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A SYSTEM FOR MONITORING COST AND PAYMENT WITH 5D BIM

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เชียว เฟง ลิน : ระบบสำหรับติดตามต้นทุนและการเบิกจ่ายด้วยเทคโนโลยีแบบจำลองข้อมูลอาคาร 5 มิติ (A SYSTEM FOR MONITORING COST AND PAYMENT WITH 5D BIM) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: วัชรระ เพียรสุภาพ, 184 หน้า.

การติดตามต้นทุนและการเบิกจ่ายเงินเป็นขั้นตอนสำคัญสำหรับการบริหารโครงการ การติดตามต้นทุนและการเบิกจ่ายใช้เพื่อทราบถึงสถานะของต้นทุนโครงการในช่วงดำเนินการก่อสร้าง อย่างไรก็ตามข้อมูลของต้นทุนและการเบิกจ่ายเงินในทางปฏิบัติจะต้องตรวจสอบเอกสารหลายอย่าง ได้แก่ แบบรูป ข้อมูลต้นทุน และตารางงาน ดังนั้นการปฏิบัติด้วยวิธีดั้งเดิมจะใช้เวลาอย่างมากกับงานที่ไม่จำเป็น และเกิดความยุ่งยากในการคำนวณซ้ำเพื่อติดตามความก้าวหน้าของต้นทุนและการเบิกจ่ายของโครงการ เพื่อแก้ปัญหานี้งานวิจัยจึงนำเสนอระบบการติดตามต้นทุนและการเบิกจ่ายด้วยแบบจำลองข้อมูลอาคาร (BIM) ซึ่งเรียกว่า 5D BIM โดยระบบสามารถประยุกต์ใช้เพื่อแลกเปลี่ยนข้อมูลเวลาและต้นทุนใช้ร่วมกับโมเดล 3 มิติ เพื่อพัฒนาระบบงานวิจัยนี้เริ่มต้นจากสำรวจการปฏิบัติงานในปัจจุบันเกี่ยวกับการติดตามต้นทุนและการเบิกจ่ายเงินด้วยการสัมภาษณ์ผู้เชี่ยวชาญเกี่ยวกับกระบวนการและข้อมูลที่เกี่ยวข้อง ผลการสัมภาษณ์นำมาใช้พัฒนารอบแนวคิดของระบบการติดตามต้นทุนและการเบิกจ่าย โดยระบบนี้ใช้การเขียนโปรแกรมเชิงภาพด้วยภาษาไพธอนเพื่อสร้างการเชื่อมโยงข้อมูลระหว่าง Revit และ Excel ในขั้นตอนก่อนการก่อสร้างนั้น ข้อมูลต้นทุนและแผนการทำงานถูกกำหนดใน Excel โดยระบบพัฒนาจากการเขียนโปรแกรมชุดคำสั่งเพื่อแลกเปลี่ยนข้อมูลต้นทุนและเวลากับโมเดล 3 มิติ ที่เชื่อมโยงระยะเวลาที่กำหนดในโปรแกรม Excel กับโมเดล 3 มิติ ในขั้นตอนการก่อสร้างสถานะความคืบหน้าของต้นทุนและการเบิกจ่ายที่เกิดขึ้นจริงจะถูกเก็บรวบรวมข้อมูลในโปรแกรม Excel และ โมเดล 3 มิติ โดยการเขียนโปรแกรมภาษาชุดคำสั่งให้คำนวณหามูลค่าที่ก่อให้เกิดงาน ความคืบหน้าของต้นทุน และการเบิกจ่ายในโปรแกรม Excel นอกจากนี้สถานะความล่าช้า ต้นทุนเกินงบประมาณ และงานที่ไม่ได้ชำระสามารถแสดงเป็นโทนสีในโมเดลสามมิติ ด้วยการเขียนโปรแกรมภาษาชุดคำสั่งเสริม ผลลัพธ์แสดงให้เห็นว่าระบบสามารถใช้ติดตามความคืบหน้าของต้นทุนและการเบิกจ่ายด้วยการสร้างภาพในโมเดล 3 มิติ อย่างอัตโนมัติ

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Cost and payment monitoring are claimed as the essential process for project management. Cost and payment monitoring is used for tracking the status of project cost during the construction process. However, the current information of cost and payment in the monitoring practice has to manually check with several documents including drawing, cost data and schedule plans. So the traditional practice has consumed more time with unnecessary works and caused some difficulties in the recalculation to monitor cost and payment progress. To overcome this problem, this research proposed the system for monitoring cost and payment progress by using building information modelling (BIM), which is referred to 5D BIM. The system could be applied to interchange time and cost information with 3D model. To develop this system, current practices on cost and payment monitoring is explored by interviewing experts about related process and information. With the result of interview, the framework of the cost and payment monitoring system is developed. This system applies visual programming language (Dynamo) to link information between Revit and Excel. In preconstruction stage, the information of cost and schedule plan is defined in Excel. The system is developed by using the visual programming extension to interchange cost and time information with 3D model that interacts data from excel to 3D model. In construction stage, actual progress of cost and payment are collected and stored in Excel and 3D model, the visual programming extension is designed to calculate earn value, cost progress and payment progress in Excel. In addition, the status of delay, over budget and unpaid works can be visualized in a color scheme in 3D model by a visual programming extension. Result shows that the proposed system is able to monitor cost and payment progress with visualization automatically.

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CHAPTER 1

INTRODUCTION

1.1 Significance

Scheduling and project planning is an activity throughout the lifecycle of construction project. As changes or discrepancies between the plan and real construction, the project schedule and cost estimates should be modified (Hendrickson et al., 2008). Once changes occur, related cost and schedule may make some negative impacts on project, such as delay or over budget. The modification needs cost monitoring to provide accurate and timely data to modify original cost and schedule plan, so that special attention must be placed on cost monitoring during actual construction works.

Monitoring cost involves reviewing basic cost information on a repeated basis, as well as performing a more detailed analysis on cost. First, cost manager should review the project cost to set the baseline and check whether the project cost stays within in budget which is based on bill of quantity (BOQ). Secondly during the actual construction, it is necessary to record the actual cost occurred and payment on hand, and review cost variances. In addition, it needs to check where the current cost differs from the budgeted costs on tasks, resources, or assignments. Thirdly, it is required to find the cost over budget and focus on the item which is over budget and update the information by time. Finally cost manager should analyze cost performance at the global view and summary cost information of the project (Project Standard, 2007). Here, resources that cost manager required involve drawings, cost plan, payment plan and so on.

However, project cost and schedule information is recorded and reported by separated software. Therefore, cost manager must perform the tedious task of connecting the two sets of information (Hendrickson et al., 1989). Cost manager must recalculate the quantity and cost when changes occur in the actual construction. Separated information causes low efficiency and inaccurate result. Fully keeping project information consistent is critical, especially the data related to cost. Normally the conflict exists in cost recording, which leads indistinct what the specialized cost spent for. Sometimes new cost data has already been recorded repeatedly, or cost data has been missed. Even worse, there must be repeated works to update the information after changes, such as

updating drawings and recalculating cost plan. Most of the time, cost manager wants to show the percentage of used payment and corresponding item which is related to certain payment. Manual work is full of the whole cost monitoring process, as a result, it might have inaccurate or duplicate information recorded and it is time consuming and tedious (Gundlach, 2013). Moreover, manual works usually slower than computer works, resulting from accessibility, ease of operation, and ability to perform analyses of computer works(Gundlach, 2013).

The need is a mean to identify discrepancies, diagnose the cause, and propagate effect on all related activities. While these steps can be undertaken manually, computer aids for supporting interactive cost monitoring or even automatic monitor would be helpful (Levitt et al., 1985). However, many participants prefer the traditional way to perform the actual construction process, including cost monitoring because of the external and internal factors like the cost of software and lack of technical support (Gundlach, 2013). As the limitation mentioned above, information technology is put forward to help accelerate monitoring speed and improve accuracy of cost monitoring.

As for high efficiency of computer aid and demand of information integration, building information modelling (BIM), the newest technology and trend in AEC industry, is put forward to support cost and payment monitoring. The importance of BIM is emphasized as a mean to interexchange information across different platforms and its ability to transfer record of building information throughout the building life cycle, which indicate that BIM has enormous potential to monitor cost and payment (Kumanayake et al., 2012). Research about 5D BIM and the importance of cost manager is also gaining momentum. The development of 5D capability is leading edge project cost management and firms start to realize the competitive advantages by embracing this 'new-age' system to cost management. This new trend shows the importance and reliability to combine cost and payment information to BIM model which called 5D BIM (Peter, 2016). The implementation of 5D BIM also improve the competitive advantage for companies in modern construction industry which is really necessary to explore.

In conclusion, there are several limitations to monitor cost and payment by the traditional ways, but the cost and payment monitoring has significance influence on

project profit. And 5D BIM combination, as 'new-age' system, will play a critical role to improve current cost and payment monitoring situation.

1.2 Problem Statement

Based on the current practice of cost and payment monitoring, the baseline data of cost and payment in preconstruction stage are formulated by manual calculations, both on quantity take off and cost calculation. Firstly, the process contains large proportion of manual, labour and time intensive works such as measurements, cost calculations and documentations. Secondly, the manual works may cause errors. Thirdly, the cost and payment plan from manual calculation are difficult to compare with actual cost and payment in construction stage (Ashworth et al., 2013).

Traditional way of monitoring cost and payment isolates cost and schedule which results in delays, conflicts, ambiguities and inaccuracies on cost progress. Moreover, isolation between cost, schedule and components of building cause problems too. For example, the isolation causes difficulties to track cost and payment towards current working progress based on components of building which displays inaccurate cost progress data for cost manager. In construction stage, it is still difficult to measure actual work progress and also plan cost based on actual work progress (Hwee et al., 2002). Isolation of cost, time and building components leads it difficult to update quantity and cost instantaneously when design is changed. In summary, the whole process of cost and payment monitoring lacks of automation which shows big space to improve.

In the client's perspective, they prefer to have better value to achieve their profit, like visualization with details of project. The traditional and conventional methods cannot serve clients who is unfamiliar on construction with visualization on cost progress without the technical support (Akintoye, 2000).

In construction industry, BIM technology and concept which based on digital and computerised technology has potential to integrate cost, payment and schedule information with 3D model in a highly-automatic way. Cost-time integrated 3D model is the concept of 5D BIM which links the cost and time information with 3D model components. 5D BIM provides potential to support and improve cost and payment

monitoring process. There are some software try to link cost to 3D model and integrate schedule as well, such as MS Project, Vico office, Navisworks etc. However, there is still lack of availability of comprehensive software solution and systematic process that can fully monitor cost and payment in construction stage. As a result, it should be the major barrier of cost and payment monitoring with BIM currently. For example, the way to link cost, payment, and time to corresponding 3D model components is still not automatic and accurate enough. Besides, these software are rejected to implement in company due to the high cost and inapplicability. To overcome applicability and limitations on linkage cost, time information with 3D model, visual programming by Dynamo which is an add-in of Revit, the basic BIM software, is proposed to provide technical support to monitor cost and payment with 5D BIM. However, the visual programming didn't develop well and lack of algorithm to support this process. Moreover, there is still lack of systematic approach and framework to achieve and guide whole cost and payment monitoring process by visual programming. So this research proposed a way by visual programming in Dynamo to link cost, payment and schedule information with 3D model components and monitor cost and payment.

Another difficult faced by cost manager to monitor cost is that the earn value which is budget cost of actual completed works is hard to calculate. Traditional way to measure the earn value is still effort intensive. Even with the existed BIM software, earn value is hard to output precisely and efficiently, such as MS Project, Navisworks, Vico office etc. Flexible programming of Dynamo can solve this limitation with its ability to read BIM model and calculate data from Revit and Excel. Various required visualizations can also be achieved by Dynamo to support cost analysis and report to client.

In conclusion, this research proposes a 5D BIM system to monitor cost and payment by tools of Revit, Dynamo and Excel. It enables to interchange cost, payment and time information with 3D model automatically in preconstruction stage. In addition, the system can calculate earn value and visualize cost and payment progress during construction stage. It is also able to transfer corresponding cost and payment data into excel for making S-curve. Finally, the research provides the guideline and systematic process to improve cost and payment monitoring by using proposed 5D BIM system.

1.3 Research Objective

This research aims to develop a system to monitor project cost and payment by utilizing 5D BIM concept. Firstly this research aims to explore current practices on cost and payment monitoring processes and their limitations. Secondly, the research proposes a methodology for development of a 5D BIM system that can improve cost and payment monitoring with various visualizations.

For the proposed 5D BIM system, there are three main sub-objectives to be achieved. Firstly, programming in Dynamo is designed to link cost, payment and schedule from Excel to Revit automatically. Secondly, developing programming to calculate earn value automatically and outputting required cost and payment in excel in construction stage accurately and automatically. Thirdly, it is able to visualize cost and payment progress status over construction progress in real time.

1.4 Research Scope

The research focuses on the building construction project in Thailand. Beneficiary will be construction site manager and cost manager in construction companies.

- Target location: Thailand
- Projects scope:
 - The research is scoped in basic elements of reinforcement concrete structure and the system is applied in structure of building only.
 - Cost includes material and labor cost only, exclude the equipment cost and administrative fee and so on.
 - Contract type: lump sum contract.
- Problem Scope:
 - This research explores the problems of cost and payment monitoring after contracting and during construction stage.
 - Problem mainly focuses on the cost and payment monitoring, it provides the resource data for cost analysis, but excludes cost analysis in this research.

1.5 Research Methodology

To achieve this system, the research needs to explore step by step. Then the methodologies for the research are designed.

1.5.1 Literature Review

In order to know the background and possibility of the research achievement, the benefit and feasibility of this research, related literatures are reviewed firstly. As the basis of technical support, it is important to check whether the BIM development is mature enough to support cost and payment monitoring. Thus 5D BIM related literature and previous cases provide reference to start the research design. Moreover, related methods and knowledge of cost and payment monitoring are explored to support theoretical matters.

1.5.2 Interview on Current Cost and Payment Monitoring and Summary

Target interviewees are the experienced cost managers and site managers in Thailand. Firstly, this interview focuses on the process they use in their current construction project to monitor cost and payment, including input documents, processing input and output documents. Later on, after getting the basis of cost and payment monitoring, interview also explores the problems that they meet based on current practice and the vision that they expect to improve these problems, especially with BIM. Finally, suggestions on how to improve the process by 5D BIM technology are interviewed and summarized. Based on the result of interview, comparisons and discussions among the interviewed companies on this issue are done for selecting the optimal and suitable options for proposed 5D BIM system.

1.5.3 5D BIM System Development

The result of interview on current practice to monitor cost and payment provides guidelines for 5D BIM system. This system is aided by three tools: Revit, Excel and Dynamo. It aims to monitor cost and payment efficiently and automatically, especially to visualize the cost and payment progress in Revit Model. To achieve this, the three tools collaborate together.

For excel, it is used to store input and output data such as cost, schedule plan. In preconstruction stage, it stores price information and schedule plan to be as input to Revit. It also stores the output from Dynamo, such as BOQ and cost plan. The cost plan curve and S-Curve are also made in Excel. In construction stage, actual cost is also collected in Excel. Required cost and earn value display in Excel by Dynamo in construction stage.

For Autodesk Revit, it is used to build the 3D model of project. Corresponding parameters are designed to accept and store the information from Excel, such as materials, cost, scheduling and payment. 3D model contains sufficient information during monitoring cost and payment and it is the platform to visualize cost and payment progress status during construction stage.

For Autodesk Dynamo, it is the bridge between Revit and excel. Algorithm in Dynamo is designed to achieve the whole process automatic and connect excel and Revit. The mechanism of algorithm is to structure and manage data from both Revit and excel, such as cost calculation, date comparison. Algorithm is the main tool to connect the whole cost and payment monitoring from preconstruction to construction stage. Dynamo is responsible to input the unit price to corresponding elements and calculate its cost. To monitor cost and payment, scheduling information is linked to Revit model from excel too. Finally, Dynamo filters the elements by different conditions and overrides eligible elements in color to visualize progress status in Revit. The algorithm in Dynamo highly enhances the automation and efficiency of system.

Finally, the guideline for the whole workflow of how to collaborate three tools to achieve cost and payment monitoring by 5D BIM system is summarized.

1.5.4 Validation and Verification

Once the 5D BIM system is developed, the accuracy and feasibility of this system have to be tested. It takes manual calculation on sample model which is used by system development before to validate the outcome from system, such as cost plan, BOQ and so on. The internal verification is worked out to test the accuracy on the visualization on cost and payment. The system is verified by changing the input data to test whether the output form system shows the correct visualization in Revit model as expected.

According to result of verification and validation, limitations and future studies are put forward at the end.

1.6 Research Outline

Chapter one is the introduction and overview of this research. This chapter explains why the topic is chosen and how important this research is. Then it sets up the objectives of this research and plans on how to achieve this objective. Finally, it expects the outcome of this research roughly.

Chapter two is talking about the literature review. In order to have the knowledge based on 5D BIM working for cost monitoring and methods on how to achieve this system, related literature review is required. It mainly explores the development of 5D BIM and situation on 5D BIM implementation. Moreover, the related literature on methods of cost and payment monitoring is also included. This chapter reveals the previous study on this topic and find out the limitations of current practices and previous study.

Chapter three organizes the methodology of research to achieve this system. It organizes the methodology used in following research. Interview and framework of system are designed in chapter three.

Chapter four describes result of interview on the current practices of monitoring cost and payment. It includes the problems occur during actual construction on the two issues. In addition, the research discusses the result of interview to provide the reference for 5D BIM system development.

Chapter five describes the process to develop the 5D BIM system according to the discussion from interview on current practice. It works out the process of cost and payment monitoring by 5D BIM system, including the way how to process the data in excel, Dynamo and Revit. Finally, verification and validation are used to test the result from 5D BIM system.

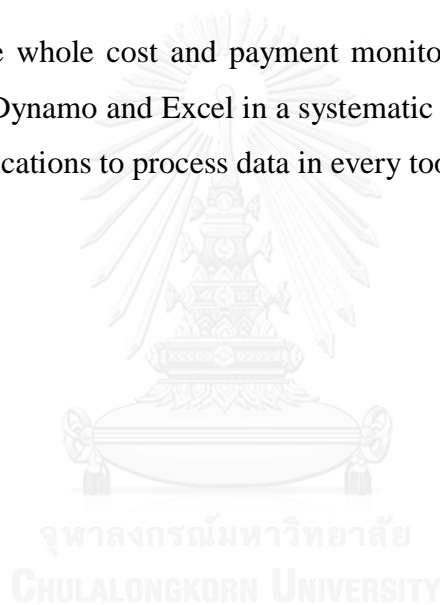
Chapter six describes the research conclusion, limitations and future studies.

1.7 Expected Benefits

The system is developed for the cost and payment monitoring with 5D BIM, so the main expected benefit is to improve the process of cost and payment monitoring by

linking and visualizing cost and schedule information with 3D model. This research plans to achieve the specific benefits below:

- Have a better outlook on cost monitoring process of current practice in Thailand.
- Algorithm in Dynamo enables to link cost and schedule to right 3D model components automatically and accurately. Algorithm in Dynamo can calculate earn value, cost of required 3D model components (delayed, unpaid etc.) to excel and visualize cost and payment progress status in Revit automatically and accurately with actual cost and payment information input. Finally, the algorithm designed in this research is also applicable for other projects at some level.
- Summarize the whole cost and payment monitoring process by collaborating among Revit, Dynamo and Excel in a systematic way, including work flow and detailed specifications to process data in every tools.



CHAPTER 2

LITERATURE REVIEW

2.1 Cost Monitoring

2.1.1 Definition of Cost Monitoring

Cost monitoring is one process of project management, which includes five stages, initiating, planning, executing, monitoring and controlling, and closing (Rupen et al., 2013). The monitoring and controlling include tracking, reviewing, collaborating the progress of cost and payment, and identifying changes and extra increased works (Project Management Institute, 2013). Cost monitoring can give an overview picture for understanding project progress, it identifies the deviation between plan and actual works. Cost monitoring contributes project manager or cost manager to make corrective decisions by providing useful information to avoid lost (Gundlach, 2013).

In handbook of project management (Young, 2007), the content of cost monitoring contains the record on completion of activities and corresponding cost. The expected delay on payment and activities, any new activities occur outside current forecasting are also in cost monitoring content. Later on, any new independent activities that are not identified and estimated are also considered by cost monitoring. In summary, the issues in relation in cost during actual construction activities are all in cost monitoring scope.

It is necessary to figure out the difference among cost management, cost control and cost monitoring which are ambiguous. The relationship among cost management, cost control and cost monitoring should be identified clearly. Process of cost management put forward by Chris is showed in Figure 2-1 (Hendrickson & Au, 1989). The definition of cost monitoring has not come to unified. Raut proposed cost control is one process that included in cost monitoring (Figure 2-2) (Raut et al., 2013), while another one proposed that the cost monitoring process is included in cost control (Figure 2-3) (Wayne J et al., 2013).

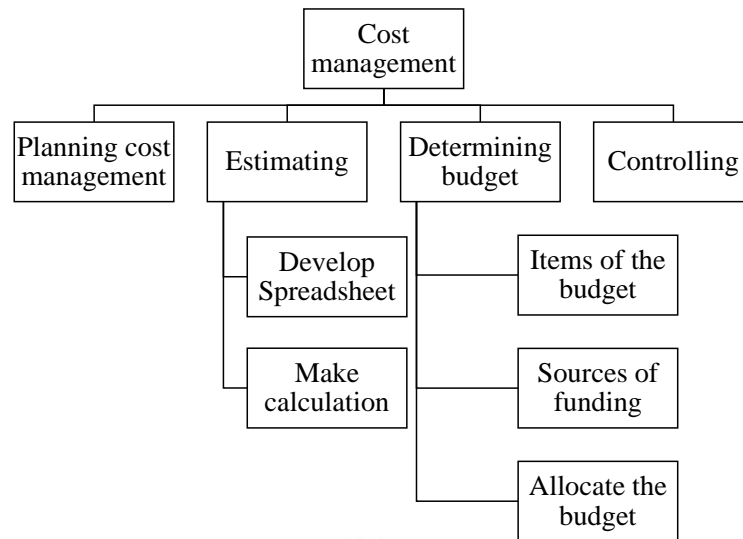


Figure 2-1: Cost Management Process (Chris Hendrickson et al., 2008)

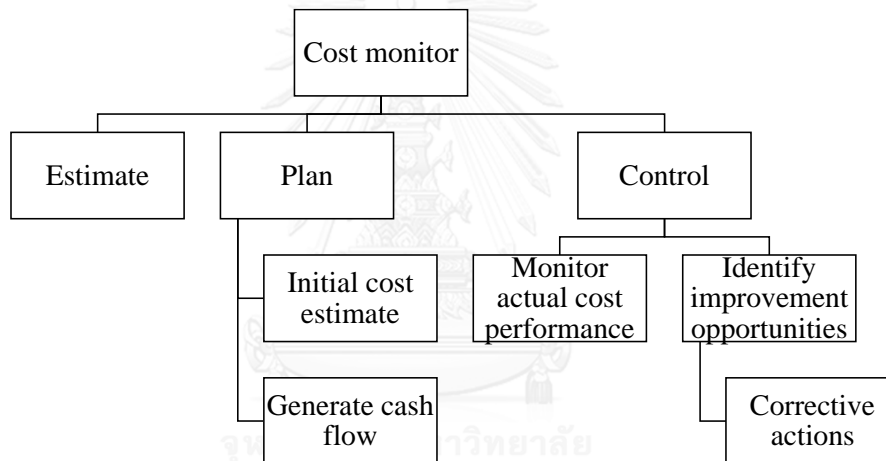


Figure 2-2: Process of Cost Monitor from Raut (Raut et al., 2013)

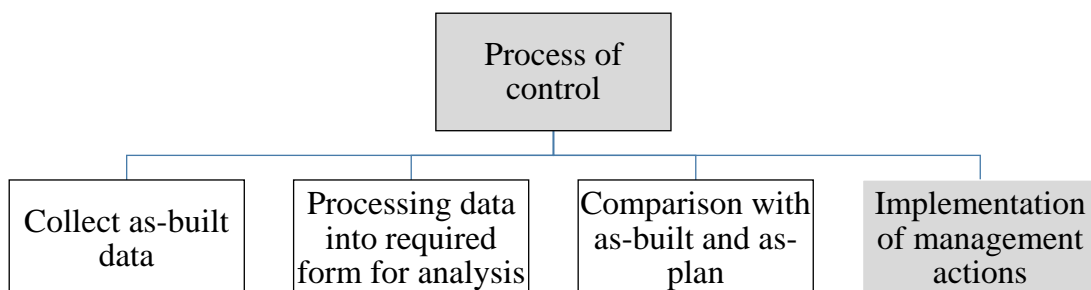


Figure 2-3: Process of Cost Control ((Wayne J&Pico, 2013)

To be consistent, this paper defines cost monitoring to be the five steps: 1) cost plan and payment plan, 2) collect as-built data, 3) processing the data into the form that cost

analysis required, 4) compare as-built cost data and planned cost data, 5) report for implementation of corrective action for deviation. The process is shown in Figure 2-4

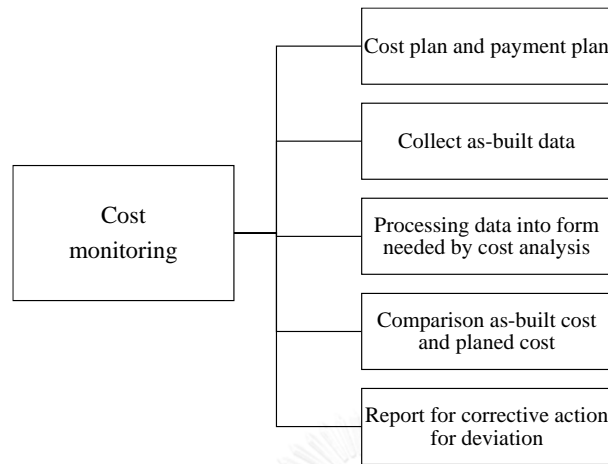


Figure 2-4: Process of Cost Monitoring for this Research

2.1.2 Function and Benefit of Cost Monitoring

Result of Cost monitoring affects the performance of change control which is related to successful project completion. The data in regards with cost is critical during the construction cycle (Gundlach, 2013). The reason why project management needs to monitor cost and payment is that the construction project consists of complicated components, and information is limited at the initial stage. Thus insufficient cost plan is needed to be modified during actual construction stage. This paper focuses on monitoring cost and payment which is to take project back to track (EuropeanCommission, 1998). Secondly, the uncertainty of price and construction site condition and so on occurs during the actual construction. It makes the actual cost deviate away from cost plan. In most cases, it results in cost over run and delay which are the negative effects.

Thus cost and payment monitoring has to provide timely and accurate information for cost controlling to decrease the negative impacts on cost caused by various contingency and shortage of cost plan. It ensures that the cost does not exceed the budget.

