020310 Exterior Wall Installation GF	20 days	23
57	020320 Glazed Curtain Wall Installation GF	290 days	56SS+1 day
58	020330 Interior wall Installation GF	10 days	56
59	020340 Door Installation GF	5 days	58FF+1 day
	020400 First Floor	80 days	
61	020410 Exterior Wall Installation 1F	36 days	29
62	020420 Glazed Curtain Wall Installation 1F	79 days	61SS+1 day
63	020430 Glazed Windows Installation 1F	27 days	61FF+1 day
	020500 Second Floor	53 days	
67	020510 Exterior Wall Installation 2F	36 days	33,61
68	020520 Glazed Curtain Wall Installation 2F	52 days	67SS+1 day
69	020530 Glazed Windows Installation 2F	27 days	67FF+1 day
	020600 Third Floor (Wing A &B)	53 days	
73	020610 Exterior Wall Installation 3F	34 days	38,67
74	020620 Glazed Curtain Wall Installation 3F	52 days	73SS+1 day
75	020630 Glazed Windows Installation 3F	26 days	73FF+1 day
	020700 Forth Floor (Wing A &B)	42 days	
79	020710 Exterior Wall Installation 4F	25 days	43,73
80	020720 Glazed Curtain Wall Installation 4F	41 days	79SS+1 day
81	020730 Glazed Windows Installation 4F	18 days	79FF+1 day

V. BIM PROJECT COST ESTIMATION

BIM model has the ability to accurately takeoff element quantities through an as-planned modeling process. Such QTOs and scheduling parameter requirements have been rigorously and specifically demonstrated in previous Project Scheduling. However, prevalent cost estimation processes have not yet benefit from the strength of building information modeling nor utilized scheduling information such as quantity or duration. This section therefore covers BIM project cost estimation applying rational cost data reference for elements included in line with aforementioned schedule parameters derived to this case study.

Cost Data and Element Integration

Firstly, elements must have linkages to cost data and for themselves to be referenced. Building Construction Cost Data 2009 was then applied as the connection between cost estimating and BIM elements. In addition, unit meanwhile plays an integral part among cost estimation linking element parament and quantity as of which in the project scheduling does. Elements were then be sorted by category and family as well as type with connection of unit cost data including material, labor and equipment. Take wall elements for instances, foundation wall would be coded as 03 31 05.70 0200 for its concrete formation with QTO unit in cubic yard (C.Y.), while curtain wall would be, on the other hand coded as 08 44 13 0150 for its curtain panel formation with QTO unit in square feet (S.F.).

Element and Task Cost Estimating

Recall the hierarchy of BIM project schedule. Such scheduling classification would be utilized for cost estimating while it tangibly contained both element-task relationship and the previously identified most appropriate quantity, or quantity in short for the rest of the section. Cost estimating then started from simply yielding the unit cost of element by summing up the total unit cost of an element on all resources (equation 6). The component quantity Q* here multiplied with such element unit cost contributing for the cost of a task element (equation 7). Therefore, the task cost would be achieved by summarizing inclusive element cost for a single task (equation 8). The results of cost estimating in terms of element and task have been demonstrated and organized into a spreadsheet as Element and Task Cost Estimation.

$$UC_e = UC_{e,Material} + UC_{e,Labor} + UC_{e,Equipment} \quad \text{(equation 6)}$$

$$C_e = Q_e^* * UC_e \quad \text{(equation 7)}$$

$$C_t = \sum_{e=1}^{e=n} C_e \quad \text{(equation 8)}$$

where

UC_e = the unit cost of element,
$UC_{e,Material}$ = the unit cost of element on material,
$UC_{e,Labor}$ = the unit cost of element on labor,
$UC_{e,Equipment}$ = the unit cost of element on equipment,
C_e = the cost of a task element,
Q_e^* = the quantity of an element, and
C_t = the cost of a task.

