Approach of Cost Monitoring with 5D BIM on Construction Project

Thailand blanchnamwan@gmail.com, pvachara@chula.ac.th
Lin Xiaofeng, Vachara Peansupap
Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok,

Abstract

As changes frequently occur during construction phase, they lead lots of variance on the project budget. Cost monitoring is one of the most important techniques to summarize the project cost during construction stage. Effective construction cost monitoring allows project manager to know the status of project cost by time which can be identified early enough to take corrective measures and avoid cost lose. Current cost monitoring approach replies mostly on manual work which is not efficient and inaccurate.

With the development of building information modelling (BIM) in construction industry, it's expected to enhance the efficiency of cost monitoring and payment visualization, while the BIM including cost information is called 5D BIM. This research proposed an approach to monitor project cost and payment by linking the cost and payment information to 3D model, enabling record of cost update automatically by time. This approach includes combination of WBS and BOQ for cost monitoring by coding system with software Dynamo. Illustrative example will be implemented to test the approach with real data from one exist construction project. This approach will distinguish paid and unpaid elements in 3D model by different payment stages. Secondly, corresponding S-curve based on payment stage is provided. From this 5D model, cost and payment can be easily visible in building model at different progress time. Result shows that the proposed approach improves the efficiency of cost monitoring significantly and make the progress payment visible by times. Finally, the discussion and limitations and expectation on the further study are provided in the end.

Keywords: 5D BIM, Cost Monitoring, Payment Visualization, Dynamo, Progress Payment

1. Introduction

As changes or discrepancies between the plan and construction occur, the project schedule and cost estimates should be modified and new schedules need to be devised (Chuck Eastman et al. 2012). Cost monitoring is one process of construction monitoring, target on cost and progress (Hendrickson & Au 1989). During construction, owner payment cannot cover cost expense (Abraham 2011). Any activity changes are possible to cause delay or over budget, which need cost monitoring data to modify original cost and schedule plan. Thus special attention should be placed on cost monitoring and payment management during actual construction.

Current practices of construction monitoring are not accurate, consistent, reliable, or timely enough to support project control decisions (Vick & Brilakis 2015). Previous practice on cost monitoring is making spreadsheet report of actual cost against budget. It does not present the cost performance well since there is no progress information and the payment status.

However, the inefficient manual process can be improved and automated by integrating cost and time information with 3D Model which is called 5D BIM. 5D BIM enables to integrate quantity takeoff and cost estimation with design result automatically, and related software is available (Wei Zhou et al. 2015). The Integrated BIM environment enables 3D model to be linked with databases like BOQ and WBS information, which enable the QS/cost manager to make suitable adjustments to quantities, rates and other ancillary costs and modifications (RICS 2015). These researches on 5D BIM provide the technology and knowledge base for cost monitoring and progress payment management. However, there are limited researches mentioned payment and monitoring cost with 5D BIM, especially in a visual programing way to enable process automatic.

This research proposed an approach to monitor cost and visualize progress payment in 3D model automatically in a visual programming way. This approach is concerned on the integration of BOQ with cost codes and quantity takeoff with WBS items codes to make the whole process automatic. The linkage between cost plan in spreadsheet and 3D model in Revit is developed in Dynamo. Cost and payment on any time point are able to be visible and accessible with corresponding 3D model view. Furthermore, the approach help contractor show the status of progress payment with all corresponding items in 3D model to owner for better communication and payment management.

2. Literature Review

2.1 Cost Monitoring

Cost monitoring is one process of project management, which including initiating, planning, executing, monitoring and controlling, closing five stages (Rupen Sharma & McDonough 2013). Cost monitoring consists of two main process which are cost plan and cost control. To be identified clearly, there are the relationship between cost management, cost control and cost monitoring below. Process of cost management is shown in figure 1 (Hendrickson & Au 1989). Karan Sawant proposed cost control is one process of cost monitoring which includes cost estimate, plan and control. Cost control contains the process of monitoring actual cost performance and identifying improvement opportunities (Raut, Pimplikar & Sawant 2013). while Wayne J. Del Pico proposed the cost monitor is one process of cost control which includes collecting data, processing data into required format, comparison as-built and plan, and implementation of control actions (Del Pico 2013). The two different inclusive relationship between cost monitor and cost control is shown in figure 2.