2.1.3 Process of Cost Monitoring

Cost monitoring is the key component of project management cycle. Cost monitoring relies on the accurate and complete cost planning which distributes the cost on items in working breakdown structure (Oberlender, 1993).

In Project management, there is a system called management cost and control system (MCCS). This system contains planning (phase I), work authorization and release (phase II), cost data collection and reporting (phase III), cost analysis (phase IV), reporting of customer and management (phase V). Cost data collection and reporting are the means of cost and payment monitoring in construction stage. Actual cost (ACWP) and the budget cost for work performed (BCWP) are accumulated in detailed cost. The flow chart is showed in Figure 2-5.

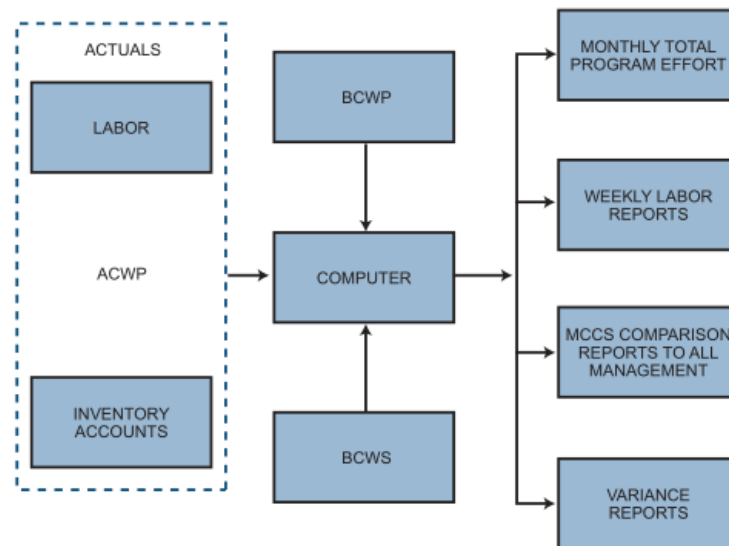


Figure 2-5: Cost Data Collection and Reporting Flowchart (Kerzner, 2013).

2.2 Techniques of Cost and Payment Monitoring

2.2.1 Cost Monitoring Techniques

There is a basic technique of cost monitoring called Earn Value management (EVM) which is used to check whether the current cost is within budget (Rupen&Michele, 2013). Earned Value (EV) analysis utilizes the earned value fundamental formula to determine the project performance indices related to project cost and schedule. Earn value is a part of the cost control in project cost management. There are two indexes for cost management, first is Cost Performance Index (CPI) which represents the amount of completed work of a project for every unit of cost spent. It is computed by Earned Value (EV) / Actual Cost (Muzvimwe, 2011). CPI tells whether this project is still within budget or not. Another index is Schedule Performance Index (SPI) represents the gap between actual completed works and schedule plan. It is calculated

by Earned Value (EV) / Planned Value (PV). The two indexes are the typical cost and schedule monitor techniques which are really important for project manager or cost manager to master and control the project.

In the book of project management body of knowledge, there is a methods utilizing the above indexes. To-Complete Performance Index (TCPI) is used to determine whether the project performance currently completed as budgeted on track or not by utilizing earned value management (Project Management Institute, 2013).

To monitor cost progress, the data on cost and schedule should be tracked. To check the cost overrun or any other problems where there are likely delay in schedule and incompleteness of works, an integrated cost/ work/ schedule system is needed to provide timely and useful feedback during the project. The system starts from setting up this system, then decide integrated relationship of the three basic components of a project: scope, budget and schedule. Later on, this system needs to measure the actual data of work, cost and time. Thirdly, system puts the actual cost and works accomplished to be superimposed onto the curves, compare the actual cost with planned cost. Finally the status of project is showed. Here is a problem on the work measurement, because time is by days, cost is by dollars which are easily to measure (Oberlender, 1993). For traditional way to measure working progress, there are three common ways. Start/Finish technique, project earns a percentage of progress when the task starts and the other half is earned once the task is complete. This method is only focused on capturing the starting point and the finishing point of the task and nothing in between. Second is Weighted or Equivalent Units, the tasks that are being calculated tend to occur over a longer duration time and includes multiple subtasks, where subtasks can have different units of measurements. Final one is based on experience of project manager to get percentage of completion by physical observation (DelPico, 2013). These ways take much efforts to get precise working progress, while the subjective judgement is easy but inaccurate.

The other objective of cost monitoring is to track changes during constructing activities. Most changes, regardless of extra activities or price fluctuation and so on, are in relation of cost. So the changes and variance analysis are necessary for cost monitoring which is talking about comparison of planned project performance to the actual project

performance. This analysis helps project manager to have an overview on the causes of variance which supports project manager to make better decision on corrective actions (Rupen&Michele, 2013). Moreover, because of the changes, the recorded cost should be categorized by four types with corresponding works during the actual construction: distributed budget, management budget, undisturbed budget, contract changes (Kerzner, 2013).

2.2.2 Cost Coding

To organize building project better, building elements need to be defined and classified well to help cost manager or project manager distribute cost and time. Models, documents, project information and specifications need to be organized to ensure interoperability and help the external processes such as cost planning (RICS, 2015). 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 (United States DOE, 1997). To link building components with corresponding cost, bill of quantity (BOQ) and work breakdown structure (WBS) are introduced below.

Working breakdown structure (WBS) has two standards: Unifomat and Masterformat. Unifomat is the WBS of functional elements of building which can be used by owner, designer, or general contractor. Elements in Unifomat, as defined here, are major components of most buildings. Masterformat is the WBS on materials, methods and “work results” for contractor and subcontractor (Takim et al., 2013). The detail level of BIM model is defined for the main elements. The Masterformat is applied in the structure and hierarchy of BOQ. There is an example of the Unifomat II standards (part of it) from U.S. Department of Commerce shown in Table 2-1.

Table 2-1: Example of Unifomat II Standards (United States Division of the Federal Register, 1938)

Level 1 Major Group Elements	Level 2 Group Elements	Level 3 Individual Elements
A SUBSTRUCTURE	A10 Foundations	A1010 Standard Foundations A1020 Special Foundations A1030 Slab on Grade
	A20 Basement Construction	A2010 Basement Excavation A2020 Basement Walls
B. SHELL	B10 Superstructure	B1010 Floor Constructions B1020 Roof Construction
	B20 Exterior Closure	B2010 Exterior Walls B2020 Exterior Windows B2030 Exterior Doors
	B30 Roofing	B3010 Roof Covering B3020 Roof Openings
C. INTERIOR	C10 Interior Construction	C1010 Partitions C1020 Interior Doors C1030 Specialities
	C20 Staircases	C2010 Stair Construction C2020 Stair Finishes

BOQ sets up the budget baseline to monitor actual cost progress in construction stage. Collaboration between cost code and WBS is not only beneficial to cost estimation, but also for cost monitoring. It proposes a mean for detecting omission and duplication of items in budget estimation. It is also helpful to record construction status on cost, payment and time changes occurrence during actual construction (United States DOE, 1997).

2.2.3 Payment Monitoring Techniques

Payment monitoring is to ensure that the cash flow is still within control. The outcome of payment monitoring provides the reference to adjust the plan. Payment method depends on, the clause they agree in contract on payment. It is constrained by the contract conditions and type as well. The milestone payment method and lump sum contract simplify the payment process (DeWitt et al., 2015). Under a lump sum contract,

the contractor prepares and submits payment application monthly. The payment amount is based on actual progress percentage of the lump sum prices, instead of detailed measurements of actual quantities (Gendreau, 1997). There are two payment methods are considered, milestone payment and progress payment.

There are some indexes to perform the payment and cost comparison which contributes the project manager to master the financial situation and make the decision on cost strategy. Payback period is the period for a company to cover its expense based on cash flow. Payback period, Net Present Value NPV) and cash flow are the indexes to detect payment during construction progress(Kerzner, 2013).

2.3 5D BIM

2.3.1 Definition and Development of BIM

BIM is an abbreviation of building information modelling, which is an approach to design, construct and manage facility. BIM is used to help information exchange and interoperate in digital format. The BIM related approach and concept occurrence could be traced back to 40 years ago, while the terminology has been spreading for latest 20 years so far (Eastman et al., 2012). There is a definition of BIM from The US National Building Information Model Standard Project Committee, it says that BIM is a digital representation of physical and functional characteristics of a facility. BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle(NBIMstandard, 2016). CIDB defines BIM as a process supported by technology of computer to generate model. in addition, the generated model is used in collaborate the process to supplement information and simulate the planning, design, construction and facility operation (Holiday Inn Glenmarie et al., 2013). There are various definitions on BIM from different persons. BIM becomes the new trend in AEC industry in the global world, it transforms the construction industry from 2D drawings times to 3D or higher dimension model times now. BIM is being developed as a key technology, policy and process shift in whole life cycle of construction project. BIM implementation significantly improves the collaboration, communication and coordination among the AEC industry stakeholders (Badrinath et al., 2016).

In a global views, there are different levels of BIM development by its own characteristics in construction industry, while they learning from each other and fast-developing themselves in this modern technology ages.

In UK, the Cabinets office has published the policy “Government Construction Strategy” to require fully collaborative 3D BIM, and emphasized to develop standards for enabling all stakeholders and multidisciplinary members related project to collaborate through BIM in year 2011 (Dawood, 2015). It declares that all public sector’s centrally procured construction projects will be delivered with minimum Level 2 BIM using by 2016, which means UK is almost the most developed country who implement BIM well with integrated standards and regulations (HMGovernment, 2015).

In Sweden, the most common objective of using BIM is visualization. And for the implementation of BIM in general contractor, the determined factors are individual’s subjective on BIM, positive or negative, instead of the demand from client and company itself (Isaksson et al., 2016).

In Finland, the Common BIM Requirement 2012 handbook was compiled for the growing need of standardization and common rules, and building related common requirement has been announced for infrastructure project. This is the similar promotion with other countries. But they still meet many challenges, such as competence and competitiveness of technologies, social negative opinion on BIM implementation (Tulenheimo, 2015).

As for Poland and Czech, there are some particular projects partially or fully implemented BIM. It is far away from implementation of BIM in countries so far as well as other eastern countries (Juszczuk et al., 2015).

In Thailand, the BIM developed from the year 2012 when the sense of broad awareness began to the year 2015 when the BIM related service become high competitive (Virulrak, 2015). However, previously BIM development in Thailand is still in the initial stage, government hasn't issued BIM related implementation standards and regulations. Moreover, one of the main barriers and difficulties construction industry companies currently face is the lack of skilled architects and engineers who are aware

and able to use the technology to support the BIM implementation in their company (Worthington, 2014).

There is a survey reveals the countries different implementation level on BIM as contractors in Table 2-2 below by Stephen Jones in McGraw Hill Construction.

Table 2-2: Percentage of Contractors at High/Very High BIM Implementation Levels (by country) (McGraw-Hill Construction, 2007)

Country	2013	2015
US	55%	79%
Brazil	24%	73%
Germany	37%	72%
Australia	33%	71%
France	39%	71%
UK	28%	66%
Canada	29%	54%
South Korea	23%	52%
New Zealand	23%	50%
Japan	27%	43%

According to survey in 2015, there are several major benefits from BIM towards different participants in construction project. Such as the improvement of final design constructability, increasing the understanding of owner on the proposed design, and the reduction of final cost as the significant positive impact. Finally, most respondents cited BIM accelerate the completion.

As for the different roles in construction project, they have different impacts on BIM implementation which brings them significant benefits. At the average level, the percentage of impact on BIM in different participants in construction project by the survey result of McGraw-Hill report is summarized in Table 2-3

Table 2-3: Five Top-rated Positive Impact on BIM (McGraw-Hill Construction, 2007)
Overall, the BIM develops fast across the world. It opens a new view and breaks traditional way to design, construct and collaborate in construction industry. Apparently that every country is trying to promote BIM implementation in construction industry.

2.4.2 Related Software

In the BIM market, there are endless number of applications and software for various function and area to be utilized. There are the software categorized by company showed in Table 2-4.

Table 2-4: BIM Common Software and its Affiliated Companies (Wang, 2014)

Autodesk	Bentley	Nemetschek Graphisoft	Gery Technology Dassault	Tekla Group
Revit	Bentley Architecture	ArchiCAD	Digital Project	Tekla Structure
Dynamo	Bentley Structural	AIIPLAN	CATIA	Xsteel
Navisworks	Bentley Building Mechanical system	Vector works		

According to functions of software needed in one certain field, there are the categories of BIM software showed in Table 2-5.

Table 2-5: Software Classified by Functions (Wang, 2014)

Function	Software
DEEP DESIGN	Tekla Structure (Xsteel) ,
CLASH DETECTION	Navisworks , Projectwise Navigator , Solibri
COST MANAGEMENT	Innovava, Solibri, Dynamo, CostX
OPERATION MANAGEMENT	Archibus , Navisworks, Primavera, Microsoft project
PUBLISH AND CHECK	PDF, 3D Pdf, Design Review

For sure there are still many other software utilized in BIM area with broad function in construction industry that not showed in above table.

There are many factors affect to chose a proper software for construction companies. Software capability must fit for the requirements and demand of company expectation, such as the function of software and usability. Later on, the features in software like unit and default calculation should follow the standards in industry from government if it is required to comply. Currently, there are not many software fit for cost-efficient matter. Finally the budget matters come out too, that the cost on utilizing one certain software requires the cost on purchase and maintenance of software. The economic but strong capability software is hard to find in market either. Normally the BIM related software is more expensive than the traditional 2D software.

Particularly, for cost related BIM software, the high dimension BIM applications always collaborate with 3D model software and progress software. There is a summary on software in BIM market for cost management which is possible to be helpful on this research showed Table 2-6 below.

Table 2-6: Software - Feasibility Tool for Cost Related (BIMForum, 2011)

Product Name	Manufacturer	BIM use	Manufacturer's Description	Primary Focus	Supplier Web Link
Tekla Structures	Tekla	Shop Drawing	It streamlines the entire workflow from sales, bidding, cost estimation, and conceptual design to detailing, fabrication erection, and follow-up	Structure-centric fabrication	www.tekla.com
Digital Project Designer	Gehry Technologies	Model Coordination	Full range of capabilities, from takeoff to estimating, to scheduling and project management	Full featured suite, based upon CATIA application	www.gehyrtechnologies.com
Synchro Professional	Synchro Ltd	Planning & Scheduling	BIM for Delivery from concept to commissioning (versus BIM for Design or Facilities Operations); Integrated and collaborative 3d model based scheduling, budgeting/cost and supply chain management	Schedule-driven site coordination	www.synchro Ltd.com
Vico Office	Vico Software	Multiple function	Allows GCs to combine BIMs from Revit, Tekla, ArchiCAD, CAD-Duct, and IFC files. The "whole mode (whatever its level of detail) can then be coordinated, scheduled and estimated	As the level of detail increases, the schedule and estimate become more precise.	www.vicosoftware.com
Vico Takeoff Manager	Vico Software	Quantity Takeoffs	Generates quick and highly accurate model- and location-based quantity takeoff derived from 3D models created with leading BIM authoring tools. Since quantity takeoff is a live view, newly published and activated model versions result automatically updated quantities.	Quantity Takeoffs, feeding into estimating and scheduling	www.vicosoftware.com
Vico Control	Vico Software	Scheduling	Using Control, planners can design significantly compressed schedules without increasing risk. The incorporation of locations, estimated quantities and productivity rates early in the planning phase yields clear, accurate, and feasible schedules	Schedule is scientifically derived from the resource-loaded, cost-loaded, location-based BIM	www.vicosoftware.com
QTO	Autodesk	Quantity Takeoffs	With QTO, cost estimators can create synchronized comprehensive project views that combine information from Autodesk Revit applications	Generating takeoffs from multiple environments both 2D & 3D	www.autodesk.com

Besides the software mentioned above, there are still other software particularly used for cost management. The firms use both proprietary and in-house software. The

CostX program is now the most widely used software of this type (Smith, 2014). Vico production Control is applied for resource-loaded, cost-loaded, location-based BIM (BIMForum, 2011). Compared to Vico office series software, this proposed 5D BIM system is based on flexible visual programming. It still remains the traditional spreadsheets during cost monitoring process which make it easier for current engineers to apply this proposed system instead of Vico office software. Moreover, Dynamo is one add-ins of Autodesk Revit, the most common BIM software, so this system is more economic than Vico office. Finally this system is able to visualize and analyses payment which is not available in Vico office.

There is no a perfect and prescriptive software yet which can maximize the benefits of BIM to perform cost management with BIM so far, even many options are provided. Choosing appropriate software that can be usable for its service provide for client and satisfied their particular demands is a long process. Thus it gives out the space for researchers explore more options and solutions on this field where there are many possibilities and potentials.

2.4.3 Computer-based Cost and Payment Monitoring

To manage the large number of information related to cost, payment and progress, the computer technology is applied to aid the manual works. The way of computer-based monitoring require the well-organized hierarchy on objects in model to match with cost, payment and progress information. In the view of users, the interface should be friendly to transfer highly abstraction data to visible patterns. To improve and analyze initial schedule based on a computer program, the breakdown of location and activities need to be defined (Kalle et al., 1990). We cannot talk BIM without the computer technology base, the BIM base simplifies the process of cost estimation and monitoring activities and enables project participant's view and evaluate construction progress with geographical conditions. There is a cost estimation and monitoring model based on BIM proposed a model with MS access, Revit, MS Project and Excel (Emad et al., 2014). The information in model is always consistent with the design which enables outcome updatable when a change occurs in design. Changes are rippled to the related documentation and result data from design. It apparently reduces the time and errors from traditional human works to monitor cost and payment progress. The integration

between attached information and BIM platform to exchange data and visualize the right information should consider about the object oriented concept and the bridge between outside data and BIM platform.

2.4.4 5D BIM Definition and Development

BIM provides the opportunities for cost management in construction area with challenges as well. 5D BIM is 3D model with linked cost and time information. This research technology and knowledge are all based on 5D BIM to support cost and payment monitoring to enhance the efficiency and automation.

BIM not only contains the 3D model, but also further dimensions such as schedule, cost and payment. 5D BIM integrates the additional cost information on 4D basement. It helps to simulate 3D model with progress, quantity and parallel cost (Peter, 2016). The creation of 5D model enables the various participants (from architects, designers, contractors to owners) of a construction project to share cost, time, 3D information at the same time and visualize the progress of construction activities with corresponding cost and payment (NIBS, 2012).

The importance of 5th dimension to the project cost management has been the key role in construction industry which called “5D Project cost manager” (Mitchell, 2013). Muzvimwe backs up this notion that the value of 5D BIM for cost manager is that being able to simulate and analyze various design and deviation scenario by the integrating cost and progress data in one living 3D model. The cost information is linked in the 3D model with progress information as well, which makes the changes in design reflect related impact in the two deliverables(cost and time) immediately (Muzvimwe, 2011).

5D BIM develops from the 3D BIM to 4D, where the 4D technology has been seen that its implementation increased productivity successfully (Heesom et al., 2004). During the literature review, there are several researches on 5D BIM. A Croatia research comes up with a schematic data flow about how 5D BIM application process showed in Figure 2-6. The 3D model combined with associated project data required at initial stage in IFC format which is the normative format in BIM as input. Bill of quantity, construction diary, schedule report and invoices can be output from this

system. 5D BIM application is used to generate the process, enable input to work out output automatically.

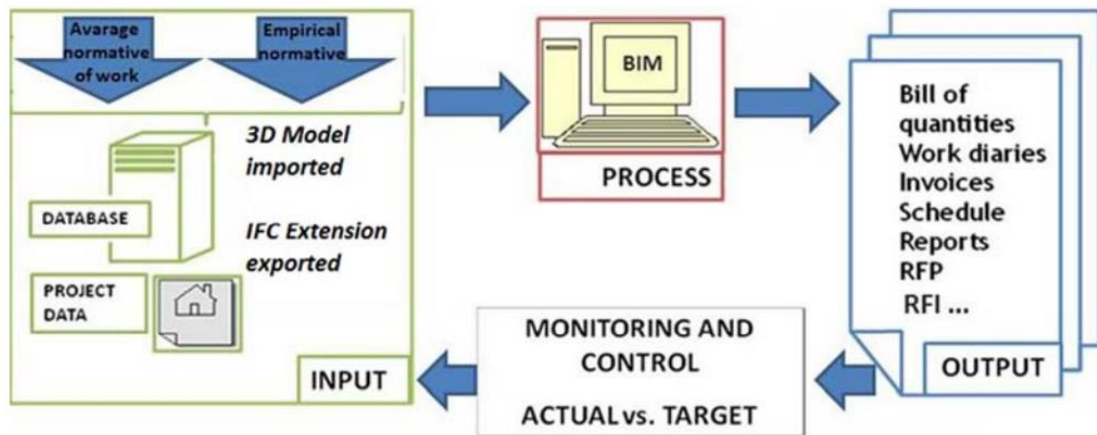


Figure 2-6: 5D BIM Application Process Diagram (Blažević et al., 2014)

This concept shows a basic flow of BIM on project management, it focus on the common phase and concept of 5D BIM application process which proposes a guiding for coming research to explore the details during the common process.

As for the standards development of 5D BIM, there are some advanced regions which utilize BIM declared related standards for 5D BIM, with corresponding level of details on BIM model. 5D BIM application is related to the level of details of BIM, like the component information should be detailed enough to extract the cost of materials (Peter, 2016). An agreement has been reached to solve cost engineering related problems under the building SMART Alliance. It aims to develop systems and protocols for collaboration and coordination of cost engineering and estimating through the project lifecycle (Larson, 2012).

Since only limited researches on 5D BIM for cost and payment monitoring, especially in Thailand. The owners are hard to control the cost and payment schedule without the visualization over construction progress. For contractors, timely and accurate cost monitoring and payment condition are required to make better decision on cost and schedule strategy.

2.4.5 Application of BIM on Cost and Payment Monitoring

BIM as the innovative approach in construction industry, it brings various benefits in construction area. BIM is applied in whole lifecycle of building projects as the main

concept of BIM which says that BIM integrate lifecycle information of building in one model to manage project from design to maintenance (Eastman et al., 2012). So there are variety of BIM applications in construction industry. For cost and payment monitoring, it is based on 4D BIM development and 5D BIM improvement. The current researches integrate existed BIM software mentioned above and propose new ideas to improve construction problems. To monitor cost and payment, there are many issues need to overcome from preconstruction phase to construction phase.

To link cost to 3D model, automatic quantity takeoff and cost estimation need to be achieved. 5D BIM can provide quick quantity takeoff (QTO) automatically since the BIM model is built with precise geometric information and some non-geometric information which give the base for automatic quantity takeoff and update quantity information over time with visualization (Stanley et al., 2014). 5D BIM enables the solution for integrating QTO and cost estimation into design result to analyze cost automatically with spreadsheet and related available architecture software (Zhou et al., 2015). 5D BIM integrates the time and cost information in 3D model and enables the update changed by time, so that contractor can optimize schedule to predict the project cost more comprehensively. Integrated location-based scheduling should enable schedule optimization over CPM-based approaches, resulting in shorter overall duration with more continuous resource use (Kala et al., 2010). An approach for timber construction based on model, which contains the cost and time information, is proposed. The model components are linked to performance, the amounts can be determined in the model and are passed directly to the spreadsheet shown in Figure 2-7 (Hollermann et al., 2016). But it doesn't consider about construction phase on monitoring.

Even though, cost and time information are linked to 3D model, there are still barriers in linking BIM with in-use building performance management, like cost monitoring, in construction phase (Gerrish et al., 2017). Ahmad proposed an integrated BIM system to track the time and cost which enables early involvement and project integration plus thorough time and cost management by utilizing Autodesk QTO, MS Project and Navisworks to collaborate together (Jrade et al., 2015). It provides an Earn value management platform by MS Project to measure actual working progress and link it with 3D model in Naisworks. However, this needs several platforms to exchange

information and actual working progress is tracked in MS Project based on duration and it doesn't matched with earn value that is calculate based on cost. Moreover, the visualization on payment is also required and corresponding output of cost is still inflexible.

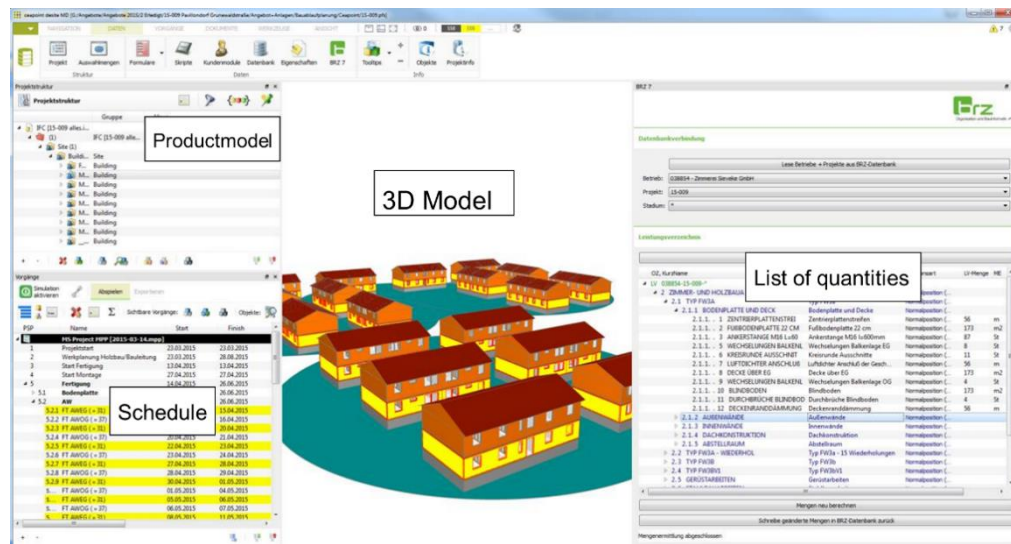


Figure 2-7: Timber Construction Model with Cost Information (Faghihi et al., 2014)

To overcome the inflexibility of cost extraction and visualization, algorithm programming is proposed. Algorithm is able to reach the components of 3D model and automatically generate 3D model, including processing parametric data and also visualization. Genetic algorithm is proposed to read the BIM model and define sets of rules to express element dependences to produce different schedule. Then it has a two-way interactive environment between project geometric model (BIM) and its schedule for scheduling analysis (Faghihi et al., 2014). For cost, algorithm choose an appropriate cut point of a numeric attribute by computing all possible cut points and assign a node through test all attributes which is a research to forecast cost by algorithm (Zhao et al., 2017). Daniel Huber described several algorithms to evaluate project performance (cost and time) by recognizing, identifying and classifying building components (Tang et al., 2010). From these researches, we can see high potential on algorithm to produce customize output from BIM which proposes algorithm for this research to overcome limitation of existed software. Dynamo is a visual programming language add-in of Revit which is able to read and extract Revit parameter values and communicate with Excel. Moreover, Dynamo is a platform by visual programming language and it works

as algorithm which is highly potential to manage data, calculate various data and change property of 3D model components in Revit (Allen, 2016). There is a research on BIM parametric designing by collaborating between Revit and Dynamo to analyse energy performance on building projects (Mengana et al., 2016). A script is coded in this research to determine and allow the parameter variations of the building model in Revit. It provided an example to show how Dynamo and Revit can successfully cooperate. Touloupaki integrated evolutionary algorithm and energy simulation for minimizing energy consumption through parametric modelling which is through visual programming in Dynamo. Dynamo is able to define rules of linking variables, such as materials properties, location of doors, to make decision of building characteristics to save energy (Touloupaki et al., 2017). Dynamo is also applied in an integrated platform for design and numerical analysis of shield tunnelling processes on different level of details. In this research, many kinds of visual programming is designed to generate design model and automate the numeric analysis (Ninić et al., 2017). Moreover, Dynamo is used in BIM-based performance optimization, such as day lighting, energy and so on. Algorithm in Dynamo is designed to parametrically interact with Revit for BIM-based optimization and write all of the decision variables in the whole optimization process and their corresponding performance analysis results to a CSV file. At the same time, the visualization of optimization result within the same BIM platform is achieved by Dynamo visual programming too (Touloupaki&Theodosiou, 2017). From these literature review on algorithm and Dynamo visual programming, the advantages and application on algorithm in Dynamo is able to interact with Revit model parametrically and visualize the result within the same BIM platform. But the applying of Dynamo are more about energy optimization and target to infrastructure or tunnels, there is lack of visual programming development in Dynamo to help cost and payment monitoring which is also able to achieve by managing parameters from Revit model, such as cost, materials and schedule information. It is also potential to improve the visualization of cost and payment progress. So this research proposes to apply Dynamo to link plan cost data and as-built data, such as actual working progress and actual cost to Revit model, then extracting data in Revit model to analyse the cost progress status to achieve automatic cost and payment monitoring.