Task Cost Examples

To better illustrate the feasibility of element-based cost estimation, fourth floor to Level 6, a small portion of the entire project coded tasks, 010700 and 010720 has been pulled out for detail computed demonstration to element and task cost formation. Four tasks, 010710 Column Installation, 010720 Beam Installation. The first task: Column Installation coded as 010710 has only one steel column element support to be installed on level 4. This is because on this level there was basically none supportive column designed to be to installed which also could be seen matching the structural drawing S502 with Steel Column Schedule whilst the vast majority of steel column installing levels were on basement, level 3, and level 5. Nevertheless, it was indeed required to have the corner reinforcement designed from approved structural analysis. However, if cost/purchasing department of general contractor merely followed the Column Schedule for its simply and easy countable features rather than design drawings when placing steel orders, such unbalanced information may result in missing required materials or delay in project schedule thus diminishing construction quality on jobsite. Instead, the as-planned BIM modeling process, on the other hand, strictly modeling align with what has been rigorously designed by structure engineers would be less likely to conduct such missing or QTO failures. Therefore, the element-based cost formation has the ability to reassure not just common structure but rarely seen element placements and bring about reliable cost formation. As a result, cost estimation for task 010710 could simply be achieved by multiplying Quantity Q* = 1 (each) with Unit Cost of element HSS6X6X1/4 UCe = 482 dollars (cost of each) accounting for 482 dollars as the cost of task 010710. Next, 010720 Beam Installation. Accurate and the most appropriate quantity of complex beam structure on this level could be systematically extracted from BIM model with rationally normalized unit of quantity with regards to element component as of what have been fully discussed Project Scheduling. Relatively complex cost estimation for all beam elements would be able to derived sequentially following these equations from 6 to 8. Owing to yet also benefit from the normalized and predefined quantity Q* as well as unit of quantity UQ*, it is therefore straightforward to compute the cost of each element within the fairly sophisticated beam hierarchy.

VI. BIM PROJECT MONITORING

Cost estimation with BIM elements has been fully reviewed, while project scheduling composing of element components has been sequenced and measured. It is therefore feasible to build project standards for screening and controlling performance, or project monitoring with BIM. Firstly, applying BIM element data for setting up Budgeted Cost of Work Scheduled (BCWS) as the baseline monitoring project timeline and cost. Next, measuring project performance regarding earned value, Budgeted Cost of Work Performed (BCWP) changes over time according to the baseline. And lastly, screening project performance in terms of cost variance, Actual Cost of Work Performed (ACWP) while dynamically controlling project performance.