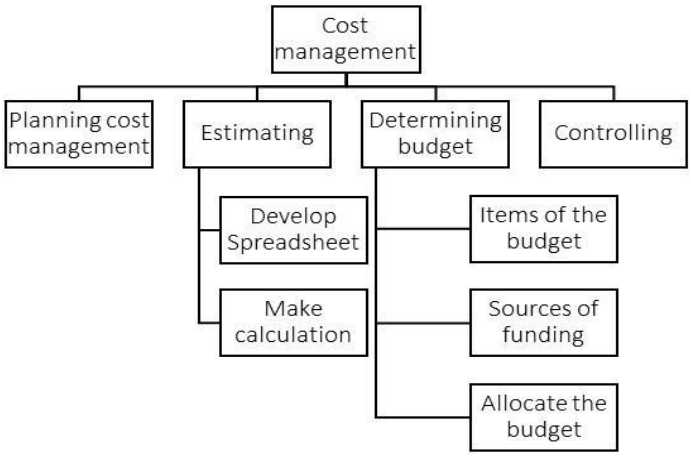

Figure 1: Cost Management Process

According to above, definition of cost monitoring has not come to be unified. To be consistent, in this research, cost monitoring is defined to be the five steps, the process is shown at the right side of figure 2. The process of cost monitoring is defined as five steps which are referenced from the two above definitions: 1) cost plan and payment plan 2) collect as-built data 3) processing data into form needed by cost analysis 4) comparison as-built cost and plan cost 5) report for corrective action for deviation.

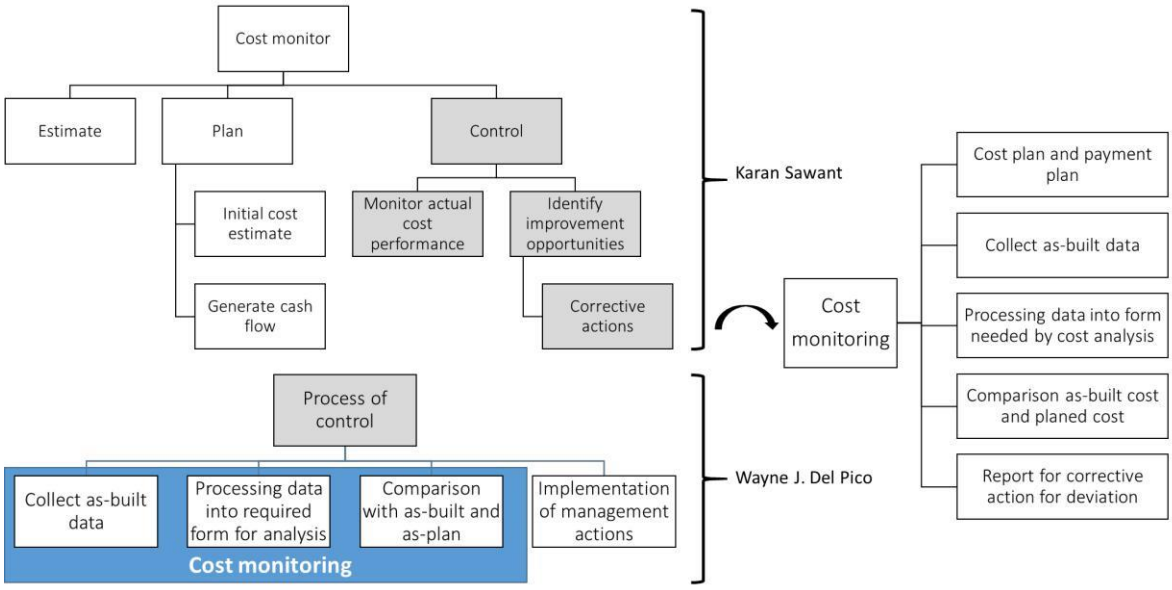

Figure 2: Process of Cost Monitoring

To organize building project better, building elements need to be defined and classified well which to help cost manager or project manager allocate cost and time. The cost codes are introduced for automatically link cost with items in model. Cost code is logical breakdown of a project into controllable elements for the purpose of cost control and reporting. The breakdown is a numbered structure, organized in a logical manner (DOE 1997).