For the payment 5D BIM is proposed to be applied cash flow analysis. Cash flow must perform after quantity take off, cost estimation and schedule completed, and further information has to be concerned by contractor like payment delay and retention from owner. Kim has proposed that preparing cash flow analysis based on BIM to predict project cash flow when many constraints on cash resources automatically (Kim et al., 2013). However, the cash flow is not connected with components of 3D Model which is not flexible to track objects of payment.

Radio Frequency Identification (RFID) and 3D laser scanning can be used to keep track of the material delivery status to help the progress monitoring (Hergunsel, 2011). It enables the cost and payment monitoring with 5D BIM more applicable to get actual working progress automatically. These ways are still difficult to integrate schedule and cost with corresponding components in 3D model, since it is hard to track the right components of 3D model to match with cost and also schedule. Moreover, the visualization and cost extract in customize condition needs improve too.

BIM allows model to be equipped with plenty of information which define various attributes of elements in building model. The Integrated BIM environment enables model to be linked with databases like mentioned before, cost and schedule information. It enables the QS/cost manager to make suitable adjustments on quantities, rates and other accessorial costs and modifications (RICS, 2015). The BIM environment is applied in the whole lifecycle of building project which indicates the high potential of BIM to improve cost and payment monitoring.

2.4 Previous Research and Limitations

According to the previous researches, they have complete knowledge support on cost monitoring. The function and benefit of cost and payment monitoring are proved by long term construction development. However, there are still many limitations on cost and payment monitoring. Since restrictions of technology or cost problem, the process on this area has not improved to be more effective and automatically.

Firstly, the most provided researches on cost monitoring and payment management are full of manual works like the status report spreadsheet (Oberlender, 1993). Since the extensive manual processes, the efficient cannot be ensured, don't say the accuracy of

the outcome from this way. Structure coding system needs to be improved more to fit for 3D model with cost monitoring and payment management in construction stage. There is lack of the standards on cost code with WBS and BOQ which is helpful on assigning information into 3D model to monitor cost and payment. This research is trying to find a proper way to integrate the BOQ and WBS in 3D model. The previous researches also have studied the way to integrate cost, time and 3D model based on BIM, a Taiwan research proposed a model to link cost and schedule data automatically following linkage to BIM elements with MS visual C+ (Fan et al., 2015). However, visual C is hard to apply and also this model didn't consider about the visualization on progress status. The cost and time linkage with 3D model still takes much efforts and linkage is not accurate enough.

Within 5D BIM research, most research link the cost in BIM are concerned about cost estimation, like a Chinese research proposed a way to extract required construction information from typical specification and used to BIM model to automatically estimate project cost with appropriate work breakdown structure (Ma et al., 2014). And there is a study proposed a process to automatically infer to the right work items for cost estimation by BIM which make it easier to use BIM data (Lee et al., 2014). However, there is lack of research on cost monitor which requires actual working progress input in construction phase.

For the as-built data like the actual cost report and actual working progress information inputting to 3D model, there is no proper way and matured research on this part. To achieve the automatically linkage with 3D model and cost monitoring over project period, the arrangement on information and features in the elements of 3D model is required indeed, which is used to coordinate the process of time, schedule and elements. Within the integrated system with existed software, it is still a challenge for specialist disciplines to find the best software to meet their individual needs. The same with the cost and payment monitoring requirements. The proposed integrated system, such as integrated system (Jrade&Lessard, 2015) by Autodesk QTO, MS Project and Navisworks, it is lack of flexible visualization and performance evaluation on cost and payment during construction progress.

To be easier to master the situation of construction status and completion status with cost, it's necessary to distinguish and visualize components in 3D model by different status. So that owner and contractor can have better understanding on project cost status complied with progress information. The previous research is lack of the attention on the visualization of cost and payment monitoring over construction progress. Moreover, there is not only the visualization progress status is required but also the corresponding cost extraction for cost and payment monitoring flexibly.

Algorithm is flexible to identify, classify and evaluate the data from BIM model and achieve the project performance evaluation, such as the research mentioned above (Tang et al., 2010). This is only checking the working progress performance by laser scanner which is lack of cost consideration. To overcome the above limitations on the customized various output on cost by actual working progress and visualization, we mentioned the Dynamo to be as the algorithm programming platform to process data automatically. There is great lack of algorithm programming in Dynamo for cost and payment monitoring which requires to link data from Excel and Revit model, calculation, identification and classification both on time and cost, and so on. Algorithm is used to highly generate the Revit model and data from Excel and Revit on cost, payment and scheduling information.

The literature review shows that 5D BIM is highly potential to apply for cost and payment monitoring. Moreover, algorithm by Dynamo is really useful to break the limitations of existed software and achieve a greater automation. It is still difficult to integrate cost and time efficiently and accurately, actual working progress is also lack of attention and earn value calculation is hard to be calculated. Even the integrated system with existed software still takes much effort. Moreover, this kind of integrated system also lack of flexibility on cost extraction and visualization for individual requirements in construction phase. To over come these limitations, this research propose a system to monitor cost and manage based on 5D BIM which is aided by Revit, Dynamo and Excel. Algorithm in Dynamo is designed to connect the information through the whole process. It's designed to link the cost and schedule data from Excel to Revit, every item of the 5D model can be directly linked to the schedule and cost in preconstruction stage. In construction stage, by tracking working progress in Excel and

3D model, algorithm in Dynamo identify out the cost and payment progress status by comparing data extracted from 3D model components. Algorithm also calculate the cost of model components that identified by comparison and output to Excel, visualizing in 3D model at the same time with color scheme. The algorithm in Dynamo helps contractor to get more needed data with individual demands, such as over budget components, unpaid components and delayed components at different time with corresponding visualization. Moreover, the algorithm is able to calculate out the precise earn value to Excel based on the cost and schedule linked model. The system generates the way of this linkage between excel and Revit by Dynamo and workflow of whole process, which is trying to solve the limitations mentioned above at high or low level.



CHAPTER 3

RESEARCH METHODOLOGY

3.1 Research Type and Approach

Many kinds of methods are applied in this research, like interview, questionnaire and so on. To achieve the objective of this research mentioned before in above chapters, main methods are interview, verification and validation. This research plans to develop a system to monitor construction cost and payment with 5D BIM. Current cost monitoring and payment management practice data is required for guiding this system, so the interview is put forward which is the way to summary interviewees' perception and behaviors on specified issue about cost and payment monitoring. According to the result of interview, knowledge base and current problems are settled to guide proposed 5D BIM system development.

According to the above methodologies, this research is classified to be qualitative research as the view of information sources type (Booth et al., 2003). Qualitative research is used to unfold a certain range of behavior and the perceptions towards a certain issue (Denzin et al., 2005), for this research is cost and payment monitoring during construction. To collect the data on current practices, interviewing several related experts, such as cost managers, BIM managers, is put forward. Interview targets on a small group of experts and experienced people on cost and payment monitoring. With the result of interview, 5D BIM system is developed to solve the problems from interview on cost and payment monitoring process.

3.2 Research Design

To achieve this research objectives, the whole process of research is designed below, Figure 3-1. Research starts from literature review to find theoretical and technical support, then specify the research problems and find out the research gap. After a thorough review of related literature, it was evident that a 5D BIM system is really necessary. At beginning, scope of research is defined. Theoretical knowledge from literature review is not enough to solve the problems, so the interview is come up to explore the current practices on cost and payment monitoring. The interview is designed

to explore the details on the cost and payment monitoring, including BOQ, cost plan, actual cost recording and payment recordings. Moreover, it also explores the problems they meet during the process which is possible to be improved by BIM. According to this result, the system of cost monitoring and payment management is developed. The system is developed by building a sample structural model in Revit and develop the whole process step by step. Manual calculation is done to validate the accuracy of system's output, such as BOQ, cost plan. And multiple verifications on visualization are done to verify system's other output which cannot obtain from current practices. Finally, it summarizes the contribution and limitation, coming up with future studies after system development.

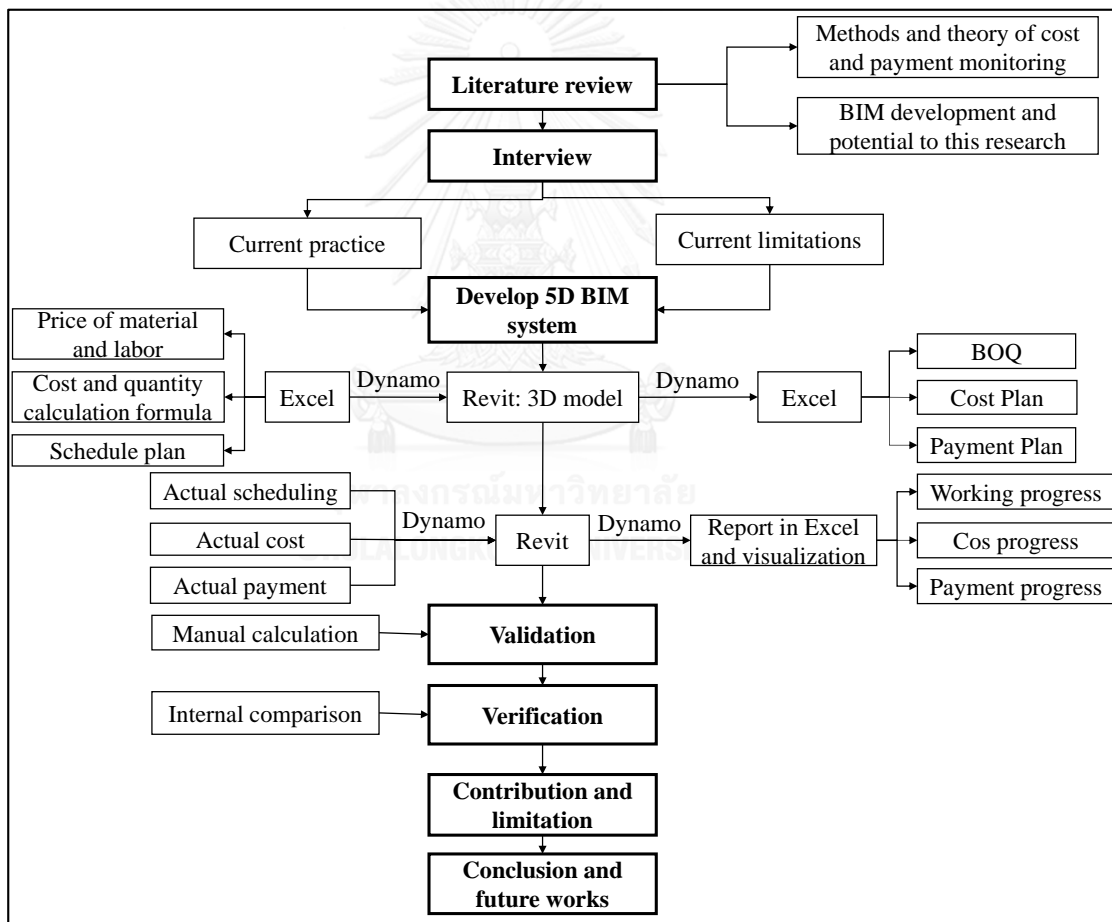


Figure 3-1: Research Technology Diagram

3.2.1 Literature Review

Literature review aims to build up the knowledge base of this research to support proposed system and summarize the previous researches to find the gap on this topic.

It introduces the definition, function, process and development of cost and payment monitoring. Then indicate the coding system to support for automation of this system to monitor cost and payment. Moreover, the development of 5D BIM in construction industry is summarized to be the technical background. So that the applications of 5D BIM related to cost and payment monitoring is also provided for technical support. In the end of literature review, the potential and research gap are summarized for advanced research and proposed system.

3.2.2 Explore Current Practice of Cost Monitoring and Payment Management

After getting the knowledge base and background of cost and payment monitoring and with 5D BIM, this research is going to explore the current practice by interviewing cost managers, project managers and BIM coordinators for the current practices on their projects on hand.

4.1.1.1 Interview Objective

The interview aims to know the practical process in current companies to monitor cost and payment, including how they measure the completed works, how they organize the cost monitor report, and so on. Moreover, the BOQ and schedule plan are also included in the plan data preparation stage. On the other hand, the BIM coordinators are also interviewed for the 5D BIM implementation about cost monitoring in their company to get the reference for proposed system. Comparison and discussion on every steps and documents among interviewed companies is done to summarize out the most common ways to process data during monitoring cost and payment. The suitable way is found out for proposed system development from the discussion.

4.1.1.2 Target interviewee and project type

Project manager, cost manager, site manager, site worker, BIM coordinators and any cost, schedule coordinators are in consideration. The qualification of every interviewee are experienced in construction industry, so that the result is more accurate and feasible. As for project type, projects interviewed can be many type of projects, but project for system development is reinforced concrete structural construction project only that is built in Revit. Normally, the interview is by face to face, it is about cost and payment monitoring, including the methods, processes, input, and output and so on.

3.2.3 Development of the System

Based on result and discussion of interview, 5D BIM system is developed. Firstly, software used in this system are: excel, Autodesk Revit and Dynamo. A 3D structural 3D model is built as a sample for development.

In preparation stage, materials distribution in sample model is assumed and designed. Schedule plan is designed to detect the cost and payment and to set baseline for cost and payment progress in construction stage. These original price and schedule data are put and organized in excel. Dynamo programming has to be designed to put these original price data to 3D model and calculate quantity and cost automatically. The output in Excel by Dynamo in preparation stage should contain QTO, BOQ, cost plan and payment plan. In construction stage, the actual scheduling, actual cost and actual payment are recorded. Dynamo programming should filter elements by comparing actual cost and payment with its baseline (plan cost and payment) to visualize corresponding progress in Revit. So the programming in Dynamo has to be designed to have the functions which are, linking price to Revit model and exporting QTO, BOQ, cost plan and payment plan to Excel after automatic calculation in preconstruction stage. The design of algorithm in Dynamo in construction stage is to utilize actual scheduling, cost and payment data to export corresponding cost progress, payment progress to Excel, and visualize corresponding progress status in Revit. So these algorithms programming in Dynamo has to be designed to connect the whole process to monitor cost and payment amount and progress status automatically and accurately.

The 5D BIM system result should be tested whether the information output from system meets the result from real cases. So verification and validation on this system are done to check the accuracy of this system result. The details are describes in development of 5D BIM system part. Verification is by comparing with the manual calculation and validation is by checking system result from different input parameter values.

3.2.4 Conclusion and Future Expectation

According to the result of verification and validation of proposed system, conclusion is given, compared with current practices and pervious researches. At the end, this conclusion has to answer whether the proposed system is feasible or not, where the

system has improved on cost and payment monitoring process. Limitations of the research and system is summarized.

3.3 Explore Current Practice of Cost Monitoring and Payment

To explore current practice of cost and payment monitoring, this research designs to interview a number of engineers. To achieve this objective, interview should be designed well. Interview design describes the process of interview and prepared questions. Pilot questions are designed to target the main needed documents that required during cost and payment monitoring, and the way how they process these documents. Finally, the interviewees' information is summarized to clarify the interview data resource and what kinds of roles in industry are supported by this interview result. The process of interview is roughly summarized below:

- According to literature review, design the interview questions. This questionnaire is the pilot questionnaire which be checked with 2-3 experienced cost managers to ensure the feasibility of questionnaire.
- Interview design and execution, including answers sorting and question improving.
- Qualitative data analysis, including summarize all interviewee's answer and compare them. The discussion on the comparison is targeted to provide reference for proposed system.
- Make conclusion

3.3.1 Interview Design

Interviews provide in-depth information pertaining to participants' experiences and viewpoints of a particular topic (Turner, 2010). This research designed an informal interview which mainly towards experienced cost managers and BIM engineers. The interview process designed like in the Figure 3-2. There are three types of the qualitative interview, 1) informal conversation interview, 2) general interview guide approach, and 3) standardized open-ended interview which includes the construction of research questions as well as the analysis of interview data (Creswell, 2007). This research

applies the informal interview to explore the current practices on cost and payment monitoring. The interview is designed step by step.

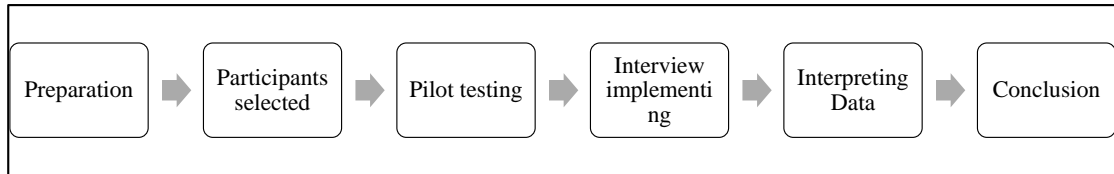


Figure 3-2: Process Design for Interview

1) Preparation

Preparation includes the presenting the concept of this proposed system. The introduction of system and interview questions.

2) Participant's selection

The target participants are mainly experienced cost managers and BIM engineers. In addition, contractors are seen as the main participants since the system contributes to contractor in major.

3) Pilot testing

Creating effective questions is helpful to get better and faster answers from interviewees. So the pilot questions are tested first with experienced cost managers to improve the questions more specific and make the interview more effective. For example, the question should be more detailed like what's the structure of cost plan table when we ask the process of cost monitoring. During the testing, the questions are suppose to be improved.

4) Interview implementation

The whole process of interview is controlled in 2 hours. The interview starts from mutual introduction and then present the concept of proposed system on cost and payment monitoring. After that, questions about current practices on cost and payment monitoring should be asked one by one. Moreover, it is better to prepare some examples for the pattern of answers towards some questions to make the participants understand more easily. It is important to take the recording tool to record answers which is used to help analyze data analysis later.

5) Data interpreting

This is a qualitative research and interview, so the data interpretation and analysis need to be careful. For example, there are some questions on process, after interview, the process diagram should be drafted according to the description. Moreover the documents related to this cost and payment monitoring process, such as BOQ, cost plan and schedule plan, should be summarized as an integrated spreadsheets according to description from participants.

6) Conclusion

After data collection and data interpreting, the questions and answers are grouped and categorized as the conclusion report of this interview about current practices on cost and payment monitoring.

3.3.2 Pilot Questions Design

The full pilot questions are in the appendix 1. The questions aims to get the process of cost and payment monitoring, and the detailed structure of the documents needed during this process, such as BOQ, cost plan and schedule plan. The process and input, output documents are still used to refer the proposed system development. The pilot questionnaire will be tested by 2 experienced cost managers and BIM engineers from contractor. The questions are kept improving during the interviews.

Before interview, questions are sent to interviewees before interviewing. As respond, we can get the basic information on interviewed companies too. The main questions example are given below:

- Did you implement BIM in this project?
- What the process of cost monitoring
- Table used for cost monitoring
- Payment type
- Payment monitoring process
- Cost report during construction and how to measure the works
- The opinion on BIM implementation on cost monitoring

- Opinion on payment status visualization

These are some examples of the pilot questionnaire, it is being improved when it goes to execution stage.

3.3.3 Data Analysis

According to the result of interview, summarize the answers and analyze the results. Since the answers are descriptions and tables which are the qualitative data, thus qualitative data analysis method is introduced. Qualitative data analysis process is shown in figure (Grbich, 2007) below:

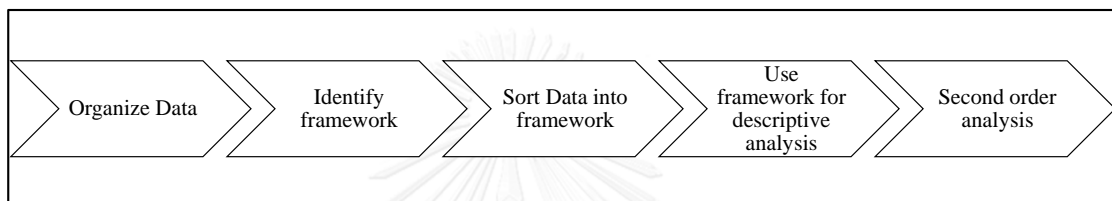


Figure 3-3: Process of Qualitative Data Analysis (Grbich, 2007)

For the second process, identify framework, this research plans to define and category data by the questions. Another way for identifying data is categorizing by answers. Data analysis is to meet the requirements from the developed system which needs to know the process of cost monitoring, required input and output documents during the process.

3.4 Development of the 5D BIM System

3.4.1 Initial Framework of the System

The initial framework aims to guide 5D BIM system development before. The initial framework for developing 5D BIM system is summarized in Figure 3-4. The system aims to track cost and payment over progress with corresponding elements in 3D model and visualize cost and payment progress status in 3D model. There are 3 main parts in this system: spreadsheets, visual programming, and 3D model. It corresponds with the three software: excel, Dynamo and Revit. Spreadsheets in Excel and 3D model in Revit both are information but in different format and platform. Visual programming is the bridge between the two different types of information to enable two sides of information interexchange automatic and in an expected process. It means the data in excel can be transferred in 3D model. In contrary, the same information in 3D model can be

transferred to excel too. The system relationship among the three parts is showed below in Figure 3-4.

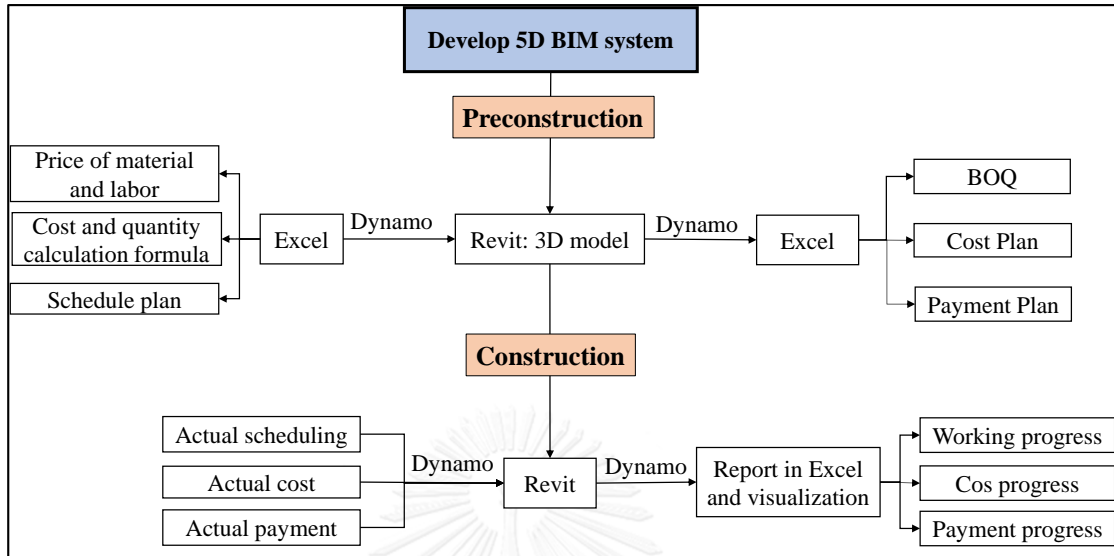


Figure 3-4: Initial Framework for 5D BIM System Development

There are two stages that are preconstruction stage and construction stage. Revit is used to build the 3D model with preliminary information base on 2D drawings, and it is used during the whole process in both preconstruction stage and construction stage. For the spreadsheets in Excel, there are two type spreadsheets, one is to input and another one is output. Dynamo connects excel and Revit through out the whole process in this 5D BIM system.

For the input spreadsheets, there are: unit price of materials and labors, calculation formula and schedule plan in preconstruction stage. Output spreadsheets in preconstruction stage are: BOQ, cost plan, and payment plan. Input spreadsheets in construction stage: actual scheduling, actual cost, and actual payment. Output spreadsheets in construction stage are: working progress report, cost progress report, and payment progress report.

From the Figure 3-4, Dynamo has two main functions through out the process. Firstly it connects excel and Revit, inputs information from excel to Revit and outputs information form Revit back to excel. Secondly, in construction stage, dynamo filter elements by conditions on cost and payment progress to visualize progress status about scheduling, cost progress and payment progress.

3.4.2 Spreadsheets Design

There are two type of spreadsheets, the data input to Revit and the data output from Revit as mentioned above. Mostly the output spreadsheets are automatically exported from Dynamo to Excel, so the input spreadsheets should be designed strictly. There are main contents and requirements are highlighted in Table 3-1 about main input spreadsheets in Excel.

Table 3-1: Main Input Spreadsheets Highlights

Unit price	Masterformat
	Refer to formula to calculate cost
Schedule	Work breakdown based on schedule plan
	Schedule Plan
	Activity Code for activity package
Construction records	Working progress, Cost progress, Payment progress.
	Data resource of S-Curve
Other	Work breakdown structure (WBS)
	Formula for material quantity and cost calculation
	Specification for modeling standards and other specification

The main input spreadsheets are independent but partially connected, different spreadsheets have its own function to collaborate together and connect with Revit. The data in spreadsheets should be organized well to match the 3D model, so that the data can be input correctly and efficiently.