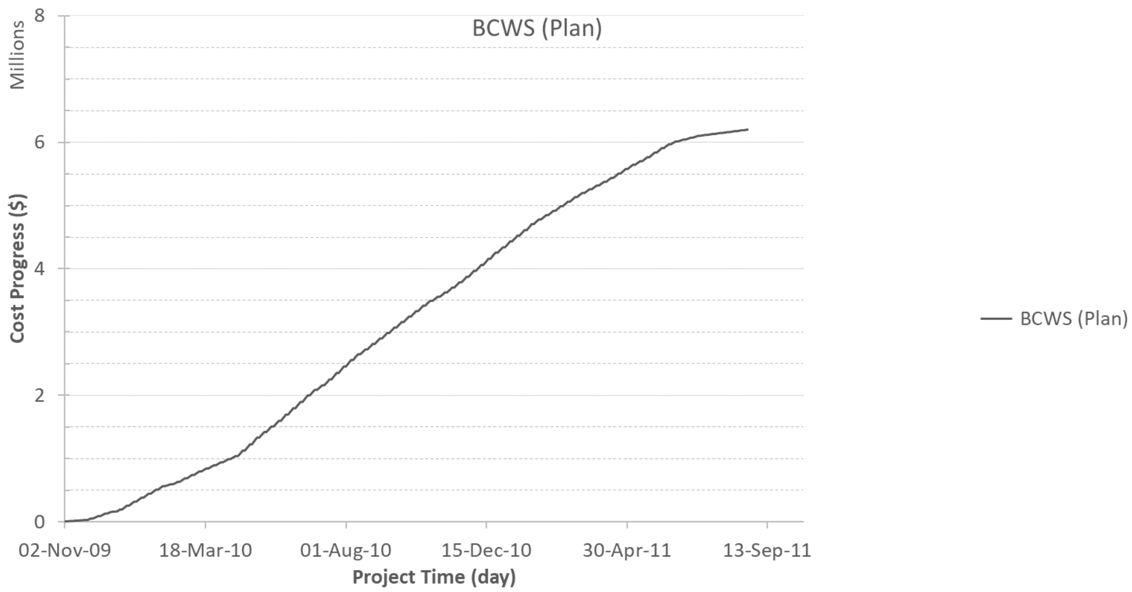

Figure 2 BCWS of BIM Project

BCWS

Planning a desirable project baseline with respect to budget and time is critical for project monitoring. Among the previous BIM applications deliverables including task duration and cost, it is obvious that the budgeting timeframe, BCWS would be able to be established via the fraction regarding daily task cost. While the task duration Dt has been obtained in project scheduling, the task cost Ctday has been handled with in cost estimation, the cost of task in a day Ctday would be directly formulated in the fraction form of cost over duration of for a single task (equation 9). The results of daily task cost have been organized into a spreadsheet as Scheduling Daily Task Cost (Table 4). Each task has been assigned the daily task cost with a specific duration, and these tasks overall could be sorted by sequential starting day. It is then viable to establish the time-cost budgeting line BCWS by accumulating task costs on a daily basis (Figure 2).

$$C_t^{day} = \frac{C_t}{D_t} \quad \text{(equation 9)}$$

where

C_t^{day} = the cost of a task in a day,

C_t = the cost of a task, and

D_t = the duration of a task.

Table 4 Scheduling Daily Task Cost

Task Name	Task Duration Dt	Task Cost Ct	Daily Task Cost Ctday
BIM Project Schedule	474 days		
Construction Phase	474 days		
010000 Structural	327 days		
Sub Structure	135 days		
010100 Foundation	95 days		
010110	32 days	30,486.92	952.72
010120	11 days	12,209.23	1,109.93
010130	16 days	87,181.22	5,448.83
010140	45 days	51,917.66	1,153.73
010150	2 days	5,294.00	2,647.00
010160	61 days	75,876.76	1,243.88
010200 Basement	57 days		
010210	2 days	3,561.95	1,780.98
010210	41 days	203,983.50	4,975.21
010220	53 days	82,597.00	1,558.43
010230	5 days	16,210.00	3,242.00
010240	2 days	1,408.01	704.00
Super Structure	327 days		
010300 Ground Floor	184 days		
010310	68 days	42,110.32	619.27
010320	31 days	296,572.49	9,566.85
010330	100 days	150,365.25	1,503.65
010340	115 days	194,231.81	1,688.97
010350	5 days	16,210.00	3,242.00
010360	5 days	5,581.69	1,116.34
010400 First Floor	148 days		
010410	34 days	162,082.13	4,767.12
010420	29 days	280,899.81	9,686.20
010430	118 days	237,463.01	2,012.40
010440	5 days	12,646.00	2,529.20
010500 Second Floor	148 days		
010520	31 days	310,181.63	10,005.86
010530	117 days	221,420.14	1,892.48

010590	5 days	12,646.00	2,529.20
010600 Third Floor (Wing A &B) and Roof Deck (Wing C) to Level 5	171 days		
010610	20 days	94,510.84	4,725.54
010620	29 days	245,110.58	8,452.09
010630	115 days	223,802.12	1,946.11
010640	4 days	8,482.00	2,120.50
010700 Forth Floor (Wing A &B) to Level 6	138 days		
010710	1 day	482.00	482.00
010720	23 days	196,856.85	8,558.99
010730	78 days	156,571.77	2,007.33
010740	4 days	8,482.00	2,120.50
020000 Architectural	291 days		
020300 Ground Floor to Level 2	291 days		
020310	20 days	104,736.51	5,236.83
020320	290 days	842,971.82	2,906.80
020400 First Floor to Level 3	80 days		
020410	36 days	147,811.17	4,105.87
020420	79 days	150,789.96	1,908.73
020430	27 days	51,246.00	1,898.00
020500 Second Floor to Level 4	53 days		
020510	36 days	147,002.56	4,083.40
020520	52 days	150,342.15	2,891.20
020530	27 days	51,246.00	1,898.00
020600 Third Floor (Wing A &B) to Level 5	53 days		
020610	34 days	139,238.64	4,095.25
020620	52 days	150,240.90	2,889.25
020630	26 days	48,873.50	1,879.75
020700 Forth Floor (Wing A &B) to Level 6	42 days		
020710	25 days	97,751.96	3,910.08
020720	41 days	116,824.54	2,849.38
020730	18 days	33,215.00	1,845.28

While it is familiar enough to see features including Task Code, Start, Finish, Duration Dt, Task Cost Ct, and Daily Task Cost Ctday as repeatedly referenced in previous sections, cumulative daily cost as well as BCWS plays an integral role in illustrating project expected progression though they are conceptually meaningful and useful. The sum of daily cost SCi literally formulated by cumulating all task cost for each day (equation 10). And then for each day, the BCWSi+1 would be formulated as the summation of sum of daily cost SCi+1 and BCWSi, with an initial BCWSi equals to SCi at the beginning of the project day (equation 11).

$$SC_i = \sum_{t=1}^{t=j} C_t^{day} \quad \text{(equation 10)}$$

$$BCWS_{i+1} = SC_{i+1} + BCWS_i \quad \text{(equation 11)}$$

where

C_t^{day} = the cost of task t in a day

SC_i = the summation cost on date i, and

$BCWS_i$ = the budgeted cost of work scheduled on date i.