On the other hand, components in model need to be named for classification. Thus for better organization, cost codes in BOQ and item codes in quantity takeoff will be integrated to suit for 5D BIM automation and linkage. The one type of WBS called Uniformat, the organization of major components on most buildings (Al-Mashta 2010), will be developed and adjusted for the proposed approach to name items in 5D BIM.

2.2 Payment Type

In construction contract, there are different methods of payment implemented within construction industry. The trend towards contractor self-monitoring of progress, greater use of contractor invoicing, milestone payment and lump sum payments to streamline the reporting and payment process (Steven DeWitt et al. 2015). Under a lump sum contract, contractor will prepare and submit monthly payment estimates based on progress as a percentage of the lump sum prices, instead of detailed measurements of actual quantities (American Association of State et al. 1997). For the milestone payment, the owner pay contractor with completing a pre-determined milestone, on or ahead of schedule. Milestone payment method is tested in this proposed example in the following content.

2.3 5D BIM

BIM is being developed as a key technology, policy and process shift on construction project in whole life cycle, and the BIM implementation significantly improved the collaboration, communication and coordination among the AEC industry stakeholders(Badrinath et al. 2016). There are various BIM cost management software, such as Vico Office, which is used for precise schedule and estimation.

Vico production is applied for resource-loaded, cost-loaded, location-based BIM (BIMForum 2011). Compared to Vico office series software, this proposed 5D BIM approach is based on flexible visual programming. It still take the traditional spreadsheet as reference during cost monitoring process which make it easier for current engineers to apply this proposed approach instead of Vico office software. What's more, Dynamo is one add-ins of Autodesk Revit, the most common BIM software, so this approach is more economic than Vico office. Finally this approach is able to visualize and analyze payment which is not available in Vico office. In conclusion, there is no prescriptive software which can maximize benefits of BIM to perform cost monitoring yet, even many options are provided. Choosing appropriate software that can be usable for its service provided to clients and meet contractors' own requirements will be a long process with number of available software. This research propose visual programming way by Dynamo.

5D BIM enable the solution for integrating QTO and cost estimation into design to analyze cost automatically with spreadsheet (Wei Zhou et al. 2015). Kala proposed that integrated location-based scheduling should enable schedule optimization over CPM–based approaches, resulting in shorter overall duration with more continuous resource use (Kala, Seppänen & Stein 2010). Cost and time information are able to be integrated with 3D Model. Each component is linked to time and cost performance. Quantity can be determined by 3D model and be delivered directly to the spreadsheet (Sebastian Hollermann & Buhr 2016). 5D BIM is also promised to analyze cash flow which give the reference of progress payment management, this approach can predict project cash flow when many constraints on cash resources automatically (Kim & Grobler 2013). The application and studies indicates the high potential on 5D BIM for efficient and automatic cost monitoring.

However, it's still difficult to link cost and progress information with 3D model precisely (Hendrickson & Au 1989). This research links bill of quantity (BOQ) and WBS with 3D model which will achieve cost monitoring more efficient and the method is different from previous researches. The development of standards on cost code with WBS and BOQ in implementation of 5D BIM for cost monitoring is not enough yet. Finally the most important and difficult part, linking cost information into 3D model and updating data synchronously, has not been well automatic and enough accurate according to previous studies. These limitations will be solved in this research.

3. Research Methodology

The research is developed step by step, from the literature review to the example test. The process of approach for the example is given in the next part of paper, it will be introduced roughly as diagram below figure 3. As for the spreadsheet design, BOQ and WBS are also connected by the quantity and cost of components of building. The details of every spreadsheet will be showed in following example.