For unit price, it contains the labor and material price. This spreadsheet contains unit price of materials and labor, it will be input and linked to components of 3D model by Dynamo. To track the elements in Revit model by the information in excel, coding system is proposed. For material and labor unit price, masterformat is referred to track the right elements for the corresponding unit price. Unit price is the reference of cost calculation formula. The calculation is done by algorithm programming in Dynamo.

BOQ is the output spreadsheet by Dynamo after price linked to Revit model. So it is connected with unit price closely and the calculation is done in Dynamo by designing visual programming. In BOQ, the quantity is gathered from default information in Revit

and calculation formula with unit price. Finally dynamo exports the cost and quantity of project to Excel as BOQ.

For schedule plan, customized codes are proposed to track the elements included in schedule activity. This customized codes are helpful to assign schedule date in right elements of model. Schedule date provides the progress information on cost and payment. With the customized codes, the schedule activity have to be categorized by the element base which can corresponds with elements in 3D model.

Finally the construction records are designed for many objectives. Firstly, construction report includes the schedule plan, cost plan and payment plan, actual cost information, actual payment status and so on. Secondly, the construction report will be the resource data of S-curve to support cost monitoring output for cost analysis. Thirdly, the actual information in construction report is designed for recording in construction site based on the actual construction working progress, including actual data of activities, actual cost and payment status information. Finally the data in construction records on time, cost and payment are input in 3D model by Dynamo. In a summary, the relationship among the spreadsheets and main contents inside are summarized in Figure 3-5 below:

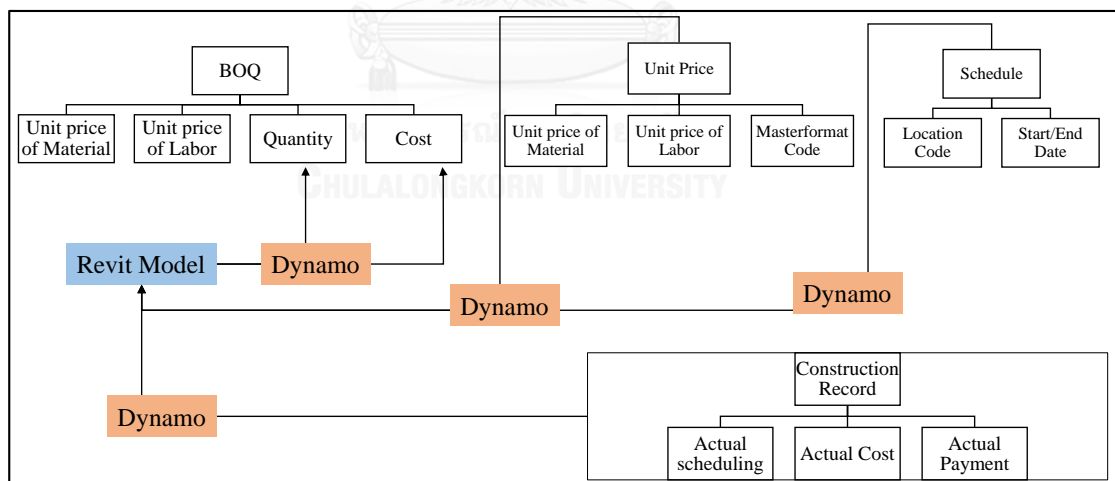


Figure 3-5: Relationship and Calculation among Unit Price, BOQ and Construction Report

From the Figure 3-5, Revit model stores most information, including cost, schedule and so on. The input information are used to serve the Revit model, and these spreadsheets are connected by Revit model at the same time which a mutual relationship. Based on the interview results and during the real system development, the spreadsheets may

change and increase. The output spreadsheets may also change and increase to make the system more precisely and practicable. Finally the most important part is the linkage between spreadsheets and Revit 3D model, this system proposes the dynamo to link the information together by visual programming. The linkage programming are introduced detailed in following chapters.

3.4.3 Revit Parameters

Initial 3D model just contains default information, such as dimension, family, type and so on. To communicate with Excel and attach more information to achieve the system, more parameters should be defined and added in Revit. So far, the parameters should consider these information: unit price of material and labor, scheduling date, scheduling activity code, cost of material and labor, payment date and so on. The Revit model is updated and improved by parameter value which is the properties of Revit model. Dynamo assigns the value from excel to Revit and output calculated value back to excel from 3D model adversely.

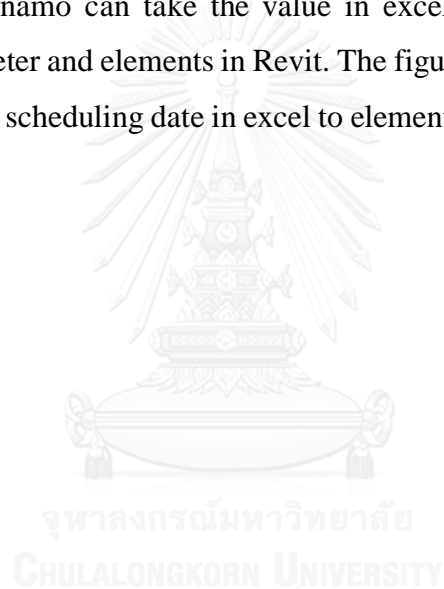
3.4.4 Dynamo Programming Design

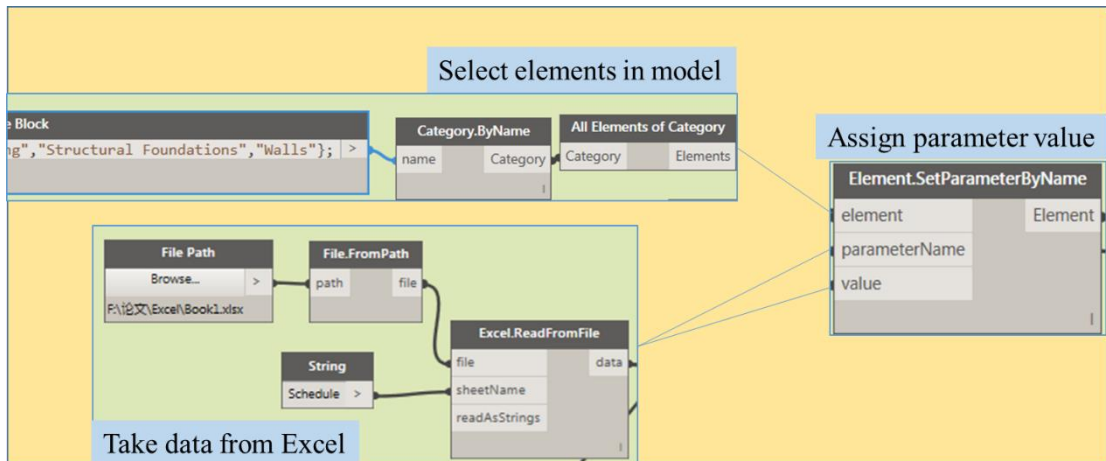
Dynamo is an open-source visual programming application that interacts with Revit to extend its parametric capabilities which connects the whole cost and payment monitoring by interacting and communication between Excel and Revit. It refers the ability to link creative problem solving with powerful computational algorithms to automate, simulate, script, parameterize, and generate design solutions (Autodesk Help, 2014). Dynamo has powerful data processing capability which is able to have a customize design. Dynamo programming is made up by nodes and wires. Nodes are connected by wires.

The objective of using Dynamo is to link the information between Revit and excel, so that the data can be input, calculated and output in excel. Secondly, Dynamo also generates the data from Excel and Revit to classify elements in Revit to figure out project's cost and payment progress status and visualize progress status in Revit model. Visualization is achieved by filtering the elements in Revit with parameter values and assign the color scheme to corresponding elements. For specific objectives from dynamo are summarized below.

- 1) Assign unit price to Revit
- 2) Assign the schedule to Revit
- 3) Output BOQ based on different objective and hierarchy and cost plan.
- 4) Filter elements based on the schedule and cost parameters value to show: delayed elements, over budget elements, unpaid but finished elements, and unapproved elements.
- 5) Calculate corresponding cost during filtering different progress status, such as earn value, cost of unpaid elements and unapproved elements.

For example, the Dynamo can take the value in excel and assign the value to the corresponding parameter and elements in Revit. The figure 3-13 shows the overview of Dynamo to assign the scheduling date in excel to elements with corresponding location code.





Overview of scheduling date assigning

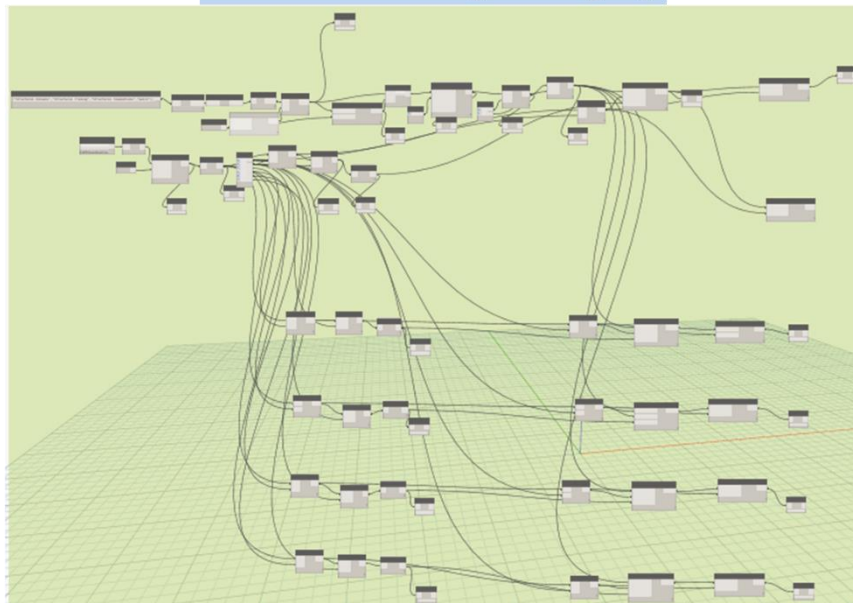


Figure 3-6: Example of Dynamo: Assign Schedule Date to Revit

This way assigns the value in excel to parameters in Revit, and the linkage is automatically updated by only updating the value in excel, then the parameter value in Revit can be updated synchronously. For example, all unit price of concrete in Revit model can be changed by just changing the data in Excel and Dynamo could automatically synchronize the changed to corresponding elements and parameter value. The related cost of materials and elements are also changed by the formula existed in Dynamo at the same time. The value of parameter in Revit is like below in Figure 3-7, taking a column to be this example in Revit.

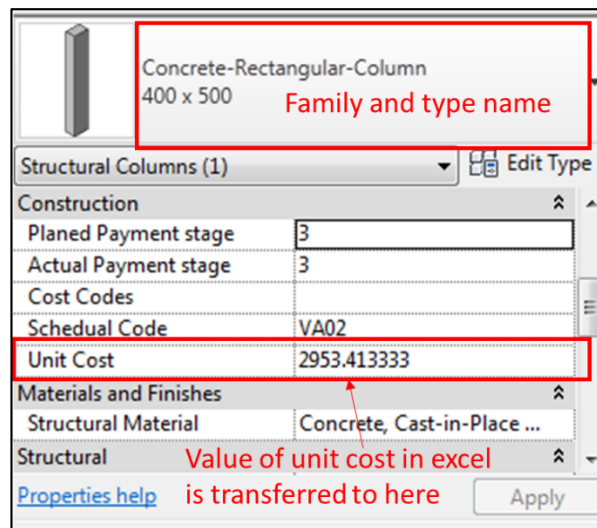


Figure 3-7: Parameter Value after Assigned in Revit (column example)

Dynamo visual programming is the most difficult and important part for this system. There is no connection and communication between Revit and excel without Dynamo. Visual programming in Dynamo is designed and describes during 5D BIM system development.

3.4.5 Verify and Validate System

Verification and validation are independent procedures that are used together for checking that whether a system meets requirements and specifications and that whether it fulfils its intended purpose. Verification is intended to check that whether a system meets a set of design specifications. Validation is intended to ensure a system results in a system that meets the operational needs of the user (Hojo, 2014). In this research, the requirements on the system result is to export the right quantity, cost and payment information in Excel, and system visualizes the right cost and payment progress in Revit. It contains two parts to test the accuracy of the system result. One part is to test whether the quantity and cost information output from system is correct or. This is tested by comparing between proposed system result and real system result (manual calculation). Second part is the verification which is used to check the result of system compile with the expected requirements on visualization. It is internal comparison by checking whether the system visualizes the required progress status after changing input parameter values. With the two parts testing, verification and validation, the result of system can be acceptable and feasible.

3.5 Summary

This chapter is about methodology of this research to show how this research is promoted. This research starts from literature review for knowledge and technology background of cost and payment monitoring. Then it explores the practical process on cost and payment monitoring by interviewing. The next step is to develop this system with a sample, including visual programming design in Dynamo, the parameters design in Revit and spreadsheets design in Excel. Finally verification and validation are took to test the system result. This chapter has described the rough process of research.



CHAPTER 4

EXPLORE CURRENT PRACTICE ON COST AND PAYMENT MONITORING

To explore the current practices on cost and payment monitoring, interview is followed after literature review. This chapter explains the 2 parts, result of interview, and discussion on the result of interview related to the following proposed 5D BIM system. The result of interview describes the current practice on cost and payment monitoring process, and the lists out different ways from interviewed companies processing related documents. The process starts from the preconstruction to the construction stage. Preconstruction stage including processing quantity takeoff, BOQ, schedule plan, cost plan and payment plan. Construction stage includes monitoring actual scheduling and finished works, monitoring actual cost, and monitoring actual payment progress. Later on, the results were compared and summarized on the different ways of interviewed companies to process the output during the whole monitoring process. The specific examples of the ways are provided for better understanding and comparison. Second part is the discussion of the interview result, it aims to find out the suitable ways to monitor cost and payment progress in 5D BIM system. Basically, the most common practices are selected for 5D BIM system. However, the most common practices cannot match with BIM property, this research proposes other suitable way to match with 5D BIM property for these cases if the common practices are not suitable to BIM way. This discussion provides a guideline and reference to develop 5D BIM system.

4.2 Interviewee Introduction

There are 6 companies involved in this interview, most of them are the contractors. The interview location focus on Bangkok and the interviewed roles focus on contractors. The interview information is summarized below in Table 4-1 Table 4-1.

Table 4-1: Interview Information Summary

Interview Information			
Number of Interviewees	6	6	6
Company Types	4 Contractors	1 Developer	1 Consultant
Location	Bangkok	Bangkok	Bangkok
Interviewees position	4 Cost managers	1 BIM manager	1 Operator
Way of Interview	Face to face	Face to face	Face to face

4.3 Result of Interview

There are 6 representatives from different companies who participated in this interview. The interview aims to explore the current practice of companies to monitor cost and payment. The interview result describes the cost and payment monitoring process in current practices of these companies, and the differences on how companies process output during cost and payment monitoring are listed out.

4.3.1 Current Practice on Cost and Payment Monitoring Process

According to the interview, the cost and payment monitoring process on current practice of companies is summarized in Figure 4-1. It describes the input, and output of every steps in cost and payment monitoring process.

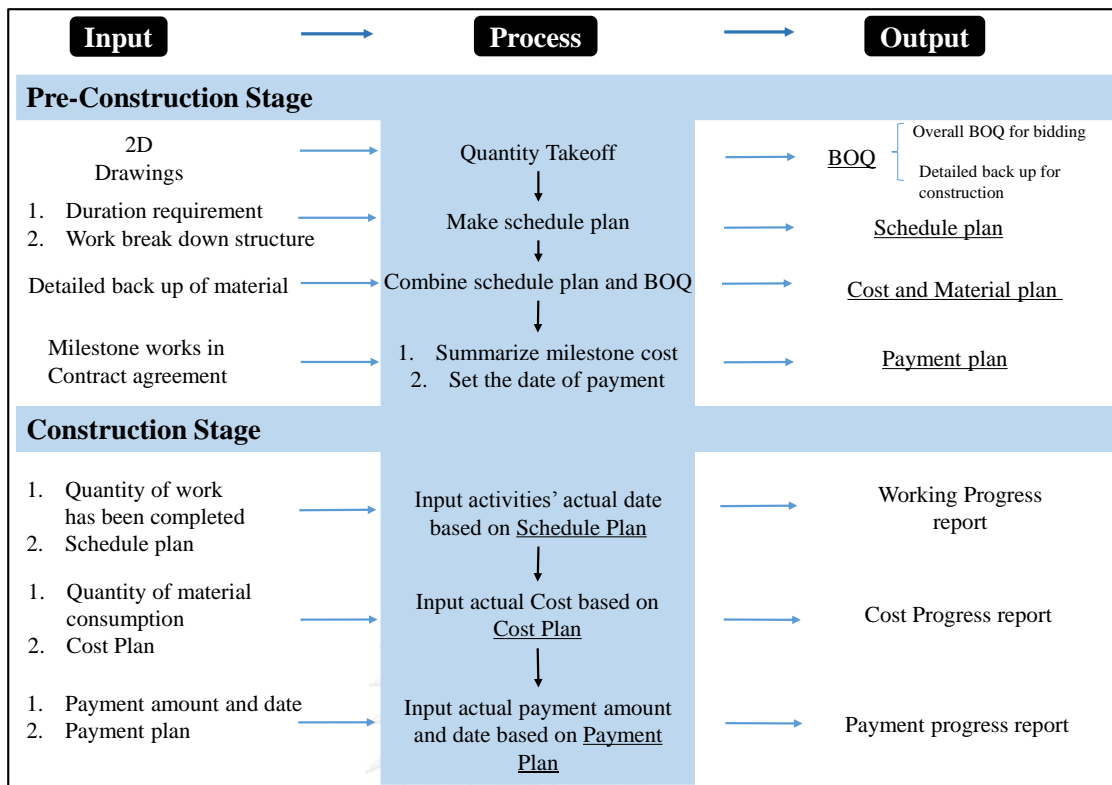


Figure 4-1: Process of Cost and Payment Monitoring in Current Practice

In Figure 4-1, the cost and payment monitoring process has 2 stages, preconstruction stage and construction stage. Preconstruction stage is to establish the baseline for monitoring cost and payment during construction stage. In preconstruction stage, first step is that contractor takes off the quantity based on the design result from designer in 2D drawings. BOQ is worked out based on price and quantity takeoff. Secondly contractor makes schedule plan based on the requirements from owner on duration. Thirdly is to get the cost plan based on detailed BOQ and schedule plan. Cost plan provides the baseline for the cost monitoring during construction stage. Finally, payment plan is made by summarizing the cost in a fixed period from cost plan. The period is determined by the payment methods, such as milestone payment method and progress payment method. Thus all documents are prepared in preconstruction stage: BOQ, schedule plan, cost plan and payment plan.

In the construction stage from Figure 4-1, contractor needs to track the three matters: working progress, cost progress and the payment progress. Firstly, contractor monitors the working progress by checking finished works quantity and comparing it with schedule plan. The output is working progress report. Secondly, the actual cost for the

finished works are monitored to compare with the plan cost of finished works which shows the cost progress status. Finally recording the actual payment amount and date to compare with payment plan to report payment progress. This is the whole process of current practice of companies on cost and payment monitoring.

In the following part, the details of every steps on the input, sub process and output are described step by step. Based on the Figure 4-1, cost and payment monitoring is divided into two stages which are preconstruction stage and construction stage.

In Preconstruction stage:

- 1) Taking off quantity
- 2) Scheduling
- 3) Making cost plan
- 4) Making payment plan

In Construction stage:

- 1) Recording working progress information
- 2) Recording actual cost information
- 3) Recording actual payment date and amount

4.3.1.1 Pre-Construction Stage

4.3.1.2 Taking off quantity

At the beginning, contractor gets the 2D drawings from designer, including the specifications and requirements. The first step to get the cost of project is to take off the quantity. In this research, there are concrete, steel and formworks in structural part quantified. For the concrete volume, 2D drawings give the required structural volume information. So the volume of concrete can be easily get from the 2D drawings, cooperated with plan view, elevation view and detailed view. Steel and formwork quantity calculation differentiate from company to company, project to project. Quantity takeoff is to provide the quantity for BOQ, so work breakdown structure of quantity takeoff should take reference from BOQ and the work breakdown structure is

different among these interviewed companies. The differences are listed in next part of comparison on quantity takeoff.

4.3.1.3 Preparation of Schedule Plan

The schedule plan is prepared based on the requirements from client and properties of project. And the BOQ provides the cost and quantity basement to schedule plan. The schedule plan is used to instruct the construction progress and materials order. According to the interview, the work breakdown structure and time unit are almost different from company to company and from project to project. For example, some structure of schedule plan is based on the materials, some are physical properties, some are sequence of construction methods, and etc. Schedule plan also establishes the baseline for monitoring working progress in construction stage.

4.3.1.4 Preparation of Cost Plan

Cost plan takes the cost information from BOQ and time information from schedule plan. According to the cost of every activities in schedule plan, the cost in progress is calculated over time. However, the most companies don't calculate the cost plan very accurately and precisely. The level of precise on cost plan is restricted by time limit and also BOQ. Moreover, the work breakdown structure of cost plan is different from project to project. It is also important to know how they combine the two documents to be cost plan. In the next part, there is a comparison among these interviewed companies on cost plan.

4.3.1.5 Making Payment Plan

The contract restricts the method of payment which determines the way to make payment plan. Normally, there are two common payment methods: milestone payment and progress payment (Every month). To make the payment plan in milestone payment method, contractor should figure out the milestone works of project, and calculate the quantity and cost of every milestone works, or check it from the BOQ. Then check the schedule plan to set the plan date of milestone payment. Another payment method: progress payment. Contractor gets payment from owner in every month, it summarizes every month's cost as payment amount, or it takes quantity percentage of finished work

as payment percentage towards total cost. Or it uses the duration percentage times total cost to be as payment amount.

There are several payment amount calculations in industry. The trend towards contractor self-monitoring of progress, and greater use of contractor invoicing, and milestone and lump sum payments to streamline the reporting and payment process (DeWitt et al., 2015). Under a lump sum contract the contractor prepares and submit monthly pay estimates based on progress as a percentage of the lump sum prices, instead of detailed measurements of actual quantities (American Association of State Highway Transportation Officials et al., 1997). In the following part, the payment amount calculations that interviewed companies used are summarized, and the structure of payment plan and payment method are compared among interviewed companies as well.

4.3.1.6 Construction Stage:

4.3.1.7 Recording Working Progress Information

The objective of this process is to measure the completed works in current status to know the working progress. Construction site measures the quantity of completed works in every period. Normally, the way to record working progress starts from checking the construction site working and remarking on 2D drawings. With the remarked working, checking the finished works and plan finished works from schedule plan to get the working progress based on quantity. Earn value is calculated by checking or calculating plan cost of remarked working in 2D drawings from BOQ. Earn value is to report the working progress based on cost. The whole process is showed in the Figure 4-2. And the current practices also exist the different way to get the working progress. The output of this process is report of working progress to show the earn value and whether the project is delay or within schedule plan. However, the actual progress report is much different from company to company. So the actual working progress report is compared in the next part.

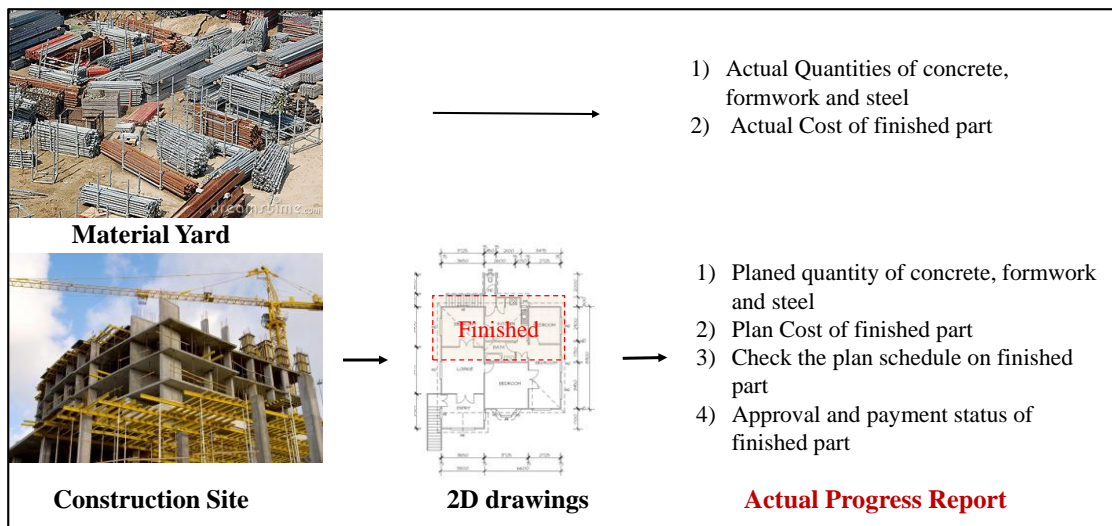


Figure 4-2: Process of Inputting Working Progress Information

4.3.1.8 Recording Actual Cost Information

The objective of this process is to record the actual cost over time and compare it with cost plan to get actual cost progress report. The report helps cost manager to analyze and grasp the financial situation and progress. In this research, actual cost includes the material cost and labor cost of the structure part. There are two actual cost sources: one is from the pay bills to subcontractors and suppliers, another is from the unit price of materials and actual quantity of material consumption. Contractor records the materials consumption, but the role of recording is not the same. Some companies record the actual cost from construction site, while some other companies record the actual cost from accounting. So at the following part, the recording role and the recording content are compared among the interviewed companies. If the company record the quantity of material consumption from construction site, the actual cost progress is calculated by the price of materials and labor timing the quantity. So the way is up to the company's regulation on authority of construction site whether they are permitted to control cost. Moreover, the structure of cost progress report is still different from company to company. The time unit of cost progress could be day, week and month according to the interviewed companies' information. The differences on way to monitor actual cost and time unit of monitoring actual cost are compared and discussed in the following part.

4.3.1.9 Recording Actual Payment Amount and Date

The objective of this process is to record the current payment progress by recording payment amount and payment date. Base on the payment plan mentioned above, there are several payment methods which determines the actual payment amount and date. For progress payment, the payment amount could be the cost of actual finished works or finished works' percentage of the total cost. During construction stage, contractor gets the payment from owner based on working progress and payment method. The amount of payment normally keeps the same in the BOQ if there are no any change orders. There are several steps for contractor to get the payment from owner. In FIDIC, there are 3 important dates for progress payment, date of application for payment, the date of payment approval and date of receiving payment. The above issues that different payment methods and payment amount calculation rules are compared in the next part.

4.3.2 The Comparison of Interview Results among Interviewed Companies

Besides the common process among these interviewed companies, there are some comparison on every steps and output during cost and payment monitoring. Cost and payment monitoring cannot be achieved without the detailed information on every process. This comparison aims to list the main options provided by interviewed companies on processing output to monitor cost and payment, and compare these options in details. This part includes the comparison of interview result on input, process and output in every step from Figure 4-1.