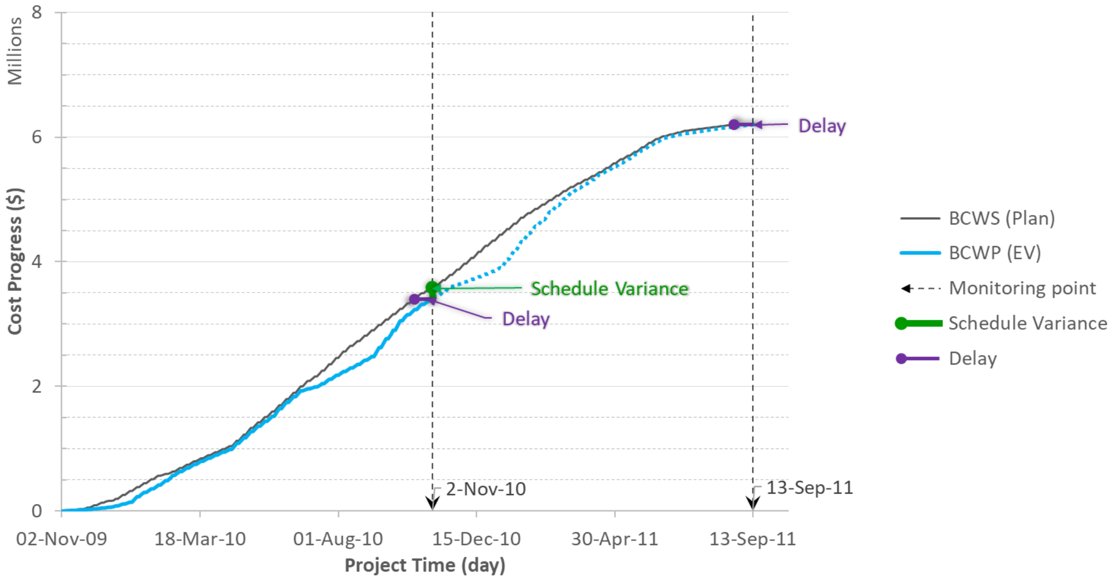

Figure 3 BCWP and BCWS of BIM Project

BCWP

Second step in project monitoring is to acquire BCWP, or the earned value of a project. While it is literally as of its title, Budgeted Cost of Work Performed, this key measure screens project work done/complete or otherwise with concerns to a cap on the budget cost. To mock up real project performance regarding schedule, two set of coefficients diminishing work efficiency have been applied mimicking certain project uncertainties underwent. Assigning a coefficient to winter times for extreme weather risk undermining works severely, while assigning another coefficient to other occasions with concerns to general work delays. It is then feasible to depict and compare the work performed BCWP with respect to the baseline BCWS (Figure 3).

Two monitoring points have been used as identifiers at different time periods. The first point functioned as a milestone splitting a present date of monitoring, November 2nd 2010, which is one year after the project start day. A blue solid line depicting project performance on the preset conditions while both schedule variance and delay were discovered. The schedule variance, denoted as a green line segment, illustrated a vertical gap between work scheduled and work performed in terms of cost at the point of time. The delay, denoted as a purple line segment, indicated a horizontal gap between BCWS and BCWP in terms of day. The second monitoring point functioned as an identifier on the project completion day. BCWP segment between the first and the second points, denoted as blue dash line, performed as a forecast screening project performance under the same preset conditions. This would be helpful for earlier monitoring project performance and come up with resolutions concerning work delay in a timely method.