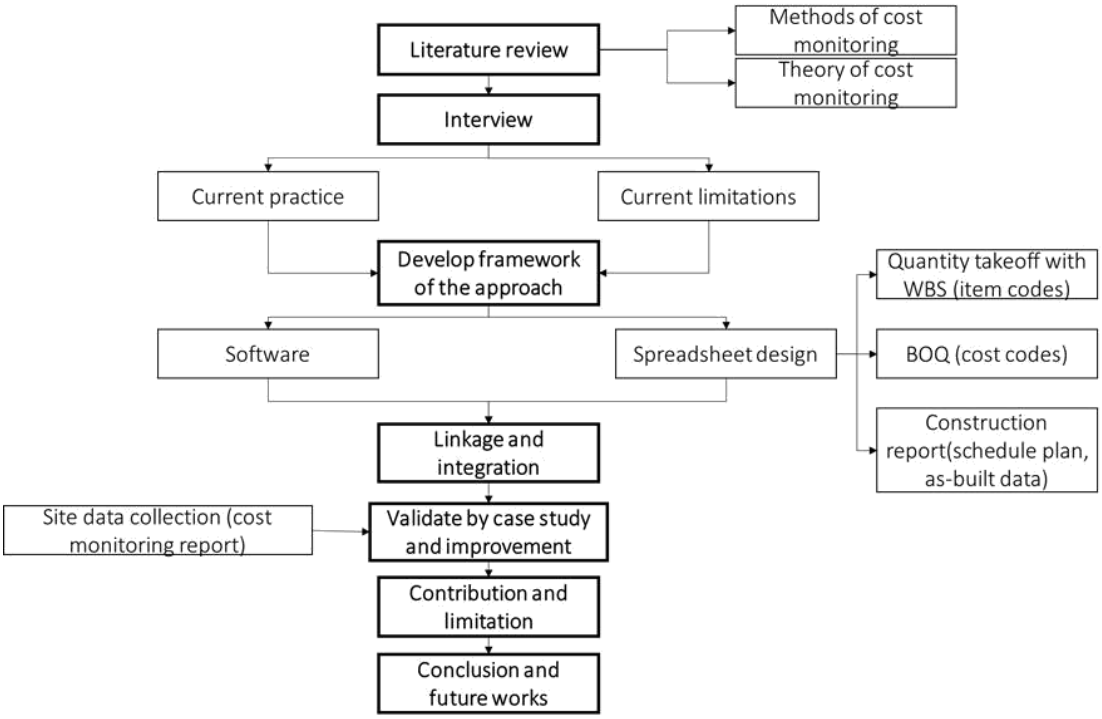

Figure 3: Methodology Diagram

4. Example of Proposal Approach

4.1 Overview and Process

Take a simple reinforced concrete structure model to be the example which contains footing, pile, columns, framing, slab and structural wall. The tools are used in this research: Autodesk Revit and Dynamo, Excel. This example take the milestone payment as the payment method, which means the owner pay contractor once the agreed milestone works in contract are completed. The process of this example is below:

Revit modelling
Quantity takeoff from Revit model to excel
Design spreadsheet BOQ, WBS and construction report based on Revit schedule information
Convert excel information to Revit model automatically by Dynamo.
Visual programming for visualizing elements payment status and get corresponding S-Curve.

- **Spreadsheet Design**

In this proposal approach, the main spreadsheets are 1) Bill of quantity (BOQ), 2) WBS with unit cost, and 3) Construction report including schedule plan and payment. In figure 4, the three main spreadsheets are connected and important content is listed below.

Firstly, according to the market research and project information, the materials and its unit cost are collected in BOQ. The hierarchy is referenced from the Uniformat II, and it's categorized by materials. Figure 5 shows the example of BOQ structure, which contains plan cost and actual cost of material and labor titles. BOQ will record the cost of materials of components in building. Quantity of material is the key to connect BOQ, WBS and 3D model, and it's got from Revit schedule.