4.3.2.1 Quantity Takeoff

This part summarizes the comparison result on quantity takeoff from interview. The difference mainly appear on work breakdown structure of quantity take off, calculation formula, the software used. In addition, the options of work breakdown structure are element type, building physical, and Material. The formulas to calculate the quantity for different materials are compared. In fact, the formula chosen determined the level of details on the quantity take off, since the formula determined the precise level of quantity takeoff result. The result of comparison is summarized in Table 4-2. In Table 4-2, it shows all factors for comparison, the options of corresponding factor, and the

corresponding companies which chose this options. 1-6 represents the each interviewed companies respectively.

Table 4-2: Result of Comparison on Quantity Take off

Quantity take off			
Compare Factor	Option level 1	Option level 2	Company included
Work breakdown structure (WBS)	Element type base		1
	Building physical base	Material	1,2,3,5,6
	Material base		2,3,4
Calculate formula	Concrete	Volume of element	1,2,3,4,5,6
	Formwork	Precise calculation	2,3,4,5,6
		Ratio	1
	Steel	Precise calculation	5,6
		Ratio	1,2,3,4
BIM	Yes		5
	No		1,2,3,4,6
Applications	Revit		5
	CAD		1,2,3,4,6
Code	Unifomat		2,3
	Master format		
	No(customized codes)		1,4,5,6
Result	Excel		1,2,3,4,5,6

For the WBS of quantity takeoff in Table 4-2, company 2 and 3 use building physical base and material base both, it means they need to summarize the quantity takeoff for two types. They need to have quantity takeoff result based on materials and floors. Physical base means the size and structure of building, such as the zone and floor of building. Company 5 used Revit to take off quantity too, they put the rebar in Revit model to get the precise quantity of rebar. However, this way takes much time to put rebar into model. The representative of company 5 mentioned that it is huge works to put rebar in Revit and it is even more than manually calculations. For quantity take off, not many companies apply the standards codes. Only company 2 and 3 use the unifomat. At the end, the result pattern of quantity takeoff is shown in Excel for all interviewed companies.

- 1) Work break down structure for quantity take off

There are three main bases of category for quantity take off result which are element type base, physical base and material base. Later on, there is an example for every type of quantity take off result to figure out the differences.

In above table, the element type base means that the first level of work breakdown structure is based on element type to categorize the building. For the element type base, column, beam, slab and structural wall are the element types in building project. So that the quantity of every element type have to be calculated one by one. Then gather all quantity of every element type. The result is like in Table 4-3.

In this type of WBS for quantity take off, the unformat can be applied for element type. In the Table 4-3, for every type of element, there are still some subcategories. So there is the second level for every element type, for example, column has Columns – CIP, Columns – Precast, Columns – Steel, Columns – Wood.

Table 4-3: Example of Element Type Base for Quantity Take off (Unformat code)

Quantity Take off (Element Type)			
Code(Unitformat)	Element type	Quantity	Unit
A1010	Foundation		
B1010240	Column		
B1010310	Beam		m ³
B1010410	Slab		m ³
B1010210	Structural wall		kg

The physical building base is to category building components base on the physical property of building like the foundation and the superstructure. And for superstructure, it is broken down as floors or zone. The example is showed in Table 4-4. There is no standard code for this kind of work breakdown structure, but this way is good for schedule plan which usually breaks down project by the building physical properties as well. Second level is the element type and final is material type. This hierarchy is normally used to the schedule plan and material order.

Table 4-4: Example of Quantity Take off based on Physical Property

Quantity Takeoff (Physical Property)			
Object	Quantity	Unit	Level 2
Superstructure			
Floor 1-10			
1st floor Zone A		m ³	1 st floor Beam & Slab
			1 st floor Column & Wall
1st floor Zone B		m ³	1 st floor Beam & Slab
			1 st floor Column & Wall
1st floor Zone C		m ³	1 st floor Beam & Slab
			1 st floor Column & Wall
2nd floor Zone A		m ³	2 nd floor Beam & Slab
			2 nd floor Column & Wall
2nd floor Zone B		m ³	2 nd floor Beam & Slab
			2 nd floor Column & Wall

The last type is material base for quantity takeoff which means the work breakdown structure is categorized by material type. Materials are cast-in-place concrete, precast concrete, and reinforcing steel, concrete formwork for structure part in this example in Table 4-5. The code is from CSI masterformat which also takes the material of building as the category base (Construction Specifications Institute, 2014).

Table 4-5: Example of Material base for Quantity Takeoff

Quantity Take off (Material Type)			
Code(Masterformat)	Item	Quantity	Unit
033000	Cast-in-place Concrete		m ³
034000	Precast Concrete		m ³
032000	Reinforcing Steel		kg
031000	Concrete Formwork		m ²

2) Calculate formula for quantity take off

Concrete quantity is just from the volume of every objects. There is one thing need to be emphasized out is that the ratio applied in formwork and steel. The result of whether companies apply ratio or not is pointed out in Table 4-2. For some irregular shape element, they calculate manually and approximately. The exact ratio of formwork and

steel that the interviewed companies used are referred to 5D BIM quantity take off. The exact ratio is summarized in next part about BIM material calculation formula table. As for the ratio of steel, there are two companies calculate the rebar precisely on the design drawings to get the precise quantity of steel. The others apply the ratio to calculate the rebar. So common choices are precise calculation for concrete and formwork, ratio for steel.

4.3.2.2 Bill of Quantity (BOQ)

This part compares and summarizes the interview results on processing BOQ based on quantity takeoff and price. There are different types of BOQ for contractor based on different purpose. In most cases, the 3 BOQ types are bidding, purchasing, and construction budget. The result of companies' option on different purpose of BOQ is showed in Table 4-6. All the companies needs the BOQ for bidding to client and the cost is highly summarized from purchasing BOQ (plus markup) since owner doesn't need the details of construction expenses at bidding stage. So there is no bidding BOQ in comparison Table 4-6.

Table 4-6: Result of BOQ Comparison

BOQ		
	Compare factors	Company included
Purpose	Purchasing	1,2,3
	Construction budget	1,2,3, 4,5,6
	Master format	2,3,4
Code	Customized Code	5,6
	No	1

Purchasing BOQ is based on the materials to order the materials. Construction budget BOQ is used to guide the construction progress and the budget is the internal cost of contractors to instruct the construction works.

1) BOQ for Purchasing

The purchasing BOQ is used to instruct material ordering, so that the structure of purchasing BOQ is categorized by the material type and sum the quantity of every materials. Moreover, the quantity should be separated and grouped according to the

schedule plan, in case that some materials will not order huge quantity at once. So materials are separated by the size of building as well, like the concrete is grouped by every 10 floors or 5 floors. In another case, some companies order the material at the beginning for whole project, but the consumption is recorded during construction in details. There is an example of purchasing BOQ structure in Table 4-7 which is grouped by the type of materials by every 10 floors.

Table 4-7: Example of BOQ for Purchasing

BOQ (purchasing)					
Code(Masterformat)	Item	Quantity	Unit	Unit Price	Cost
Superstructure					
Floor 1-10					
03300000	Concrete 140pcf		M3		
03500000	Concrete 175pcf		M3		
03200000	Steel		Kg		
06000000	Formwork		M2		

2) BOQ for Construction Budget

The BOQ for construction method is mainly built for the construction site instruction. It mainly focuses on the elements type of building components. The level of details depend on the schedule plan since the construction budget BOQ aims to guide construction. The materials are distributed clearly on every floor in every schedule activity, such as the concrete quantity in 1st floor. There is an example of BOQ for construction budget in Table 4-8 which is grouped by the floor and schedule activity.

Table 4-8: Example of BOQ for Construction Budget

BOQ (Construction Budget)											
Item			Quantity	Unit	Total Cost	Material		Labor			
						Unit price	Cost	Unit price	Cost		
Piling											
Structure											
Floor 1	Concrete	Material codes	420ksc		M3						
		Material codes	350ksc		M3						
	Steel	Material codes			kg						
	Formwork	Material codes	Post-tension		M2						
		Material codes	Ordinary		M2						
Floor 2	Concrete										
	Steel										
	Formwork										
...											
Architecture											
External Works											

4.3.2.3 Preparation of Schedule Plan

This part compares the differences on preparation of schedule plan, lists of the different schedule plan types. After quantity take off and BOQ, the schedule plan is developed. On the aspect of work breakdown structure, according to interview, there are two main types of schedule plan as contractor. One is generally setting the floor as the unit of schedule, and another is by the sequence of construction methods. The two types may be subcategorized by more details. The type of schedule is up to the contractor's demand on level of details of schedule. Contractor will choose the rough schedule which is categorized by floor only if the project is very big and construction methodology requirements are not high, or contractor doesn't have much time in pre-construction stage. Or contractor will choose the detailed schedule plan which is categorized by the elements of building and construction methods. Construction site could be instructed on constructing method by this schedule plan, so schedule manager can control the progress more accurately. The comparison result of the interviewed companies' options on schedule plan is showed in Table 4-9.

Table 4-9: Result of Comparison on Schedule Pla

Schedule Plan		
Compare factors	Company included	
Work breakdown structure	Rough	1,2,3,4,5,6
	Construction sequence	2,3,5,6
Time unit	day	3,5,6
	week	1,2,4
	Month	
Codes	Yes	4
	No	1,2,3,4,5,6
Software	Excel	1,3,4
	Primavera	2
	MS Project	5,6

The example of rough schedule plan is in Table 4-10, the detailed schedule plan is in Table 4-11. As for the unformat and masterformat applying on BOQ in current practices, some company apply the masterformat in BOQ as the communication codes with other roles, like subcontractors and different disciplines' engineers. There is only company 4 who applied the schedule codes for schedule plan. And company 5 also mentioned that they should use codes for schedule plan. So in fact the codes are not applied commonly by most companies since there is no standards codes for schedule in industry. The schedule code is proposed in the following 5D BIM system.

Table 4-10: Example of Rough Schedule

Schedule Plan (Rough)						
Activity	Plan start	Plan end	Duration	Actual start	Actual end	Cost
Superstructure						
Floor 1-10						
1 st floor Beam & Slab						
1 st floor Column & Wall						
2 nd floor beam & slab						

For rough schedule, in fact most companies just take the floor as the unit of schedule plan. During the real practices on schedule plan, they don't really need too detailed schedule because the real construction is hard to follow the plan strictly. Table 4-11 shows the schedule plan based on sequence of construction method.

Table 4-11: Example of Schedule based on Construction Sequence

Schedule Plan (construction sequence)					
Activity	Plan start	Plan end	Duration	Actual start	Actual end
Superstructure					
Floor 1					
Tie beam rebar					
Set beam formwork					
Pour beam concrete					
...					

Microsoft Excel, Primavera, or Microsoft Project are the common tools for scheduling. And it is in Gantt chart to be more understandable.

4.3.2.4 Making Cost Plan

This part describes different ways to combine cost and schedule to make cost plan from interview. Cost plan is built by combining the BOQ and schedule plan. BOQ provides the cost and schedule plan provides progress. Time plus cost forms the cost progress plan. The general cost plan forming is showed in Figure 4-3.

There are two different ways to plan the cost since the confidential property of cost, one is planning by the cost directly from construction site control. Another one is planning by the quantity of materials from construction site in accordance with schedule, then the head office calculates the cost progress based on the quantity of material and working progress from construction site. The two different ways lead the difference on actual cost report on construction site during constructing, the differences are introduced later in actual cost progress report part. The result of cost plan comparison is in Table 4-12.

BOQ(Construction budget)					Schedule plan			
Item	Material	unit	Quantity of mat	Cost	Activity	Week 1	Week 2	Week 3
Floor 1					Superstructure			
Column	Concrete 140pcf	M3			Floor 1-10			
	Steel	Kg			1 st floor Beam & Slab			
	Formwork	M2			1 st floor Column & Wall			
Slab	Concrete 175pcf	M3			2 nd fl beam & slab			
	Steel	Kg						
	Formwork	M2						

Quantity Or Cost

Cost Plan(Material)					
Material	Quantity in Week 1	Quantity in Week 2	Quantity in Week 3	...	Total Quantity
Floor 1					
Concrete 140pcf	50(16.7%)	50(16.7%)	50(16.7%)		300
Concrete 175pcf			40(20%)		200
Steel	100(20%)	100(20%)	200(40%)		500
Formwork	1000(14.3%)	1500(21.4%)	3000(42.8%)		7000

Figure 4-3: Example of Cost Plan Combination from BOQ and Schedule Plan

Table 4-12: Cost plan Comparison Result

Cost Plan		
Compare factors	Company included	
Work breakdown structure	BOQ base	1
	Activity base(schedule)	2,3,4,5,6
Quantity or Cost base in construction site	Quantity	1,2
	Cost	3,4,5,6
Time unit	Day	5,6
	Week	1,2,3,4

The correlation between BOQ and schedule plan is based on the WBS of cost plan. However, there are still more than one type for schedule and BOQ respectively. Like above mentioned, there are rough and detailed schedule plan in Table 4-10 and Table 4-11, and there are purchasing, and construction budget type of BOQ. Here provides the example of cost plan which use the physical property based schedule as reference. The example is in Table 4-13, and the another example of cost plan which take construction budget BOQ as the reference is in Table 4-14. The time unit of two examples are based on the week.

Table 4-13: Cost Plan based on Schedule

Cost Plan (Schedule)					
Activity	Cost in Week 1	Cost in Week 2	Cost in Week 3	...	Total Cost
Superstructure					
Floor 1-10					300
1 st floor Beam & Slab	500	500	400		200
1 st floor Column & Wall	100	100	200		500
2 nd floor beam & slab	1000	1500	3000		7000
...					
Total	44,000	55,000	70,000		120,400,000

The detailed information in last row 'total' means the planned cost in every week and the general total cost is in the end. Every row means the cost for specific activity in every week. This is the detailed cost plan based on schedule progress. Every week's cost of specific activity is calculated by checking schedule plan for components included in activity and BOQ for cost of above components. They have to group out the quantity of components in every activities and track back materials and labor of these components in BOQ. This is a recalculation process and repeating to check between BOQ and Schedule plan.

The same rule as BOQ based on cost plan in Table 4-13, only the object of cost is the material. So every row represents the weekly cost for every materials. They have to check the quantity of each materials included in this activity.

Table 4-14: Cost Plan based on BOQ

Cost Plan (BOQ)						
Item	Material	Cost of week 1	Cost of week 2	Cost of week 3	...	Total
Floor 1						102,000
Column	Concrete 140pcf	700	500	500		
	Steel	3,000	4,000	2,500		44,000
	Formwork	300	500	500		
Slab	Concrete 175pcf	700	700	500		
	Steel	2,000	2,500	3,000		58,000
	Formwork	400	500	300		
...						
Total		70,000	85,000	67,000		120,400,000

4.3.2.5 Making Payment plan

This part describes the differences of interview result on how to making payment plan and the different content in payment plan. After the cost plan finished, the payment plan is determined by the cost plan progress and the payment methods in contract conditions. There are two main payment methods, milestone payment and progress payment as mentioned above. The result of payment methods that companies using is showed in Table 4-15.

For the milestone payment, the payment point is based on the milestone works. So that the payment is summarized by every milestone time point according to the cost plan. There is an example of how the payment plan get from cost plan in Table 4-15.

Table 4-15: Result of Payment Plan Comparison

Payment Method	
Compare factors	Company included
Milestone payment	1,2,3,5
Progress payment	4,5,6

For company 5, they said mostly they check payment every month, but the milestone works are also checked to control the whole duration of project. The period of milestone is longer than the monthly which is based on contract. It means the owner pay them in every fixed date of month, and contract also set the milestone works to control the total period and ensure the project finish on time.

Cost Plan(Material)					
Material	Cost in Month 1	Cost in Month 2	Cost in Month 3	...	Total Cost
Floor 1					
Concrete 140pcf	50(16.7%)	50(16.7%)	50(16.7%)		300
Concrete 175pcf			40(20%)		200
Steel	100(20%)	100(20%)	200(40%)		500
Formwork	1000(14.3%)	1500(21.4%)	3000(42.8%)		7000
...					
Total		545,000	566,000		

Payment Plan		
Payment date	Payment amount	Status
Month 2	545,000	Finished
Month 3	566,000	Active

Figure 4-4: Example of Payment Plan

4.3.2.6 Recording actual working progress

This part compares the different ways to record actual working progress and lists out the differences. The way to check working progress in the construction site is showed in Figure 4-2. Construction site measures the completed works and remark corresponding objects in 2D drawings. Then they check BOQ with remarked objects in 2D drawings to get the quantity of completed works. There are still some differences among interviewed companies in this process. There are also some differences on the level of details to record finished works, such as element level, floor level, or the construction sequence. The role who record the working progress is different too. The result of this process comparison is in Table 4-16.

Table 4-16: Comparison Result of Recording Actual Working Progress Data

Record Working Progress Data		
	Compare factors	Company included
Measure way	2D Drawings + Quantity	2,4,5,6
	Schedule date checking	1,2,3
Report	Monthly	1,2,3,4,5,6
	As a table	1,2,3,4,5,6
Measure Object	Element	1,4
	Floor	2,3,5,6
	Materials	5
Role	Cost manager	1,2,3
	Site manager, QS, office Engineer	4,5,6
How often	Day	2,3,5
	Week	1,4,6
	Month	1,2,3,4,5,6

1) 2D drawings and quantity

How do they get the quantity of working have been finished? Normally they check the construction site works and remarks corresponding objects in 2D drawings. With the table of quantity take off, they can get the quantity of remarked objects. So they compare the schedule plan with quantity and progress, the working progress report is in Table 4-17.

Table 4-17: Report of Working Progress with Quantity

Working Progress Report						
Activity		Total Quantity	Quantity of Week 1	Quantity of Week 2	Quantity of Week 3	...
Superstructure						
Floor 1-10						
1 st floor Beam & Slab	Plan	1000	500	500		
	Actual	1000	400	600		
	Difference		-100	0		
1 st floor Column & Wall	Plan	1400		600	800	
	Actual	1400		400	800	
	Difference			-200	-200	
2 nd floor Beam & Slab	Plan	3000			500	
	Actual	3000			600	
	Difference				100	

In Table 4-17, this example takes the rough schedule plan (in Table 4-10) as the WBS of the working progress Trace report. In this rule, once they remark the zone of the finished works in 2D drawings, they have to distribute the quantity to different activity works package in the schedule plan, so that quantity of every activity can be calculated to put in Table 4-17. Because, basically, the finished works may be grouped to the several work packages in schedule plan. And the column “difference” in Table 4-17 is accumulative difference between plan and actual. The accumulative difference represents the progress status that whether the work package is delayed or within schedule plan.

2) Check the schedule date without quantity

In this way, the quantity of completed works are not calculated. With the schedule plan, there are two columns for actual start date and actual end date which are used to input the actual working progress data. So in this way, inputting actual working progress data is by inputting the actual date of starting and ending with every activity in schedule plan. Scheduling engineer checks the activities in every time unit. The report of working progress example in this way is showed in Figure 4-5. They transfer this information to be Gantt chart to be more visible.

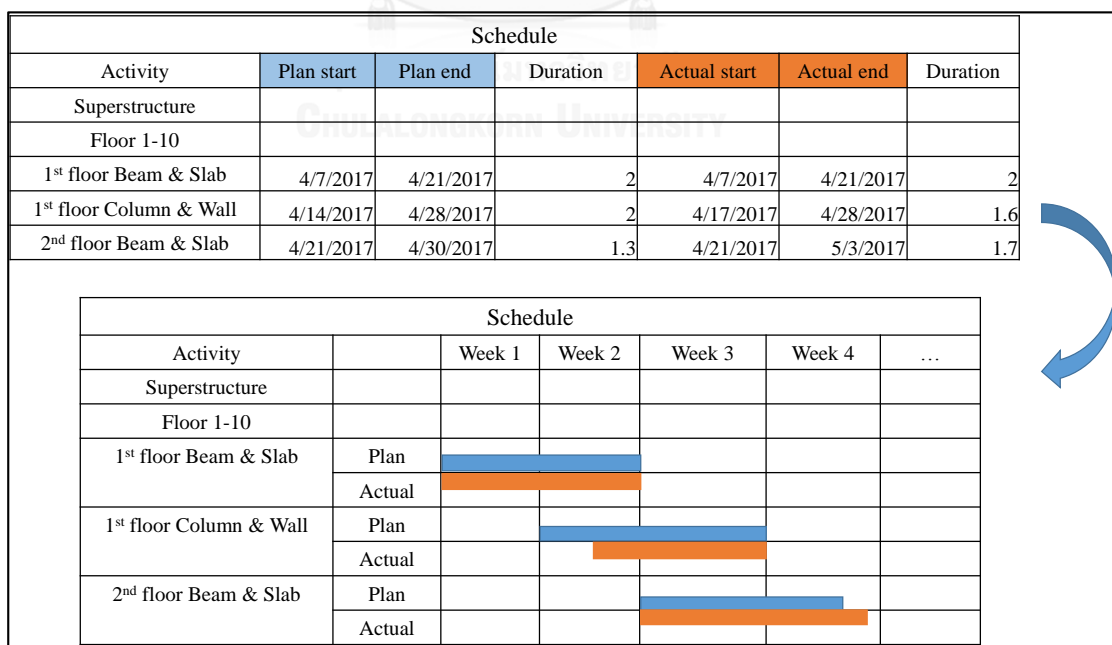


Figure 4-5: Transfer schedule to be Visible Gantt Chart

3) Level of details on trace objects

In above report example, the level of trace object is the element level. But since of the time limit and project size, they also take floor and material level as trace object for working progress. And they trace the working progress every week. For the frequency of trace, some of the interviewed companies check the working progress every day and make the working progress report every month. Obviously, more often you tracing, the more detailed and accurate outcome you will get. There are two recordings of material consumption from company 5. There are two examples of concrete and rebar status recording showed in Table 4-18 and Table 4-19 respectively.

Table 4-18: Example of Concrete Status Report Table

Concrete Status Report									
Concrete	Date	Budget Q to date	Remeasurement			Actual			Waste %
			Accumulative to now	This month	Today	Accumulative to now	This month	Today	
Concrete 420ksc									
Concrete 350ksc									

This table records the concrete consumption quantity every day and accumulative quantity of concrete until current date. So that with this table, cost manager can control and know well on the concrete consumption situation and check the shortage problems on concrete. It is helpful for working progress and cost progress monitoring by supporting cost calculation of used materials. The table of same information for recording rebar is in Table 4-19.

Table 4-19: Example of Rebar Status Report Table

Rebar Status Report												
Item	Month	transfer from other site	local purchase	total this month	last month	accu. This month	this month	accu. Last month	accu. This month	stock	swap	waste
rebar 10												
rebar 12												
rebar 16												

4.3.2.7 Recording Actual Cost

This part describes the way to record actual cost during construction and how to compare with cost plan for reporting cost progress. The result of comparison on inputting actual cost among the interviewed companies is in Table 4-20. It summarized the factors are compared on inputting actual cost and corresponding options and

companies. Firstly, compare factors contain construction authority on cost, the role who record the actual cost, how often, the way to calculate earn value, actual cost's resource and breakdown structure of actual cost report.

Table 4-20: Result of Comparison on Recording Actual Cost Progress Data

Record Cost Progress Data			
	Compare factors	Company included	Remark
Construction site authority	Quantity	2,3	
	Cost	1,4,5,6	
Role	Construction site	1,4,5,6	Construction site authority is only recording the quantity not cost
	head office	2,3	
How often	Day	4,5	
	Week	1,2,3,6	Record cost progress
	Month	1,2,3,4,5,6	Cost Progress report
Earn value	From working progress with BOQ	1,2,3,4,5,6	From BOQ and schedule
Resource of actual cost	Material consumption	2,3	
	Accounting	1,4,5,6	From subcontractors' bill
Breakdown structure of actual cost report	Materials	2,3	Record actual cost based on materials
	Schedule activity	1,4,5,6	Group actual cost based on schedule activity

Firstly, actual cost progress is based on the cost consumption on finished works over working progress. The three factors are connected: construction authority, Role and resource of actual cost. There are 2 options for resource of actual cost, one is cost of real consumption quantity of materials and labor, another one is from accounting records of bill to suppliers and subcontractors. And authority of construction site determines the resource of actual cost and role who input actual cost, so the first resource corresponds to cost authority of construction site and corresponding role is construction site, second resource corresponds to quantity authority only of construction site and corresponding role is head office.

Earn value is calculated in this step. Earn value is the plan cost of actual finished works. According above two ways, earn value is calculated in same rule but difference is on the role who check quantity of finished works and calculate cost from BOQ. The process to calculate earn value is in Figure 4-6. In this figure way 1 is from cost authority of construction site, way 2 is from quantity authority of construction site which needs head office to calculate the cost. The way that how earn value come from

the working progress is showed in Figure 4-7. Based on the quantity of finished works in every week, earn value is the corresponding cost of the finished works which are calculated from data in BOQ.

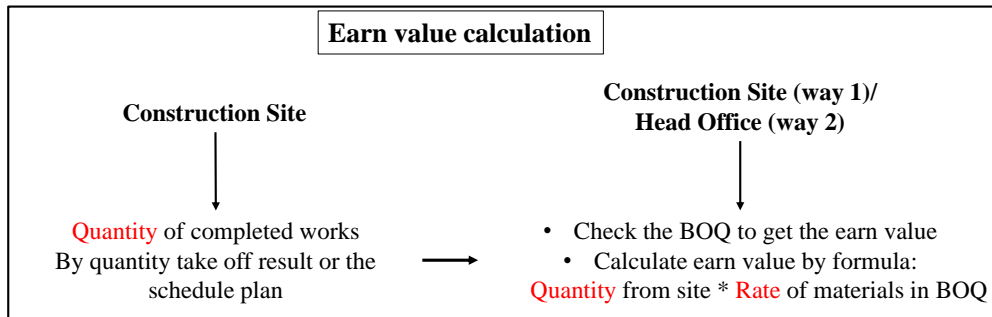


Figure 4-6: Two Ways of Earn Value Calculation

Construction Site ↷ Construction Site (way 1)/
Head Office (way 2)

Working Progress Trace					Earn value				
Activity		Quantity of Week 1	Quantity of Week 2	Quantity of Week 3	...	Cost of Week 1	Cost of Week 2	Cost of Week 3	...
Superstructure									
Floor 1-10									
1 st floor Beam & Slab	Plan	500	500			Plan	1,500,000	1,500,000	
	Actual	400	600			Earn Value	1,200,000	1,800,000	
	Difference	-100	0			Difference	-300,000	0	
1 st floor Column & Wall	Plan		600	800		Plan		1,800,000	2,400,000
	Actual		400	800		Earn Value		1,200,000	2,400,000
	Difference			-200	-200	Difference		-700,000	-700,000
2 nd floor Beam & Slab	Plan			500		Plan			1,500,000
	Actual			600		Earn Value			1,800,000
	Difference			100		Difference			300,000
...									
Total							67,000,000	75,000,000	63,000,000

Figure 4-7: The Process of Earn Value Progress Transformation from Working Progress

Based on the resource of actual cost, there are 2 corresponding break down structure of actual cost progress report. The corresponding examples are showed in Table 4-21 and Table 4-22 respectively. Time unit of actual cost trace is always longer than its cost plan, since the actual cost is from the real payment to suppliers and subcontractors. And the object of actual cost is more rough than the cost plan, for example, the cost plan calculates the cost of column concrete in one floor, but the real payment to the supplier of concrete are used to 10 floors column, beam and slab. So the object of cost is not matching together.