ACWS

An ideal project carries out jobs completed align with budgeted cost as well as work schedule, which is what BCWS theoretically guides and intends to be performed. In practical, however, a great amount of uncertainties unpredictably hindered such perfect model to conduct. Delay as well as schedule variance are most likely to occur among real projects as of what BCWP supposed to monitor. These time-relevant issues would therefore incur extra costs, more specifically, cost variance and cost overruns as a result of extended delays concerning daily labor and equipment expenses. To capture these cost variance, actual cost of work performed, ACWP, is the critical cost performance measure providing cost overruns beyond expected timeframe. A general coefficient increasing daily task cost to 20% greater than budgeted cost has been applied for illustrating ACWP in order to emulate a conservative assumption on cost variance in comparison with the cost cap/budget on BCWS and BCWP (Figure 4). Two monitoring points were used illustrating cost variance issues regarding ACWP. At the first monitoring point, a first cost variance on November 2nd 2010, denoted as a red line segment, captured the incurred cost due to schedule delay between ACWP and BCWS with the preset circumstances. In case that preset conditions remained to the end of project, it was expected to see a significant project cost raise, a second cost variance on September 13 2011, which would be a challenge in monitoring project performance.

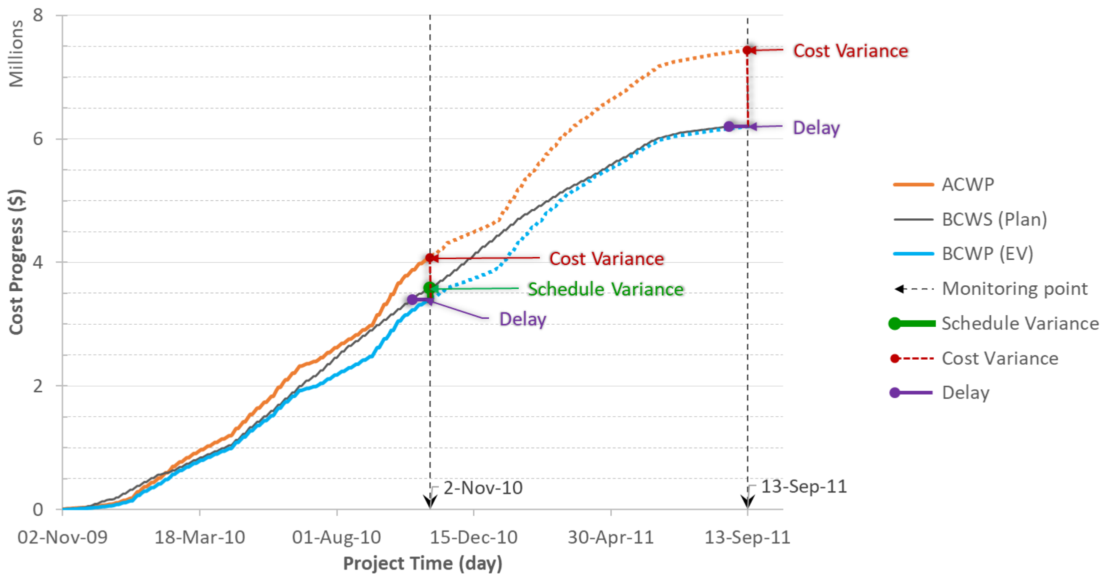

Figure 4 ACWP, BCWP and BCWS of BIM Project

VII. CONCLUSIONS

BIM modeling serves as one of emerging technologies in the modern construction industry. Its feasibility of applications in construction management appears to be magnificent with regards to purpose orientations throughout the literature review. However, the majority of research works collected has either one-time usage of a specific use of BIM model, no real model application demonstrated under a sophisticated designed framework regarding information retrievability. Still, element modeling processes specifying element data usages with construction management requirements were rarely discussed among these BIM studies.

This study therefore demonstrated a systematic way to tackle project information alongside with BIM modeling. In order to streamline construction information within a BIM model for multiple construction works, the project BIM model has been built pursuing construction information utilization with respect to time, cost, and performance purposes. With the needs to support reliable construction information and applications in construction management, a delineate modeling process has been detailly depicted among modeling specifics and construction management works in responsive to construction information requirements and BIM model integration as well as data utilization. The project case study, however, not only serves as above mentioned purposes but also extensively applied to examine the satisfaction of BIM applications in construction management in terms of scheduling, cost estimating, and project monitoring. Whereas element information modeling played an integral role in this study for information integration within a project, there are still extensive potentials for information utilization. Further developments may include automation in data retrieving and templating for such as design drawing and mechanical information requirements. Also, there are still possibilities employing BIM for space rearrangement for existing buildings responsive to critical allocation.

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