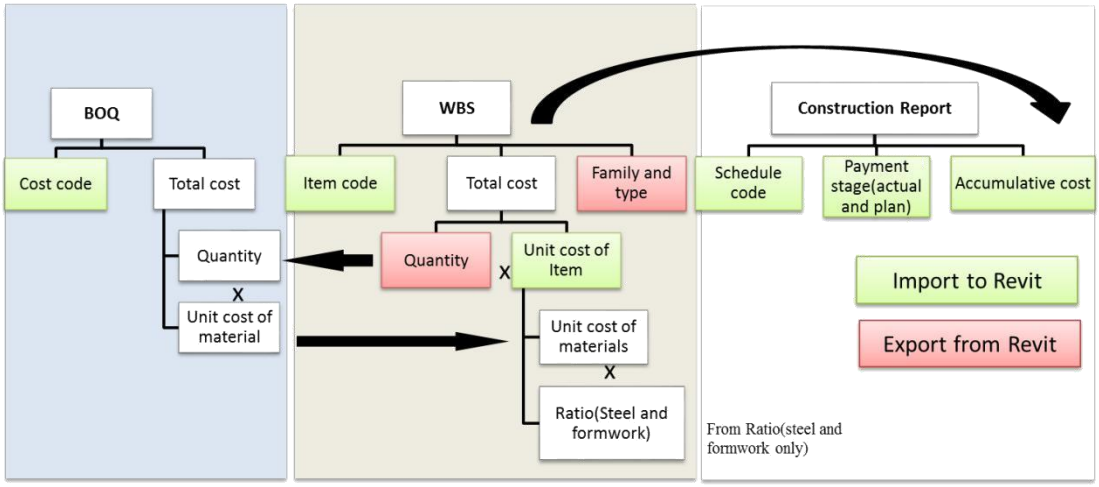

Figure 4: Relationship of Spreadsheets

BOQ

Cost Code	Item	Quantity	Unit	Mat Unit Price	Actual Mat Unit Price	Labor Unit Price	Actual Labor Unit Price	Total Cost	Actual Total Cost	Cost Code
	SUB STRUCTURE									
	PILING WORK									
1.1.1	Driven Pile									
1.1.1.1	Prestress Concrete Pile #1	12	no	5500	5500	800	800	75600	75600	1.1.1.1
1.1.1.2	Pile Cap #1	4	no	4000	4100	800	600	19200	18800	1.1.1.2
1.1.1.3	Pile Cap #2	8	no	3500	3300	800	900	34400	33600	1.1.1.3
1.1.1.4	Pile head treatment	12	no			100	80	1200	960	1.1.1.4
	EARTHWORK									
1	Excavation and backfill									
1.2.1.1	excavation	180	m3	100	100	200	200	2846.66	54000	1.2.1.1
1.2.1.2	Backfill	120	m3	80	80	100	100	2277.32	21600	1.2.1.2
	SUPERSTRUCTURE									
1.	**REINFORCED CONCRETE**									
1.	Structural Concrete									
2.1.1.1	Concrete 240 ksc	83.68	m3	1700	1600	400	350	142252.50	163171.99	2.1.1.1
2.1.1.2	concrete 240 ksc waterproof	116.16	m3	1900	2200	500	440	220704.00	306662.40	2.1.1.2
	Formwork									
2.1.2.1	Ordinary formwork	199.84	m2	200	215	150	150	39967.59	72940.85	2.1.2.1
2.1.3	Reinforcing Bar									
2.1.3.1	Rebar Dia. 6mm	83.68	kg	23	22.5	4	4	1924.59	2217.47	2.1.3.1
2.1.3.2	Rebar Dia. 12mm	116.16	kg	26	25.7	4	4	3020.16	3449.95	2.1.3.2
2.1.3.3	Rebar Dia. 16mm	46.72	kg	27	27.4	4	4	1261.38	1466.94	2.1.3.3

Figure 5: Bill of Quantity Chart (DOE 1997)

Secondly, the WBS hierarchy is used to match the elements in Revit so that the cost information can be linked to model correspondingly. Since one item consists of several materials from BOQ, so the unit cost of elements in model can be calculated by the materials and it's only in terms of quantity of item. In the WBS spreadsheet, Family Revit and Type Revit titles are from the Revit element which is used to find the elements and link the corresponding unit cost by Dynamo.

With assigned unit cost of item, the 3D model has already equipped with cost information. After this, schedule plan with time information is designed. In order to simplify the progress simulation, progress codes are proposed to define items' progress which is attached to every activities in schedule plan.

Construction report combines the plan and actual information which is showed in figure 6. This proposal approach is based on the milestone payment which means owner will pay contractor only if the contractor completed the works that agreed in contract.