Table 4-21: Report of Cost Progress based on Material Consumption

Actual Cost Progress (Material consumption)						
Material		week 1	week 2	week 3	...	Total
Foundation	Concrete	Actual quantity (m ³)	400	600	800	
		Actual cost	600,000	900,000	1,200,000	
	Steel	Actual quantity (kg)	50	55	70	
		Actual cost	40,000	44,000	56,000	
	Formwork	Actual quantity (m ²)	680	700	700	
		Actual cost	13,600	14,000	14,000	
Labor	Actual quantity (m ³)	400	600	800		
	Actual cost	300,000	400,000	700,000		
Floor 1-10	Concrete	Actual quantity (m ³)				
		Actual cost				
	Steel	Actual quantity (kg)				
		Actual cost				
	Formwork	Actual quantity (m ²)				
		Actual cost				
Labor	Actual quantity (m ³)					
	Actual cost					
...						
Total						

In this type of actual cost report, the actual cost of every time unit (here is week) is calculated by the actual quantity of works times the unit cost. Actual cost is total cost of materials and labor. So in construction site, there are some workers to record the materials consumption and also the materials order, so that materials used on specific activity can be tracked and calculated.

Table 4-22: Actual Cost Progress based on Schedule Plan

Actual cost progress (Schedule)						
Activity		Cost in Week 1	Cost in Week 2	Cost in Week 3	...	Total Cost
Superstructure						
Floor 1-10						
1 st floor Beam & Slab	Plan cost	600,000	900,000	1,200,000		200
	Actual cost	550,000	800,000	1,400,000		
1 st floor Column & Wall	Plan cost					
	Actual cost					
2 nd floor beam & slab	Plan cost					
	Actual cost					
...	Plan cost					
Total	Plan cost	44,000	55,000	70,000		120,400,000
	Actual cost					

In this type of actual cost report, the plan cost in every time unit (here is weekly) is grouped by the activities from schedule plan. The cost is calculated from every material consumption and labor used on this activity multiply its corresponding price. This type of actual cost clearer to know the total cost used on every activity. But the materials consumption cannot be seen in this table. However, to calculate the total of specific activity, the backup calculation calculated the cost of materials and labors for every activity, so the cost of materials and labors can be tracked.

4.3.2.8 Recording Actual Payment Progress Data

This part describes the differences on recording actual payment progress data, including the payment date and amount differences. The differences on this issue among interviewed companies is determined by the payment methods (summarized in Table 4-15 already) and payment calculation.

According to the payment plan, the payment recording is easy, because the frequency of getting payment is at least every month instead of every day or week like in cost plan or schedule plan. Example for milestone payment and progress payment report are in Table 4-23 and Table 4-24. The payment amount is the earn value at the payment checking date. Because the owner pays contractor based on the cost in BOQ of the actual finished works.

The process of how contractors get the payment from owner is showed in Figure 4-8. If the payment method is progress payment that contractor get the payment every month

at the fixed date, the engineer will check and measures the real quantity of the completed works every month, and send to owner for approval. Contractor will get the payment within one month from the owner's approval date. For millstone payment method, payment application date is the date when contractor finished the milestone works, and the other process is the same with progress payment process.

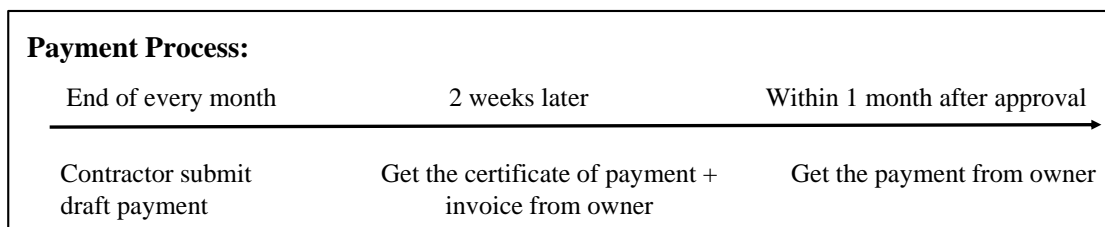


Figure 4-8: Payment Process for Progress Payment

Table 4-23: Example of Milestone Payment Report

Payment Report (Milestone Payment)						
Object	Plan payment amount	Plan payment date	Actual approval date	Actual payment date	Actual payment amount	Remark on change order
Milestone 1	300k	01/08/2016	24/07/2016	28/07/2016	300k	
Milestone 2	900k	01/02/2017	10/02/2017	15/02/2017	1,000k	Add more rooms...
Milestone 3	700k	01/06/2017	01/06/2016	07/06/2016	700k	
...						
Total	4.6m				5m	

Table 4-24: Example of Progress Payment Report (Monthly)

Monthly Payment Report (Progress payment)					
Time	Cost of work finished this month	Work finished %	Accumulative % of project	Accumulative cost of work finished	Total Cost
1 st month		10%	10%		
2 nd month		20%	30%		
3 rd month		20%	50%		
4 th month		20%	70%		
...					
Last month		%	100%		

The owner pays contractor based on the cost in BOQ if there is no any design changes from owner. The percentage in the Table 4-24 is the plan cost of the finished works compare to total cost in the BOQ. There is other rule based on quantity, the percentage

is the quantity of finished works compare to the total quantity of project, and cost is the percentage of total cost. So one is based on cost, another one is based on cost.

$$\text{Quantity base: payment amount} = \frac{\text{Quantity of finished works}}{\text{Quantity of total project}} * 100\% * \text{Total Plan Cost}$$

Equation 1: Payment Amount base on Quantity

$$\text{Cost base: payment amount} = \frac{\text{plan cost of finished works}}{\text{total plan cost}} * 100\% * \text{Total Cost} = \text{Plan Cost of Finished works}$$

Equation 2: Payment Amount base on Cost

So far, the above part talked about the details on every steps to monitor cost and payment. Different choice must have the different characteristics and effects towards the outcome. In the following part, it discusses the advantages and limitation on current practices and provides suggestions for the 5D BIM system development.

4.4 Discussion on the Interview Result

According to the result of interview, the whole process is clear and the main outcome is given out as well. The summary of main outcomes during the cost and payment monitoring is in Figure 4-9. According to the result of interview, it sets some clear objectives for the following 5D BIM system. So the 5D BIM system should try to get the outcomes in Figure 4-9 too. However, for every output, the current practices have different content, structure and processing ways. So in the following part, the optimal options for the proposed system based on the current practice are explored.

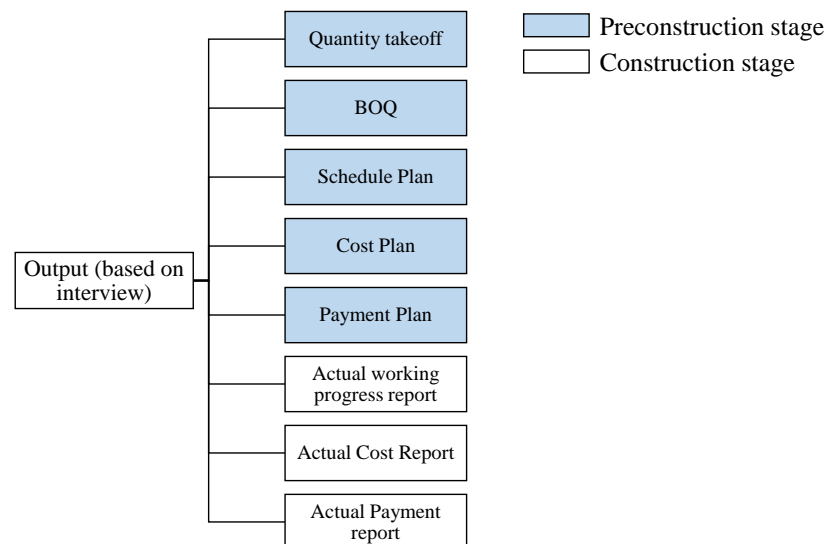


Figure 4-9: Output of Cost and Payment Monitoring based on the Result of Interview

In this figure, there are 5 main documents from preconstruction stage: quantity takeoff report, BOQ, Schedule plan, Cost plan, Payment plan. While there are 3 reports from construction stage, actual working progress report, actual cost report and actual payment report. The following discussion concludes the positive guiding from the current practice and the limitations can be improved by 5D BIM system. Not only the output documents itself is discussed but also the way how to get the documents is also considered. In the following part, the way to get the above output and the content of above output are discussed one by one.

4.4.1 Quantity Takeoff

In this part, the critical aspects are emphasized and discussed to give reference for the proposed system on quantity takeoff. The discussion is summarized in Table 4-25.

Table 4-25: Discussion on Quantity Takeoff

Quantity Takeoff (discussion)			
Factor	Able to refer	Limitations	Options for BIM
WBS	All	Cannot get all WBS base quantity at same time	Get Quantity of every group base
Calculation formula	Ratio for steel		Concrete and formwork calculated precisely
Calculation process		Manual works is too time-consuming	
Codes	Masterformat, unformat		Take both
		Cannot summarize quantity of a random zone freely	

With the comparison in the above part on quantity takeoff in Table 4-2, the most common work breakdown structure is based on the building physical property as the first hierarchy of quantity takeoff. However, the other types of WBS for quantity takeoff are also required, such as element type base, material base. Different type of quantity takeoff can be used for different purpose. For example, the element base of quantity takeoff is helpful for cost plan based on schedule activity. The material base of quantity takeoff is helpful for BOQ. Current practice cannot make multiple type of the WBS for quantity takeoff at the same time. It is possible to achieve different base of quantity takeoff by BIM technology.

In accordance with the calculation formula, the ratio of steel can be referred to 5D BIM system. The quantity of concrete and formwork are possible to calculate precisely by the 3D model. The way that interviewed companies calculate the material quantity is the manual calculation, which is time-consuming compared with the automatic computer-base calculation with 3D model.

Masterformat and unformat are applied to the proposed system to track the elements and materials for summarizing BOQ.

Lastly, the limitation from the current practice without BIM is on flexibility to get the quantity of elements in a random zone. Because the quantities of elements in the report is grouped well, it needs to recalculate to get the quantity of elements across or break the group. During the construction stage, actual completed works are not in one group strictly and working progress needs the quantity of actual completed works. The quantity of completed works is hard to calculate with current practice, they need to recalculate the quantity with BOQ and quantity takeoff. For the proposed 5D BIM system, it is improved to calculate any selected zone of building freely with 3D model.

This part discusses about BOQ on current practices connecting to the 5D BIM system, with summary of positive guiding and limitations. From the comparison from Table 4-6, there are three factors emphasized out. After quantity takeoff, contractor takes the unit price on material and labor to calculate the cost in BOQ.

4.4.2 Bill of Quantity (BOQ)

In current practice, WBS for BOQ is based on purpose of BOQ from Table 4-6. The different purpose requires different WBS of BOQ. So referring to the 5D BIM system, the WBS is planed to base on element types, material base, and by floors (this is classic type of building physical property base).

Table 4-26: Discussion on BOQ

BOQ (discussion)			
Factor	Able to refer	Limitations	Options for BIM
WBS	Construction budget, report to client, purchasing		Element types base, material base, By floors
Codes	Masterformat, unformat		Combine
		The information in BOQ cannot be tracked back to the building components	Attach the cost information to 3D model components

For the codes, it is applied for tracking material and elements. But the codes are only in BOQ that grouped by materials and elements type. Finally, the items in purchasing BOQ which is grouped by materials are separated from the objects in 2D drawings. Thus, the data in BOQ cannot be tracked back to 2D drawings objects in detail. By attaching the cost information to the 3D model components, the cost and quantity information can be tracked back the the corresponding elements in 3D model. Therefore, the BOQ outcome is easy to be updated with the 3D model synchronously.

4.4.3 Schedule Plan

Referring to the Table 4-9, the discussion on schedule plan just took part of the compare factors which are WBS, time unit, codes using and the software applying. The discussion result on schedule plan between current practice and proposed system is summarized in Table 4-27.

Table 4-27: Discussion on Schedule Plan

Schedule Plan (discussion)			
Factor	Able to refer	Limitations	Options for BIM
WBS	Rough		Hierarchy: floor – element type - zone
Time unit	Day		Day
Codes		Almost no company use codes for schedule plan, but codes are helpful to manage the activity (work package)	Set customized activity codes
Software	Excel		Excel

For the WBS, as the interview result says, the schedule plan is not necessary to be too detailed. So it is designed to build the schedule plan by the hierarchy that follows the level: floor - elements type – zone. In order to apply this system to big project, the system divide floor into several zone too which is always what the big project doing with schedule plan. Secondly, the time unit to design the schedule plan is daily, it makes

working progress inputting more flexible. Thirdly, the codes may not be really useful for the traditional ways. But in the digital BIM system, the schedule codes are helpful to improve the visualization on working progress and to track the elements 3D model based on work package in schedule plan. So that the customized schedule codes are designed for 5D BIM system.

4.4.4 Cost Plan

According to Table 4-12, the cost plan result is affected by the factors: WBS, time unit and quantity or cost bases. The discussion result on cost plan is in Table 4-28.

Table 4-28: Discussion on Cost Plan

Cost Plan (discussion)			
Factor	Able to refer	Limitations	Options for BIM
WBS	Schedule base		Schedule base
Quantity or cost base			Cost base for cost plan
Time unit	Weekly (mostly)	Daily is too detailed to record for comparison during construction	Weekly
		Cost in progress unit have to be regrouped and summarized again base on schedule in manual works	

For WBS, it takes the schedule plan base which is more reliable towards the progress and easier to control cost based in schedule. Material based cost plan always brings indistinct, since it is hard to match the activity with the material base during construction stage. For example, in cost plan, there is a total cost for consumption of concrete in this week. In schedule plan, there is several activities occur in the same week. However, the corresponding quantity of concrete for every specific activities in this week is not clear. But the cost plan on schedule base can solve this instinct and improve the efficiency on actual cost progress inputting. Secondly, whether the cost plan should be quantity or base is determined by authority of construction site. It suggests proposed system to be cost base since the cost in BOQ is automatically calculated in the 3D model, cost and quantity can be obtained at the same time.

Finally, the time unit of cost plan follows the most common option, weekly. Based on the interviewed participants' description on the way to get the cost plan, it is clearly that the way to calculate the cost plan is also time-consuming and inefficient. To get total cost in a progress unit (daily) for cost plan, it has to calculate the cost of activity in schedule first. The cost of activity is summation of material and labor cost of

components in 2D drawings included in this activity. Finally, the cost of corresponding material and labor for this components have to be checked and summed from quantity takeoff. So the whole process to get the cost plan have to repeat checking schedule plan, BOQ and quantity takeoff which is too complicated and time-consuming. Moreover, by this mean, it is hard to measure the big project when there are many work package are ongoing at the same time. The current practice of calculating activity cost in schedule for cost plan is showed in Figure 4-10 below.

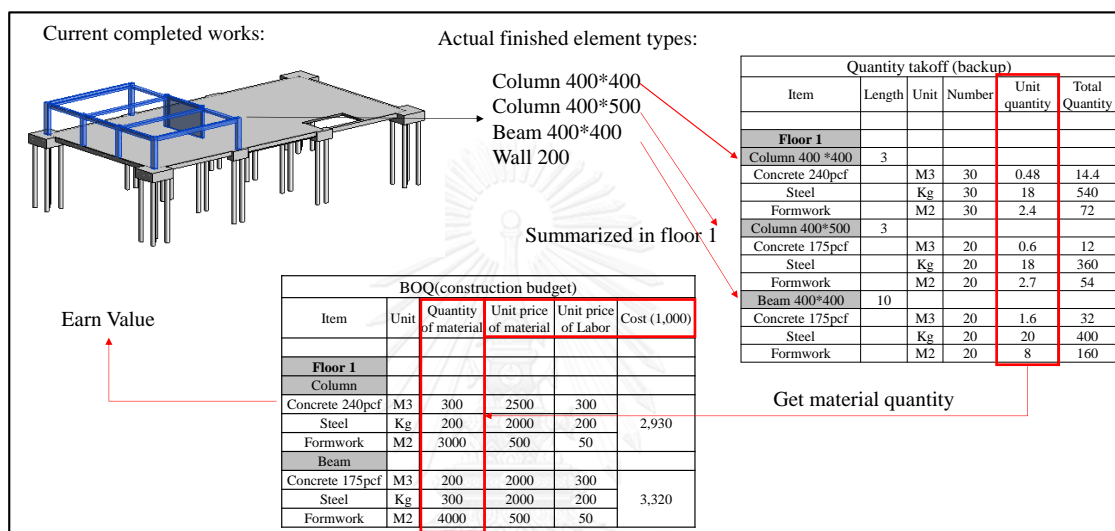


Figure 4-10: Limitations of Calculating Cost of Activity in Schedule from Current Practice

4.4.5 Working Progress Report

This part discussed working progress report from current practices on these factors: measure way, measure object and frequency of imputing working progress data. According to the Table 4-16, there are 5 factors compared on inputting working progress information. Three of them are emphasized out in this discussion, the discussion result is summarized in Table 4-29.

Table 4-29: Discussion on Actual Working Progress Report

Actual Working Progress Report (discussion)			
Factor	Able to refer	Limitations	Options for BIM
Measure way	Check with design	No match quantity with measure works straightly which is random selection of building components	Attach detailed cost on elements to get the cost of measured works
Object	Elements	For floor to be the measure unit, it's too rough to get the exact working progress. for material to be measure unit, it's too detailed for working progress.	Elements
Frequency	Check weekly and report monthly		Weekly
		Hard to calculate the earn value. It's hard to get the detailed delayed activity but only the overview status.	Design the programming to record the exact completed works and calculate earn value correctly. Compare

Firstly, it is more detailed and precise to mark the completed works on the 2D drawings to get the working progress, compared with the way that only recording the start and end date based on the activities in schedule plan (refer to Table 4-16). Since in second way (input date only), the ongoing activity which hasn't finished but has started at the inputting working progress date cannot be recorded as finished. So the earn value ignores this part of works which is lower than the real warn value. On the other hand, the first measure way (remark in 2D drawings) exist a problem on the process to calculate the earn value too. Since the cost of completed works are not matched strictly with items in BOQ. In order to get the earn value, the marked components in 2D drawings have to be checked back in BOQ for corresponding cost, it maybe need some manual tracking and calculation like in Figure 4-10. This limitation requires BIM system to be possible to calculate cost of any part of works by selection in 3D model. It can improve the efficiency and accuracy to calculate cost of completed works.

Secondly, the measure object affects the precise working progress as well. It is too rough with the floor as the minimum unit of measurement for working progress. For example, one floor needs 2 weeks to be completed, so the first week is no working progress recorded because the floor hasn't been finished. The outcome of working progress is not correct with this floor object measurement. On the contrary, taking materials as the minimum measurement unit is too detailed which follows the construction methods, like setting formworks first, then rebar, and concrete pouring at the end. So based on the result of interview, it suggests to take elements as the measure object for working progress report.

4.4.6 Actual Cost Report

This part discusses inputting actual cost report from current practice on the factors: calculating earn value, actual cost resource and frequency to input actual cost. Based on Table 4-20, there are 5 factors are compared on inputting actual cost. Three of them are discussed in this part for guiding 5D BIM system. The discussion result of discussion is in Table 4-30.

Table 4-30: Discussion on Actual Cost Report

Actual Cost Report (discussion)			
Factor	Able to refer	Limitations	Options for BIM
Earn Value	It's from cost in BOQ base on actual working progress	No matched cost with exact completed works which is a random selection of building components	Attach cost to every elements in 3D model
Actual cost	From material consumption (From accounting), schedule base	Objects in actual cost report don't match schedule, which is hard to check status of over budget on specific activity that but only general status	Remark materials consumption with served activity in schedule.
How often	Check weekly and report monthly		Weekly

Firstly, as above said about working progress measure way in checking in 2D drawings, the actual cost report is hard to calculate earn value which needs the cost in BOQ based on real completed works. Since there maybe no matched objects in BOQ which is exactly the completed works, earn value still needs to calculate random group of components of building. It comes up that the 5D BIM system should be possible to calculate cost of any part of elements in 3D model. Secondly, the actual cost resource is from the material consumption records or the signed bill to suppliers. But the two ways don't mark the materials with specific activity that materials used for. To solve this problem, there is a requirement for 5D BIM system that remarking the material consumption with schedule activity in actual cost report. Finally, 5D BIM system takes the most common practice that weekly checking as the frequency of checking actual cost.

4.4.7 Actual Payment Report

There are 4 factors emphasized in discussion on actual payment report which are payment method, payment amount calculation, process and status on payment. No matter which payment method is chosen, the same rule is to set the payment checking time point during construction progress and calculate plan cost of completed works at checking time point from BOQ. The cost calculated is the payment amount. In the

sample in 5D BIM system, it applies progress payment method which can be used by milestone payment as well by modifying the period of payment. As mention before, payment amount should be the earn value at payment checking point. In the Table 4-24, the payment amount from the percentage is not the precise earn value. Thirdly, as the Figure 4-8 says, the payment applying date and the approval date are not the same. It means there exists plenty of works are completed but haven't been paid. In terms of this matter, 5D BIM system improves the payment status towards the construction works. During construction, 5D BIM system works out the components that have been finished but not been paid in 3D model and calculate the earn cost of this part of components.

Table 4-31: Discussion on Actual Payment Report

Actual Payment Report (discussion)			
Factor	Able to refer	Limitations	Options for BIM
Payment method	Milestone, progress payment		Progress payment
Payment amount calculation	Take completed works% (quantity) as reference of payment	The percentage doesn't represent actual cost precisely to be payment amount.	Calculate the earn value precisely to refer to payment amount.
Process	Payment process is referred		Apply payment at every 28 th of month, and get approval 2 weeks later.
Status		No status provided	Compared with working progress, figure out the unpaid but finished works in 3D model

4.5 Summary

This chapter summarized the current practices on cost and payment monitoring, including the input, process and output of every steps. To monitor cost and payment, it needs to get all these documents: BOQ, schedule plan, cost plan, payment plan, working progress report, actual cost report, actual payment report. Then this chapter compared the different options interviewed companies did in every steps, and corresponding examples of options are given as well. Finally the discussion on different options in every steps is processed, it explores out the advantages and limitations of the current practice. The result of discussion guides the development of 5D BIM system. Optimal options on every step are selected to apply in 5D BIM system, and limitations provide references for 5D BIM system to be more practicable and efficient.

CHAPTER 5

DEVELOPMENT OF 5D BIM SYSTEM ON COST AND PAYMENT MONITORING

Last chapter shows the current practice on cost and payment monitoring, including input, process and output in every steps. Then the discussion provides the guides and connection to 5D BIM system development. According to the result of interview and related discussion, this chapter develops the 5D BIM system step by step to monitor cost and payment over time during construction stage. This chapter builds a simple 3D model in Revit, a 3-floor structure building model, to guide the whole process. It gives out the overview concept, process. Then it guides the whole process to develop this system in details, including building primary 3D model, documents preparation in preconstruction stage, processing and visualizing cost and payment monitoring in construction stage. Based on this sample 3D model, the corresponding manual calculation is done to compare with the corresponding result from 5D BIM system to validate this system. And other verifications are took at the end to ensure the result of 5D BIM system is correct.

This system consists of three software, Excel, Dynamo and Revit. It aims to monitor the cost and payment automatically to enable contractor to check the cost and payment over construction progress. The conceptual system is showed in Figure 5-1. Dynamo is a visual programming plug-in in Revit. Particularly, there are three main functions of Dynamo: 1) Exchange the information between Revit and Excel, like the date of activities and unit price of materials and labor. 2) Calculate the quantity, cost or other needed parameter values in Revit, 3) Filter elements in 3D model by different conditions and assign organized color scheme to 3D model during construction stage, and calculate corresponding cost to excel at the same time.

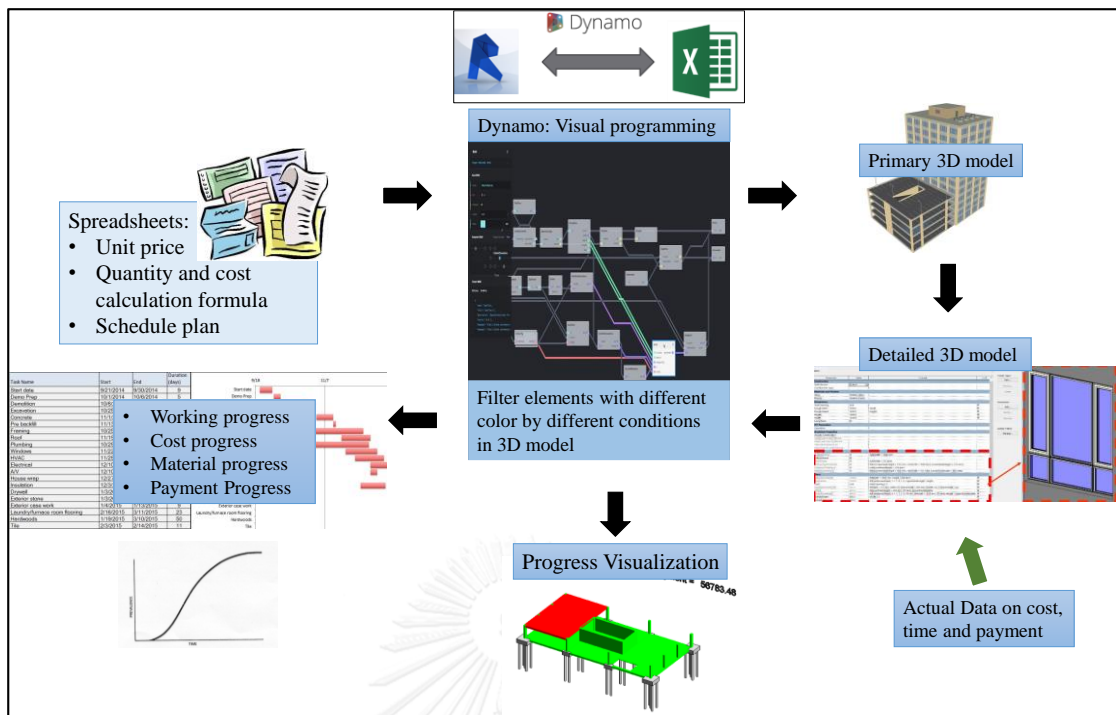


Figure 5-1: Conceptual System

The concept shows that the time, cost and payment information in plan are input to Revit model by dynamo in preconstruction stage. Then input the actual data on cost and payment data to Revit model over time in construction stage. Dynamo visualizes the progress status in Revit with color scheme and calculates corresponding cost, payment data in excel. In excel, it shows the Gantt chart and graphic chart to support analysis. The model built in this chapter is in Figure 5-2 which is a 3-floor building structure model with piles, column, beam, slab and structural wall.