Constuction Report												
Ativity	Duration	Plan start	Plan end	Duration	Actual start	Actual end	Payment	Accumulative Cost	Percentage	Schedule Code	Planed Payment Phase	Actual Payment Phase
Foundation zone A	4	25-Sep-16	9/29/2016	4	25-Sep-16	29-Sep-16	360	360.00	0.23%	F1	1	1
Foundation zone B	3	30-Sep-16	10/3/2016	4	30-Sep-16	4-Oct-16	120	480.00	0.31%	F2	1	1
Foundation zone C	3	4-Oct-16	10/7/2016	3	5-Oct-16	8-Oct-16	120	600.00	0.39%	F3	1	1
1st Fl. beam&Slab Zone A	3	8-Oct-16	10/11/2016	5	9-Oct-16	14-Oct-16	14198.65	14798.65	9.55%	HA01	2	1
1st Fl. beam&Slab Zone B	4	12-Oct-16	10/16/2016	3	15-Oct-16	18-Oct-16	14198.65	28997.30	18.71%	HB01	2	2
1st Fl. beam&Slab Zone C	3	17-Oct-16	10/20/2016	4	19-Oct-16	23-Oct-16	14198.65	43195.95	27.87%	HC01	2	2
1st Fl. column&structural Wall Zone B	5	16-Oct-16	10/21/2016	5	19-Oct-16	24-Oct-16	5779.64	52879.53	34.12%	VB01	2	2
1st Fl. column&structural Wall Zone C	3	22-Oct-16	10/25/2016	3	25-Oct-16	28-Oct-16	3903.95	56783.48	36.64%	VC01	2	2
2nd Fl. beam&Slab Zone B	3	25-Oct-16	10/28/2016	3	27-Oct-16	30-Oct-16	13458.38	83700.23	54.01%	HB02	3	3
2nd Fl. beam&Slab Zone C	3	29-Oct-16	11/1/2016	3	31-Oct-16	3-Nov-16	13458.38	97158.61	62.69%	HC02	3	3
2nd Fl. column&structural Wall Zone B	5	30-Oct-16	11/4/2016	5	4-Nov-16	9-Nov-16	543.92	101790.55	65.68%	VB02	3	3
2nd Fl. column&structural Wall Zone C	3	5-Nov-16	11/8/2016	3	10-Nov-16	13-Nov-16	4088.02	105878.57	68.32%	VC02	3	3

Figure 6: Construction Report

Accumulative cost is from the WBS based on the items contained in corresponding activity. During construction, only the blue column need be filled. The meaning of payment phase is the sequence of progress payment. The amount of payment equal to the total cost of activities which has the same value of payment phase.

4.3 Linkage between Spreadsheet and 3D Model

The bridge between spreadsheets and 3D model is developed by the Dynamo programming language. Parameters added in Revit are: 1) Actual Payment stage, 2) Planed Payment stage, 3) Schedule Code, 4) Unit Cost, 5) Cost code. In Dynamo, it will assign the value of parameters from spreadsheet to 3D model elements automatically. For example, assign the unit cost value in different elements by family and type name correspondingly, overview of this process in Dynamo is showed in figure 7. Furthermore, to show every stage of payment status in model, Dynamo will override different color by status of payment to distinguish in model automatically. The linkage enables the whole model information updated synchronously between spreadsheet and 3D model.

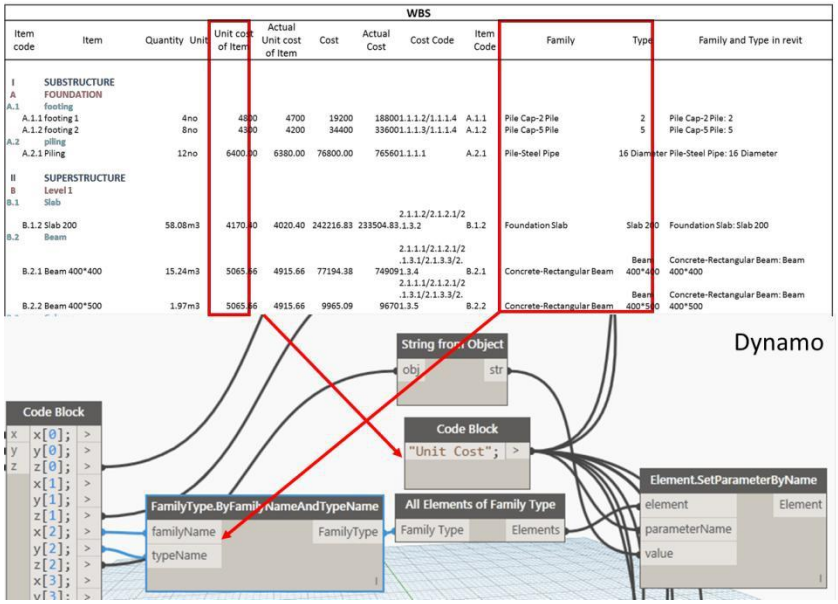

Figure 7: Linkage of Unit Cost Parameter and Value in Excel by Dynamo

4.4 Research Results

The visualization of payment status is shown in figure 8, and the right side is corresponding S-Curve with plan cost, earn value and actual cost curve comparison.

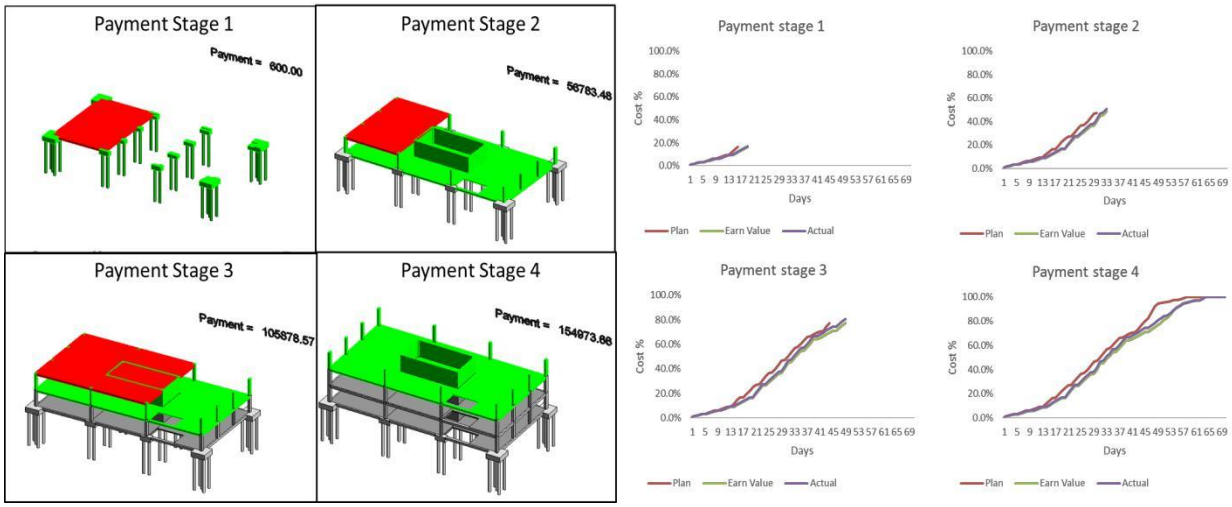

Figure 8: Payment Status Visualization in Revit and Corresponding S-curve Comparison

In addition, the payment status of construction project can be shaded into different color shown in the left side explanation:

Red: completed works but haven't been paid (will be paid in next payment stage)
Green: work completed and paid in current payment stage
Realistic appearance: completed works from previous stages
Payment: accumulative payment amount is on the right up side

For example: payment stage 2, realistic appearance (grey, foundation) is the item completed in payment stage 1; Green is the works completed and paid in current stage 2; Red is the works completed in current stage 2, but haven't been paid in this stage, it will be paid in next stage 3.

The S-curve in the right side is in relation with the payment stage and the status in above model, which is shown from Construction Report by plan cost and schedule plan, planed cost and actual progress, actual cost and actual progress respectively. In conclusion, the things contractor need to do during construction are:

- Fill the actual start data and duration of current activities
- Update actual unit cost in WBS spreadsheet if needed
- Fill the actual payment stage once get the payment
- Refresh excel and run Dynamo

Finally contractor will get the updated payment status in model and corresponding cost S-curve like above automatically.

5. Conclusion

In this research, it is feasible to monitor cost and payment by using 5D BIM. It will visualize the status of payment in model and simulate progress cost and payment. By specialized visual programming in dynamo, assigning cost and progress information in spreadsheets to 3D model to achieve 5D BIM is automatically and updatable. In addition, the approach provide corresponding S-Curve for contractor

making decision on cost control. After the example study, it's significantly enhance the cost monitor efficiency by the linkage between excel and model with dynamo. Finally the automation and visualization of the whole process provide a more intuitive data format for cost manager to grasp status of cost and progress of project at any time frame needed.