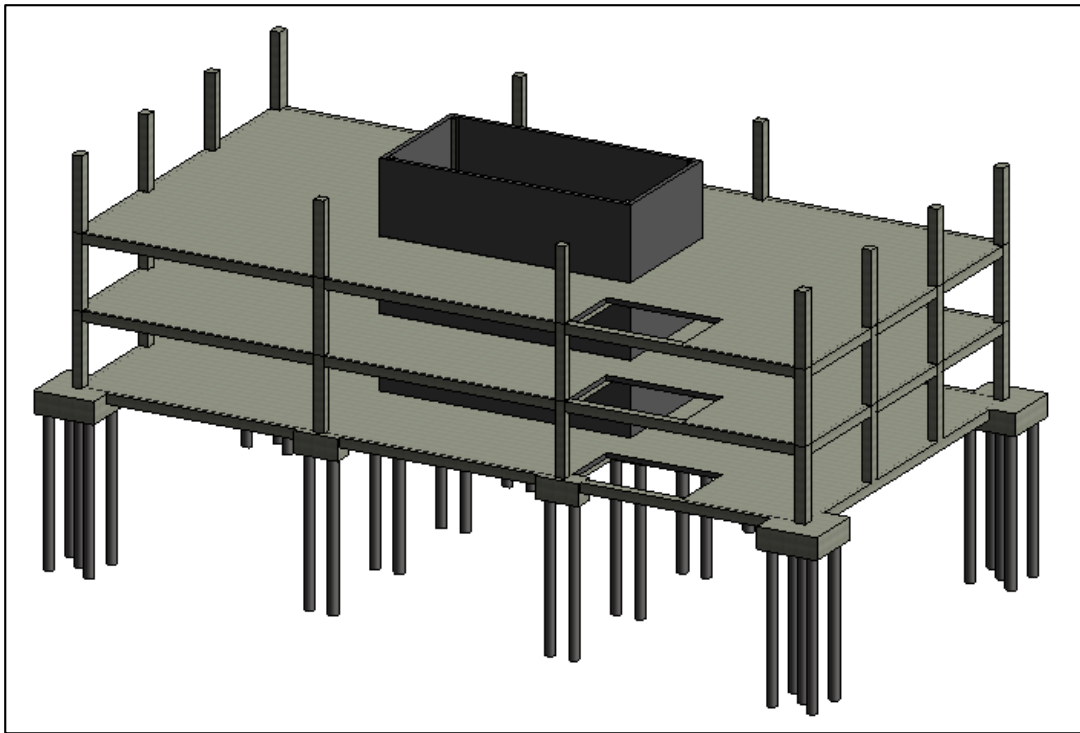


Figure 5-2: Building Structure Sample

5.1 Overview Process of System

As the last chapter summarized in Figure 4-1 from the interview, the output documents needed by the cost and payment monitoring are BOQ, schedule plan, cost plan, payment plan, working progress report, cost progress report and payment progress report. These documents are the target output of this system as well. To get these documents, the process of this system is developed in Figure 5-3 which is by means of visual programming in Dynamo.

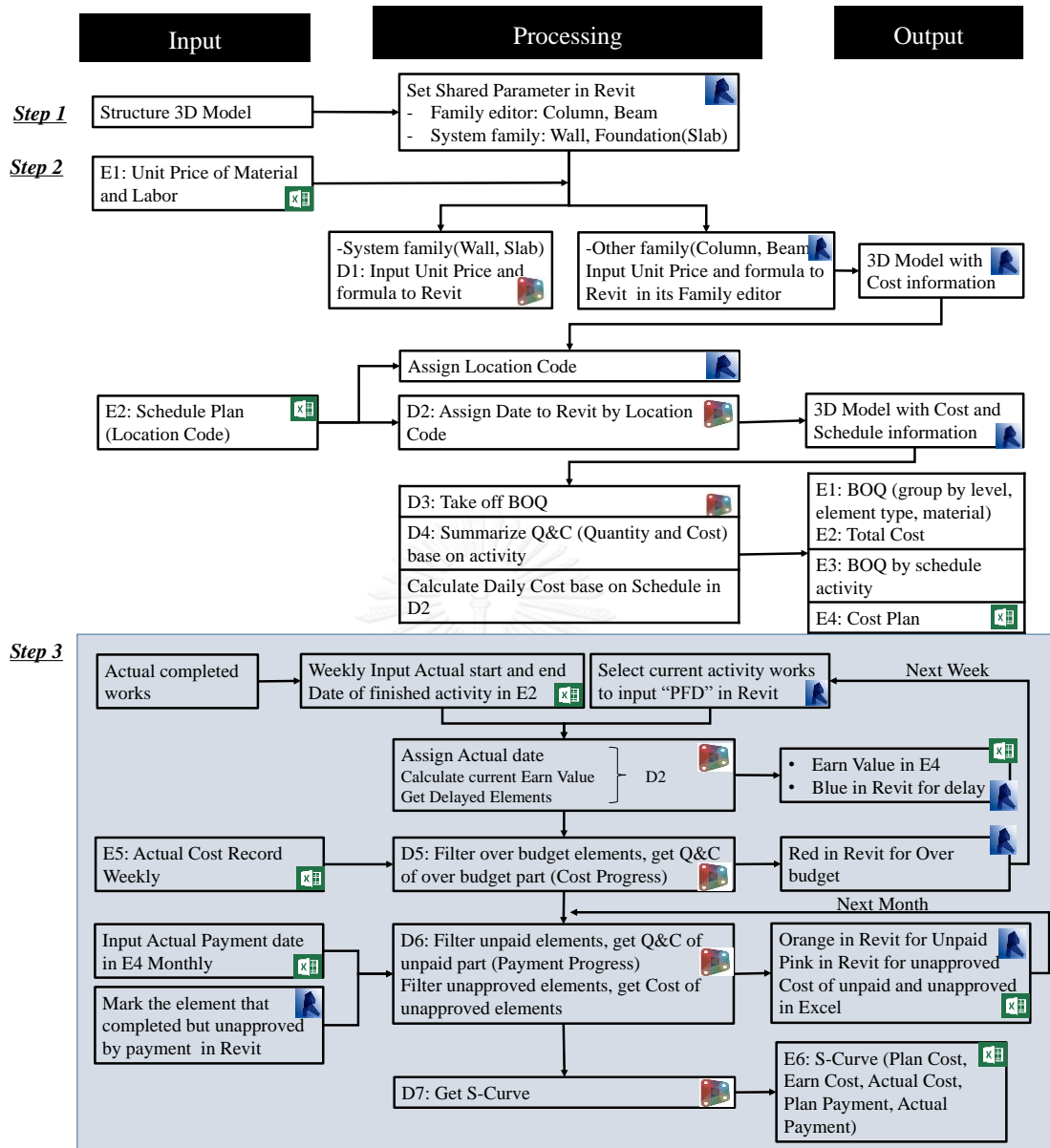


Figure 5-3: Specific Process of System

In Figure 5-3, it describes the input and output of every steps. It separates the process by two stages, preconstruction stage and construction stage. “D” represents the Dynamo, “E” represents the Excel, including input excel and output excel documents. As we can see from the figure, input is all excel documents and primary 3D model. While output are excel documents and the visualization. Dynamo is the tool to build the connection between excel and Revit. The three tools represents three different platforms, they exchange the information and corporate each other to achieve the whole cost and payment monitoring.

Process of this system:

Step 1: build primary 3D model in Revit, set required shared parameters and codes related to material and elements.

- 1) Prepare the primary documents and data in Excel(unit price of material, material types, masterformat, uniformat)
- 2) 3D model
- 3) Setting shared parameter in Revit and input needed formula to calculate quantity and cost of materials and labors
- 4) Dynamo 1: input the unit price form excel to Revit and calculate cost of materials and labors

Step 2: preparing cost, schedule and payment documents in preconstruction stage, including required BOQ, Schedule plan, and cost plan.

- 1) Manage the schedule plan in Excel, work breakdown structure of schedule plan is the work package and Location code is the codes to mark the elements with work package in Revit.
- 2) Revit: assign the location code in Revit based on schedule plan
- 3) Dynamo 2: Assign the date of schedule plan from Excel to Revit based on the corresponding location code.
- 4) Dynamo 3: take off quantity and calculate cost with hierarchy of element, level and material respectively in Excel (BOQ)
- 5) Dynamo 4: export BOQ based on work package in Schedule plan (Location Code)
- 6) Take off the quantity and cost in every time unit from Revit to Excel to get the cost progress in Dynamo 2 (cost plan).

Step 3: record actual data on completed works, cost and payment, compare these actual data with corresponding plan data to show the working progress status, cost progress status, payment progress status both in excel and Revit.

- 1) Construction site: record the actual material cost and labor cost based on the work package on schedule plan (Location Code).
- 2) Input the actual working progress data: actual start and end date into schedule plan excel, and mark the ongoing activity in Revit model.
- 3) Run dynamo 2 to assign actual date information to Revit model
- 4) Input the payment application date and approval date in excel when it occurs. At the same time, mark the elements that completed but unapproved for payment in Revit.
- 5) Dynamo 2: filter elements which are delayed and calculate related quantity and cost into Excel, then override delayed elements in blue in Revit
- 6) Dynamo 5: filter elements which are over budget and calculated related quantity and cost into Excel, then override elements over budget in red in Revit
- 7) Dynamo 6: filter elements which are paid on time and the others are unpaid or unapproved but have been completed already, calculate related quantity and cost of unpaid part and write to excel, then override element in orange in Revit
- 8) Dynamo 7: build the S-Curve to show the relationship among the progress on plan cost, Earn value, actual cost, and payment comparison. This is the overview look on cost and payment progress until the current date. The same operation to the unapproved but finished elements, output cost in excel and override another color to corresponding elements in Revit.

From the above process, all the input excel documents are summarized in Figure 5-4, all the output excel documents are summarized in Figure 5-5, all the Dynamo files developed in the whole process are summarized in Figure 5-6.

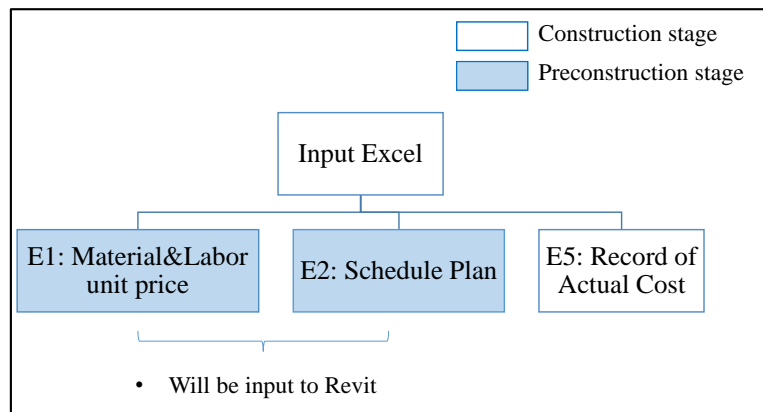


Figure 5-4: The Input Excel in Whole Process

In Figure 5-3, the record of actual cost is not input to Revit, but construction site will keep recording it and it is used to compare with corresponding plan cost to monitor over budget activities.

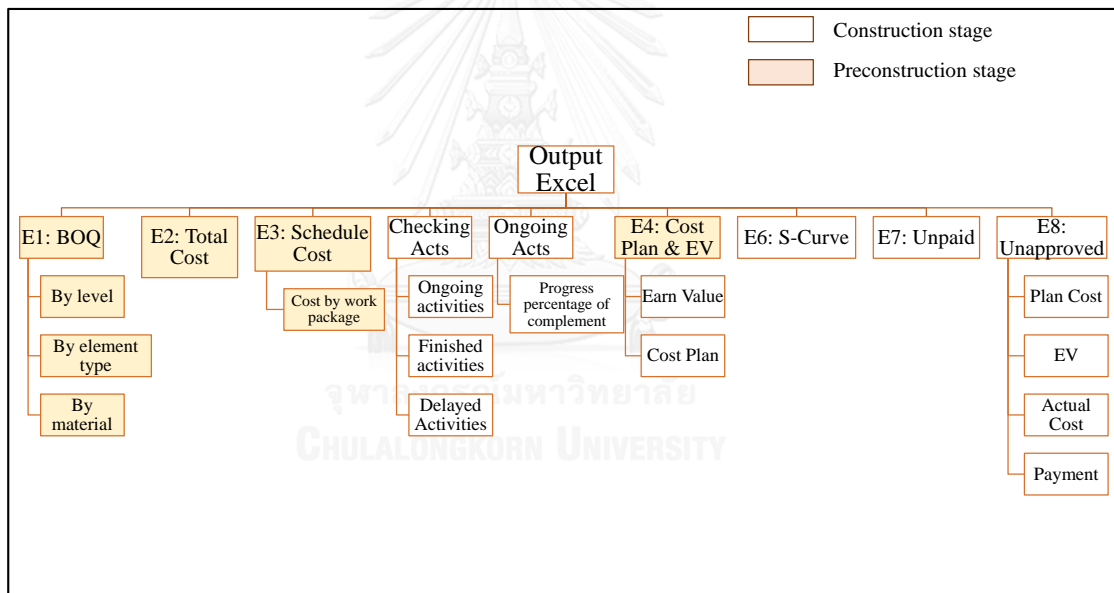


Figure 5-5: The Output Excel by Dynamo from Revit during Whole Process

In Figure 5-5, the Excel of checking Acts and Ongoing Acts are used to provide the backup information for S-Curve, and it will be linked to other excel to be as evidence of data resource, so they are not counted to be the output excel as a report independently.

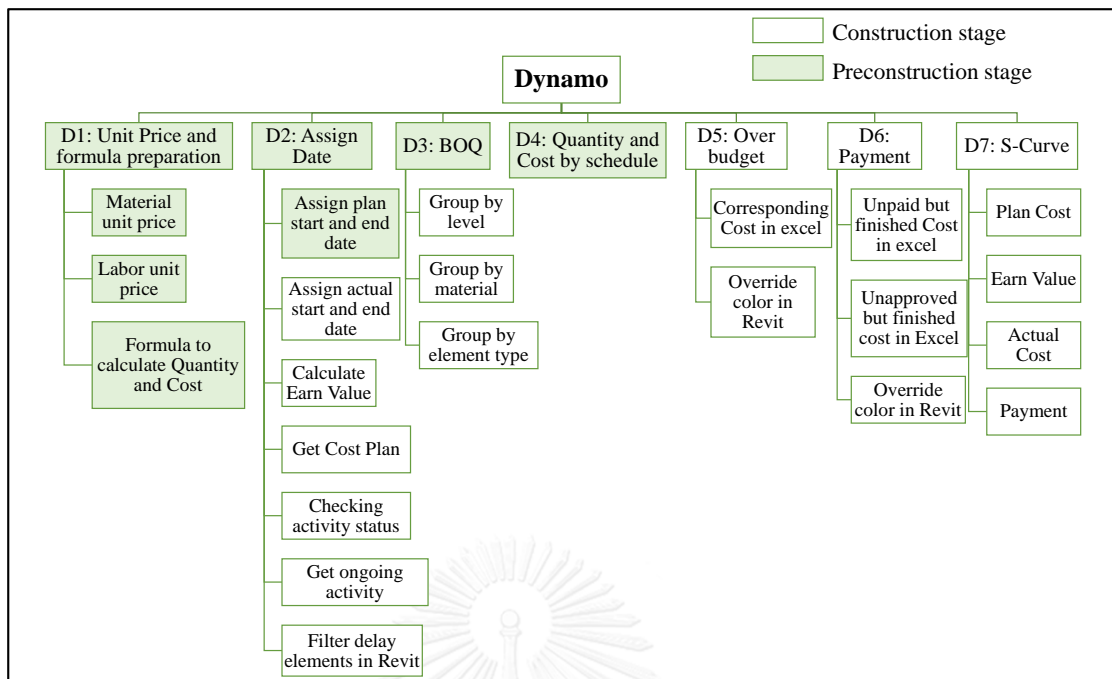


Figure 5-6: The Dynamo Files and its Functions Summary

From the “process” part in Figure 5-3, the all dynamo files are summarized in this figure. There are 7 dynamo files are developed in this system, and functions of every dynamo files are summarized below. Every required output documents of current practices from Figure 4-1 are also output by 5D BIM system which is aided by dynamo automatically. These output documents are: BOQ, cost plan, working progress status, cost progress status and payment progress status which correspond with D3, D2, D2, D5, and D6 in Figure 5-6.

With this overview look on this system, every step is introduced in details with necessary technology guidelines in the following part.

5.2 Primary 3D Model

The hierarchy of elements in Revit is showed in the figure 5-7. Category contains family types, and family type contains the elements. There are two types of family in Revit which are family and system family and these are default setting in Revit. The project elements types are summarized in Figure 5-7.

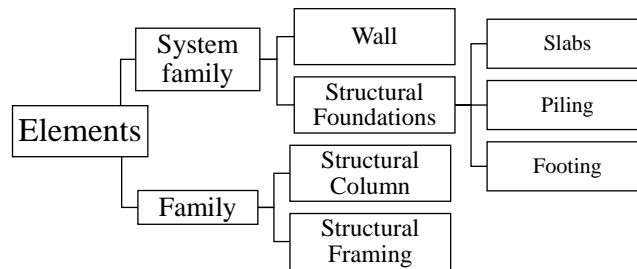


Figure 5-7: Elements Type in Revit (default)

There is no family editor for system family, Wall and slab are the system family. Families are created in the family editor which is outside of the project file. And system families are the families that are only available within a project environment. User can't create new system families but we can create new type of these system families in the project. So later the two type family instances are treated differently at some points.

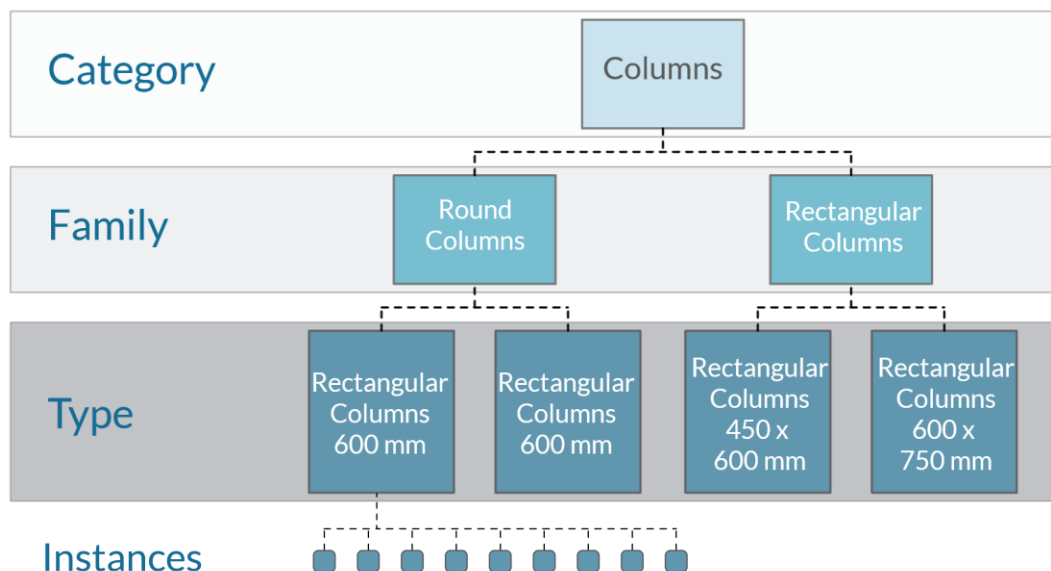


Figure 5-8: Hierarchy of Revit Elements (Column as an example)

Hierarchy of this sample's elements also follow above structure. There are four categories in this sample which are Structural Columns, Structural Framing, Structural Foundations (including slabs) and Walls (here is structural walls).

1) Category: Structural Columns

Family: Concrete-Rectangular-Column-F

Type:

400 x 500

400 x 400

2) Category: Structural Framing

Family: Concrete-Rectangular Beam

Type:

Beam 400*500

Beam 400*400

3) Category: Structural Foundations

System Family: Foundation Slab

Type:

Slab 200

Family: Pile Cap-5r Pile

Type:

5

Family: Pile Cap-2r Pile

Type:

2

4) Category: Walls

System Family: Basic Wall

Type:

Wall 200

Project unit should keep consistent, here we use Metric template to be the construction model template. To be more accuracy, there should be some guidelines for the different category elements joint. When different category elements join together, one of the category element will cut another category element by default. It leads the volume may be different from the manual calculation. There is lack of standard on building standard

3D model. The modelling rule should follow up within the construction industry to create the compatible Revit models for cost and payment monitoring. The standard can improve the accuracy of cost estimation based on Revit and Dynamo, which can improve the cost and payment monitoring system too.

5.2.1 Set Shared Parameters

Shared parameter is the parameter in Revit that user can add to families or projects to assign value to define elements properties. To achieve cost and payment monitoring, many kinds of parameters need to be defined and applied in Revit model. There is one example of parameter in Revit in Figure 5-9, it takes one column as an example. In this example, the parameters like base level, base offset, and top level and so on in left side are default parameter of column, the parameters in right side, like the Steel-Q, Concrete UP, Concrete Cost and Element Cost and so on are the customized parameters. Every parameter has its value which defines the particular column.

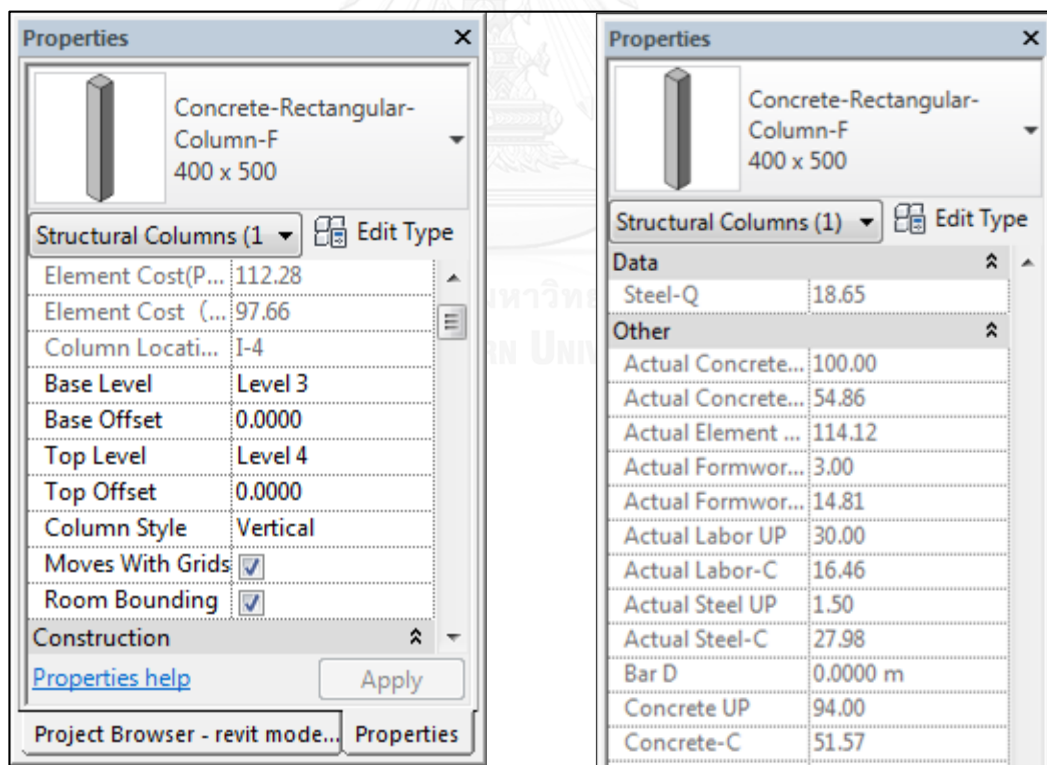


Figure 5-9: Example of Element Properties (with Parameter)

To monitor the cost and payment by time, shared parameters are assigned in this sample model in Revit. The definition is summarized in the Table 5-1 and the shared parameter editor is like in Figure 5-10 which is for Column and Beams, it shows the editable

properties for shared parameters. These parameters have to follow the right unit and type in the following steps (calculate quantity and cost with formula). For creating a new parameter, there are three properties to define a parameter type: Name, Discipline, type of parameter.

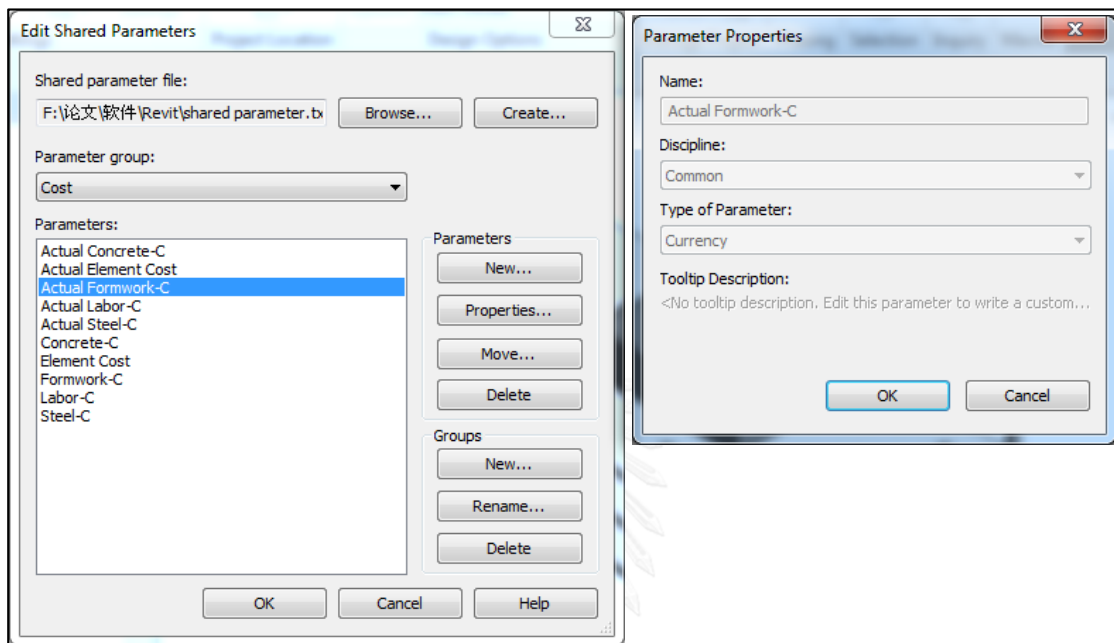


Figure 5-10: Shared Parameter Editor (Parameter Properties)

In this figure, type of parameter here is to define the unit and property of this parameter, there is still other type of parameter called type and instance which are used to define whether the parameter can vary by instance or keep the same with the same family type when we assign these shared parameters to specific family or element (refer to Figure 5-11). Once the shared parameters added and defined, they have to be assigned as project parameters to be applied by the elements. The way to assign shared parameters to be project parameters is in Figure 5-11. The project parameters for walls and slabs are showed in Figure 5-11 and also contain the type of parameters for adding shared parameter as project parameters to be attached on elements. The difference between Type and instance parameter is whether the value can vary by the elements within one type. With this character, the unit price of material and labor in the project parameter will be defined as type, so that the same type of element will share the same unit price of material and labor which reduces the time to assign the parameter value. For example, the parameter of concrete unit price of column is defined as type, so that it is just one time to put the value of concrete unit price for column, so the other column's concrete

unit price is consistent with the same value. But for the location Code will be the instance project parameter, so that the same element type like one type of column can have the different value in different activities, since there are many elements of column in model but they are not grouped in one work package of schedule plan.