6. References

Abraham, DM (2011), "Portfolio Cash Assessment Using Fuzzy Systems Theory", *Journal of Construction Engineering and Management*, vol. 137, no. 5, pp. 333-343.

Al-Mashta, S 2010, "Integrated Cost Budgeting and Cost Estimation Model for Building Projects", Master thesis, Concordia University, Quebec, Canada.

American Association of State, H, Transportation, O, Highway Subcommittee on, C, American Association of State, H, Transportation, O & Standing Committee on, H (1997), *Primer on Contracting 2000*, AASHTO, Washington, D.C. U.S.

Badrinath, Chegu, A, Chang, Yun-Tsui, Hsieh & Shang-Hsien (2016), "An Overview of Global Research Trends in BIM from Analysis of BIM Publications", *The 16th International Conference on Computing in Civil and Building Engineering*, July 6-8, Osaka, Japan, , pp. 839-846.

BIMForum (2011), Software - Preliminary Design and Feasibility Tool, viewed <*http://bimforum.org/wp-content/uploads/2011/02/BIM_Tools_Matrix.pdf*>.

Chuck Eastman, Paul Teicholz, Rafael Sacks & Liston, K (2012), "BIM Handbook: A guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors", *Australasian Journal of Construction Economics and Building*, vol. 12, no. 3, pp. 101-102.

Del Pico, WJ (2013), *Project Control: Integrating Cost and Schedule in Construction*, John Wiley & Sons, Hoboken, New Jersey, U.S.

DOE, US (1997), *Cost Estimating Guide*, The Dept of Energy, Washington, D.C. U.S.

Hendrickson, CT & Au, T (1989), *Project Management for Construction : Fundamental Concepts for Owners, Engineers, Architects, and Builders*, Prentice Hall, Englewood Cliffs, New Jersey, U.S.

Kala, T, Seppänen, O & Stein, C (2010), "Using an Integrated 5D & Location-Based Planning System in A Large Hospital Construction Project", *Proceedings of The 18th Annual Conference of the International Group for Lean Construction*, Haifa, Israel, July 14, pp. 102-112.

Kim, H & Grobler, F (2013), "Preparing a Construction Cash Flow Analysis Using Building Information Modeling (BIM) Technology", *Journal of Construction Engineering and Project Management*, vol. 3, no. 1, pp. 1-9.

Raut, S, Pimplikar, S & Sawant, K (2013), "Effect of Project Cost and Time Monitoring on Progres of Construction Project", *International Journal of Research in Engineering and Technology*, vol. 2, no. 12, pp. 796-800.

RICS (2015), *BIM for Cost Managers: Requirements from the BIM Model*, 1st Edition edn, Royal Institution of Chartered Surveyors (RICS), WParliament Square, London, UK.

Rupen Sharma & McDonough, M (2013), The Monitoring & Controlling Process Group: A Definition, viewed <*http://www.brighthubpm.com/project-planning/1675-looking-at-project-monitor-and-control/*>.

Sebastian Hollermann & Buhr, C (2016), "Model Based Timber Construction", *The 16th International Conference on Computing in Civil and Building Engineering*, July 6-8, Osaka, Japan, pp. 1591-1598.

Steven DeWitt, Gerald Yakowenko, Thomas Bohuslav & Tucker Ferguson (2015), Alternative Payment And Progress Reporting Methods, viewed 29th October, <https://www.fhwa.dot.gov/programadmin/contracts/etgpayment.cfm>.

Vick, SM & Brilakis, I (2015), "A Review of Linear Transportation Construction Progress Monitoring Techniques", *The 16th International Conference on Computing in Civil and Building Engineering*, July 6-8, Osaka, Japan, pp. 1106-1113.

Wei Zhou, Huanduan Li , Yuzang Huang & Yu, W (2015), "Automatic Quantity Takeoff and Cost Estimation in BIM Design", *The 16th International Conference on Computing in Civil and Building Engineering*, July 6-8, Osaka, Japan, pp. 492-496.