Type of parameters	Shared parameter names
Type	Actual Concrete UP, Actual Formwork UP, Actual Steel UP, Concrete UP, Formwork UP, Steel UP
Instance	Actual Concrete-C, Actual Element Cost, Actual Formwork-C, Actual Payment stage, Actual Steel-C, Concrete-C, Element Cost, Elevation level, End Date(Plan), Formwork area, Formwork-C, H&V, Location Code, Planed Payment stage, S'Ratio, Start Date (Actual), Start Date (Plan), Steel-C, Steel-Q, Zone, PFD

The image shows a software interface with three main components:

- Project Parameters Dialog (1):** A list of parameters available to elements in this project. The 'Add...' button is highlighted with a red box and the number 1.
- Parameter Properties Dialog (2, 3):** A dialog for configuring a parameter. The 'Shared parameter' radio button is highlighted with a red box and the number 2. The 'Instance' radio button is highlighted with a red box and the number 3. Below these is the text 'Type or Instance'.
- Categories List (4):** A list of categories for the parameter. The 'Structural Foundations' checkbox is highlighted with a red box and the number 4.

Figure 5-11: Type of Parameters When Shared Parameters are added to be Project Parameters

Table 5-1: Shared Parameters Definition

Shared Parameter Definition			
Name	Discipline	Type	Explanation
Group 1: Cost			
Actual Concrete-C	Common	Currency	Actual concrete cost
Actual Formwork-C	Common	Currency	Actual formwork cost
Actual Steel-C	Common	Currency	Actual steel cost
Actual Element Cost	Common	Currency	Actual cost of this element (like one column)
Concrete-C	Common	Currency	Concrete cost
Formwork-C	Common	Currency	Formwork cost
Steel-C	Common	Currency	Steel cost
Element Cost	Common	Currency	Element cost
Group 2: Material			
Formwork	Common	Material	Assign this element own this formwork material to assign keynote
Rebar 6	Common	Material	Assign this element own this rebar to assign keynote
Group 3: Ratio			
Formwork area	Structural	Section Area	Formwork area of this element(different from the element family)
S'Ratio	Structural	Weight per Unit Length	Ratio of steel(different from category and location)
Steel-Q	Structural	Weight	Quantity of steel(kg)
Group 4: Time			
Start Date (Plan)	Common	Number	Plan Start Date of this element (different from location code)
End Date (Plan)	Common	Number	Plan End Date of this element (different from location code)
Start Date (Actual)	Common	Number	Actual Start Date of this element (different from location code)
End Date (Actual)	Common	Number	Actual End Date of this element (different from location code)
Non approval	Common	Yes/No	To mark the elements that have been completed but unapproved by engineer for payment
Future	Common	Yes/No	To mark the elements that haven't start
PFD	Common	Number	Partial finished date to remark the ongoing elements at the progress checking date, it helps to calculate earn value too.
Group 5: Unit Price			
Concrete UP	Common	Currency	Concrete unit price of this element in BOQ plan
Steel UP	Common	Currency	Steel Unit price of this element(general unit price, average from all type of rebar), in BOQ plan
Formwork UP	Common	Currency	Formwork unit price of this element in BOQ plan
Actual Concrete UP	Common	Currency	Concrete unit price of this element in actual construction
Actual Steel UP	Common	Currency	Steel Unit price of this element(general unit price, average from all type of rebar), in actual construction
Actual Formwork UP	Common	Currency	Formwork unit price of this element in actual construction
Group 6: Dimension			
Elevation level	Common	Number	level of this element, to consist location code easier and sort elements by level
H&V	Common	Text	Check this element is horizontal or vertical when schedule plan need separate works by this property. And consist location code easier.
Zone	Common	Text	Define the zone of this element when schedule plan need to separate works by zone in one floor. And consist location code easier
kn	Structural	Weight	Weight to make the unit consistent in formula
m2	Common	Area	Area to make the unit consistent in formula
m3	Common	Volume	Volume to make the unit consistent in formula
Location Code	Common	Text	Be used to mark element in its activities in schedule plan

In group 3, formwork area varies by size of elements and category. It is defined by formula related with size of elements. S'Ratio varies by the category and location of elements. For example, S'Ratio of column is related with length and S'Ratio of wall is related to the area. The formulas are defined in the following part about formula for quantity and cost of materials and labors in 5.3.2.

In Group 4, date parameter type is number because of the limitation of Revit. There is no date parameter type, so number of days represents the date in this sample.

In group 6, elevation level is to define the level of elements. In fact there are default level parameters in Revit, but it is text instead of number which is hard to sort in dynamo

and the different category owes different level parameter. Moreover, this level number is helpful to consist the location code automatically. H&V and Zone parameters are used to define location code more efficiently too. H&V means the horizontal and vertical elements of building. Horizontal elements contains slabs and beams, and vertical elements are walls and columns. Moreover, foundation is defined as “F” for “H&V” parameter value. The location assigning is explained in details in Figure 5-18. “kn”, “m2”, “m3”, “m” are used to make unit consistent when calculate the quantity and cost with formula. For example, unit price is currency instead of cost per unit weight or cost per unit length, so when we want to calculate the cost of concrete, we use “concrete unit price * Volume”, the unit will be currency *m3 instead of currency. In this case, we have to use “concrete unit price * volume/m3” to get the unit of currency as concrete cost.

5.2.2 Set Masterformat and Unifomat Codes

In Revit, set the masterformat as keynote resources and set the unifomat codes as the Assembly code. Masterformat and unifomat are the text file loaded in Revit. According to the design files and 3D model, choose the corresponding unifomate code to type editor for every type of element. For the family (column and beam) editor, select right masterformat to the keynote as the material for elements. For system family, the same rule but editing in structure material of type editor.

5.3 Preconstruction Stage

In the pre-construction stage, this system needs to prepare the plan information on cost and payment plan into Revit model to be baseline for construction stage. As the result of current practice on cost and payment monitoring in chapter 4 said, the preparation documents are the quantity take off table, BOQ, schedule plan and payment plan. These documents are calculated by Dynamo from the Revit model automatically with these input information: unit price of materials, formula for quantity and cost calculation, and schedule plan.

5.3.1 Input: Unit Price of Material and Labor

Unit price of material is attached with master format codes. In this sample, according to the scope of this research, structural materials contains the concrete, steel and

formwork. Every material is allowed to have several types. This information is put in excel with corresponding material and it is showed in Table 5-2: Material and Labor Unit Price Table. The unit price of materials and labors are referred from the most quoted name in construction in report of RSMmean, building construction cost data in 2014 (Rsmeans, 2014). S'Ratio is ratio of steel quantity, it is referred from a research on steel quantity estimation report (Mahamid, 2016).

Table 5-2: Material and Labor Unit Price Table

Plan Unit price(USD)						
Assembly code	Category	Concrete UP/m3	Steel UP/kg	Formwork UP/m2	Labor UP/m3	S'Ratio(kg/m or m2)
B1010250	Column	94	1.7	2.54	30	6.8
B1010400	Beam	83	1.6	2.8	10	13.6
B1010410	Slab	91	1.7	2.84	14	0.89
B1010210	Wall	48	1.4	2.22	15	3.52
B1010211	Pile	137	1.5	3.8	25	0.89

Dynamo takes the unit price in Excel from Table 5-2, to put to corresponding elements in Revit. All the dynamo programming files are attached in appendix 2. The outcome is showed in the Figure 5-12. Based on this link, if there are some changes on unit price in excel, the data in Revit will change automatically by running this dynamo file which makes the unit price in Revit updatable.

In Revit: Wall properties

Plan Unit price(USD)						
Assembly code	Category	Concrete UP/m3	Steel UP/kg	Formwork UP/m2	Labor UP/m3	S'Ratio(kg/m or m2)
B1010250	Column	94	1.7	2.54	30	6.8
B1010400	Beam	83	1.6	2.8	10	13.6
B1010410	Slab	91	1.7	2.84	14	0.89
B1010210	Wall	48	1.4	2.22	15	3.52
B1010211	Pile	137	1.5	3.8	25	0.89

Figure 5-12: Checking the Outcome of Unit Price Assigning by Dynamo 1

In this figure, checking whether the unit price follows the price in spreadsheet from Table 5-2 or not. It turns out to be exactly matching with information in Excel.

5.3.2 Input: Formula for Quantity and Cost Calculation

This part explores the formula to calculate the quantity and cost of materials and labors for elements in Revit. Formula for calculating quantity of formwork and steel are different from the categories. The formulas calculate the quantity cost of formwork, steel concrete and labor. Because of the differences on family and system family, there are two ways for family instances and system family instances.

For family, the formula is put in family editor. For system family, the formula is achieved by Dynamo in 5.1.3.2. The formulas are showed below (m, m², m³, kn, are used to make unit consistent). All the parameters' definition can be found in Table 5-1.

Formula in family editor for columns and beams:

For columns:

$$\text{Formwork area} = 2 * (\text{Width} + \text{Height}) * L$$

$$\text{Formwork-C} = \text{Formwork area} * \text{Formwork UP} / \text{m}^2$$

$$\text{Steel-Q} = \text{S'Ratio} * L$$

$$\text{Steel-C} = \text{Steel UP} * \text{S'Ratio} * L / \text{kn}$$

$$\text{Concrete-C} = \text{Concrete UP} * \text{Volume} / \text{m}^3$$

$$\text{Element Cost} = \text{Concrete UP} / \text{m}^3 * \text{Volume} + \text{Formwork area} * \text{Formwork UP} / \text{m}^2 + \text{S'Ratio} * L * \text{Steel UP} / \text{kn}$$

For beams:

$$\text{Formwork area} = \text{Length} * h * 2$$

$$\text{Formwork-C} = \text{Formwork area} * \text{Formwork UP} / \text{m}^2$$

$$\text{Steel-Q} = \text{S'Ratio} * \text{Length}$$

$$\text{Steel-C} = \text{S'Ratio} * \text{Steel UP} * \text{Length} / \text{kn}$$

$$\text{Concrete-C} = \text{Concrete UP} * \text{Volume} / \text{m}^3$$

Element Cost = Concrete UP * Volume / m3 + S'Ratio * Steel UP / kn * Length +
Formwork area * Formwork UP / m2

The size annotation of beam and column is showed in Figure 5-13:

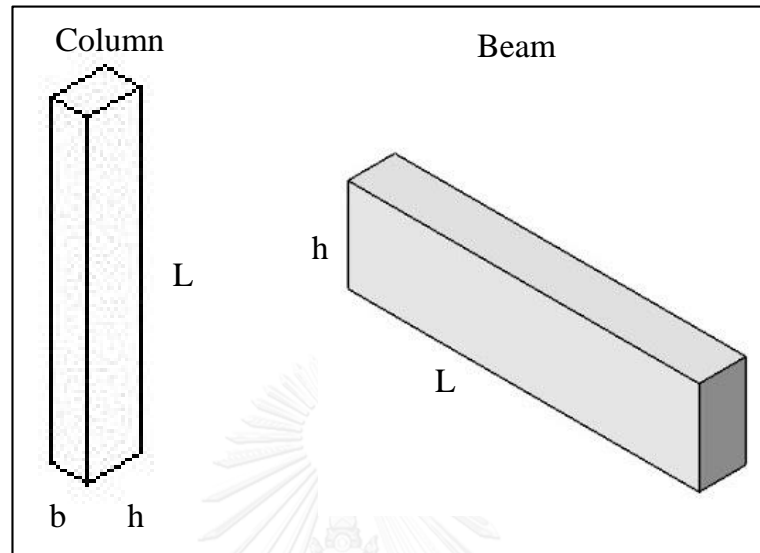


Figure 5-13: Column and Beam Annotation

To input these formulas in family editor, the shared parameters have to be added into the family editor as this family's project parameters. Then these shared parameters can be used in family editor and take them as reference in formula. The type of parameters should be noticed when we input the shared parameters to family (this act will only applied in one family instead of all families, so that this act is did again in beam family). The type of parameter has two options: instance and type (showed in Figure 5-11). Type parameter means the value of this parameter will stay all the same with one family. The formula in family editor is like in Figure 5-14. It takes column family as the example. The quantity and cost are linked with the size of elements which means the cost and quantity are updatable with this formula. The output of quantity and cost to Excel by Dynamo can be changed automatically and synchronously as well.

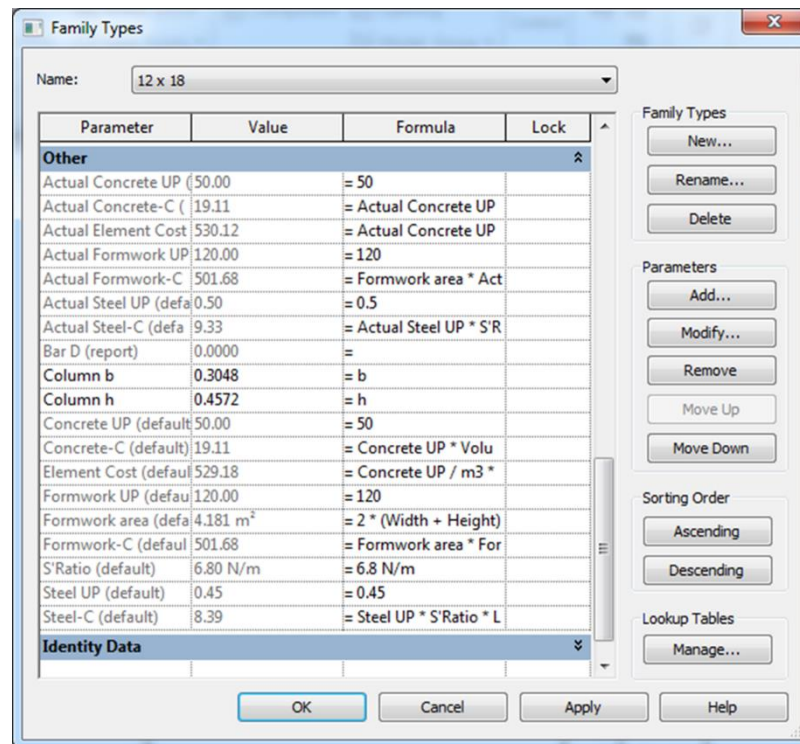


Figure 5-14: Formula in Family Editor (Column as an Example)

For the system family, the quantity and cost calculation are in dynamo 1. It takes the parameter value in Revit and calculate by the formula below for foundations and walls. The calculation results are set back to the corresponding parameters in Revit at the end.

The formulas are in below:

For Walls:

Formwork area = 2*area

Formwork-C = Formwork area * Formwork UP

Steel-Q = S'Ratio * area

Steel-C = Steel-Q*Steel-Q

Concrete-C = Concrete UP * Volume

Element Cost = Concrete-C + Formwork-C + Steel-C

For Slabs:

Formwork area = area + perimeter*thickness

Formwork-C = Formwork area * Formwork UP

Steel-Q = S'Ratio * area

Steel-C = Steel-Q*Steel-Q

Concrete-C = Concrete UP * Volume

Element Cost = Concrete-C + Formwork-C + Steel-C

Dynamo takes the existed parameter values and calculate by formulas with visual programming. And then set the value of calculation result to corresponding parameters which is no value before. The example of Dynamo calculation is showed in Figure 5-15.

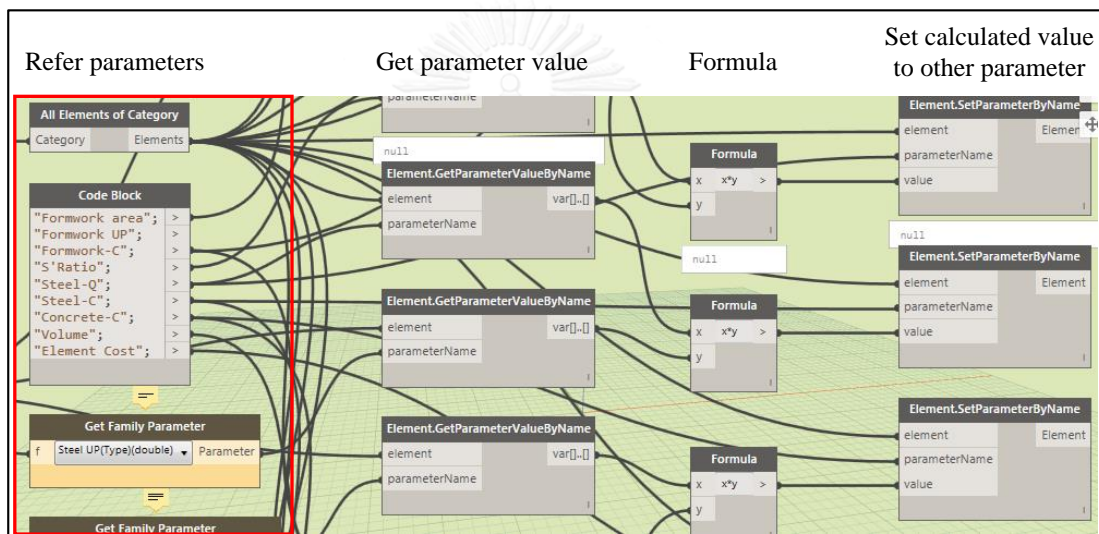


Figure 5-15: Example of Dynamo 1: Formula for Quantity and Cost

5.3.3 Input: Schedule Plan

This part describes the way to put the schedule plan data to corresponding elements in Revit by Dynamo 2. Schedule plan is used to arrange the construction activities in a timetable. It contains the work package, location code, the date of start, and date of end. Location code is the codes to mark activities. The definition of location codes is from the combination of elements' type, zone and elevation. In this sample, the WBS of the schedule plan is detailed schedule plan (Table 4-10). The hierarchy of schedule plan work package breaks the project like in Figure 5-16.

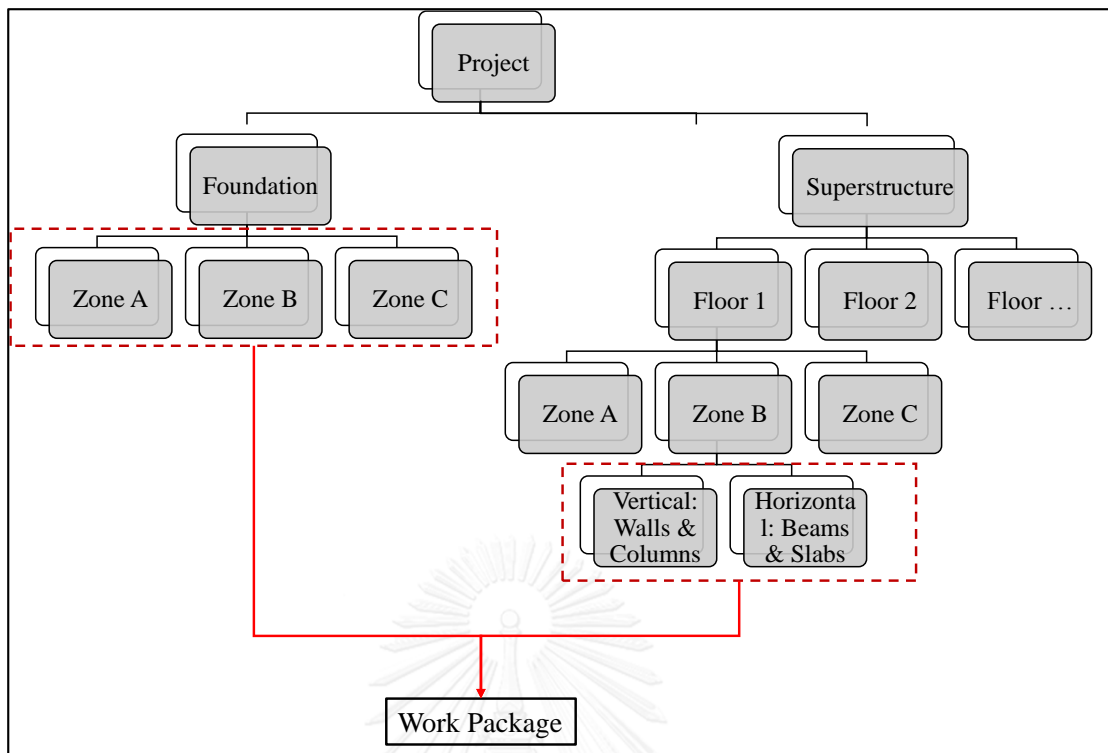


Figure 5-16: Hierarchy of Work Breakdown Structure of Schedule Plan Work Package

In this work breakdown structure of this project, the lowest level of works are the work package level which is used to arrange the schedule plan. The work package is assigned with particular location code to mark elements Revit within the work package to assign date information. Zone distribution refers Figure 5-17. The project is divided into 3 zones in every floor.

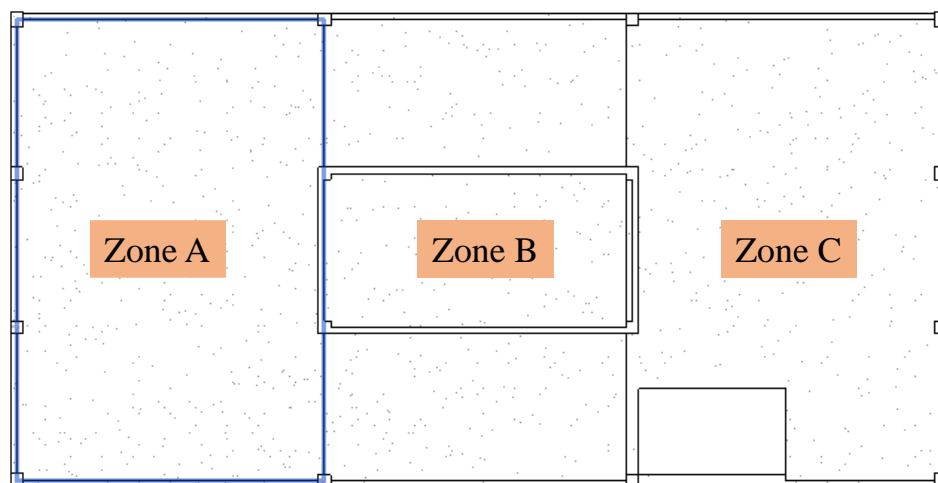


Figure 5-17: Zone Distribution (Take Standard Floor Plan as Example)

So the classic activity unit is like the every floor's horizontal or vertical elements in one zone. Then the schedule plan is designed like in Table 5-3. The time unit of schedule plan is based on day. In this table, it contains the relationship of precedence relationship by the formula in excel. In order to compare the working progress easier, this table contains the actual date as well which will be filled during construction.

Table 5-3: Schedule Plan

Work Package	Location Code	Start Date (Plan)	End Date (Plan)	Start Date (Actual)	End Date (Actual)
Foundation zone A	FA	1/1/2017	1/3/2017		
Foundation zone B	FB	1/4/2017	1/9/2017		
Foundation zone C	FC	1/10/2017	1/12/2017		
1st Fl. beam&Slab Zone A	HA01	1/4/2017	1/9/2017		
1st Fl. beam&Slab Zone B	HB01	1/12/2017	1/15/2017		
1st Fl. beam&Slab Zone C	HC01	1/16/2017	1/21/2017		
1st Fl. column&structural Wall Zone A	VA01	1/10/2017	1/12/2017		
1st Fl. column&structural Wall Zone B	VB01	1/16/2017	1/22/2017		
1st Fl. column&structural Wall Zone C	VC01	1/22/2017	1/30/2017		
2nd Fl. beam&Slab Zone A	HA02	1/13/2017	1/16/2017		
2nd Fl. beam&Slab Zone B	HB02	1/23/2017	1/24/2017		
2nd Fl. beam&Slab Zone C	HC02	1/31/2017	2/9/2017		
2nd Fl. column&structural Wall Zone A	VA02	1/10/2017	1/12/2017		
2nd Fl. column&structural Wall Zone B	VB02	1/16/2017	1/20/2017		
2nd Fl. column&structural Wall Zone C	VC02	2/10/2017	2/19/2017		
3rd Fl. beam&Slab Zone A	HA03	1/13/2017	1/16/2017		
3rd Fl. beam&Slab Zone B	HB03	1/21/2017	1/25/2017		
3rd Fl. beam&Slab Zone C	HC03	2/20/2017	2/29/2017		
3rd Fl. column&structural Wall Zone A	VA03	1/17/2017	1/20/2017		
3rd Fl. column&structural Wall Zone B	VB03	1/26/2017	2/4/2017		
3rd Fl. column&structural Wall Zone C	VC03	3/1/2017	3/10/2017		

Every work package is marked with one unique location code without overlap, since location code is used to mark the elements in Revit and assigned elements with corresponding date. Moreover, the date should be transferred as number. Because number is able to be calculated and sorted in dynamo. The transfer rule is that the first day is transferred to be 1 and so on. The transferred excel is in Table 5-4.

Table 5-4: Schedule Plan Transferred with Number of Days

Location Code	Start Date (Plan)	End Date (Plan)	Start Date (Actual)	End Date (Actual)
FA	1	3		
FB	4	9		
FC	10	12		
HA01	4	9		
HA02	12	15		
HA03	16	21		
HB01	10	12		
HB02	16	22		
HB03	22	30		
HC01	13	16		
HC02	23	24		
HC03	31	40		
VA01	10	12		
VA02	16	20		
VA03	41	50		
VB01	13	16		
VB02	21	25		
VB03	51	60		
VC01	17	20		
VC02	26	35		
VC03	61	70		

In order to assign the date automatically and efficiently to Revit, the location code is assigned to Revit too. There are many work packages in schedule plan, it is not efficiently if assigning location code one by one. So this system provides a way to assign the location code faster. Three accessorial parameters: H&V, Zone and Elevation level are proposed in Revit. Location code is combined with the three parameters. The definition of three accessorial parameters used to assign location code is summarized in Figure 5-18. In this step, one tool is used to fasten this operation called “BIM one: Excel Import/Export”. This tool enable schedule in Revit can be exported in excel and imported back to Revit again. So it is possible to process data in Excel which is more convenient and efficient.

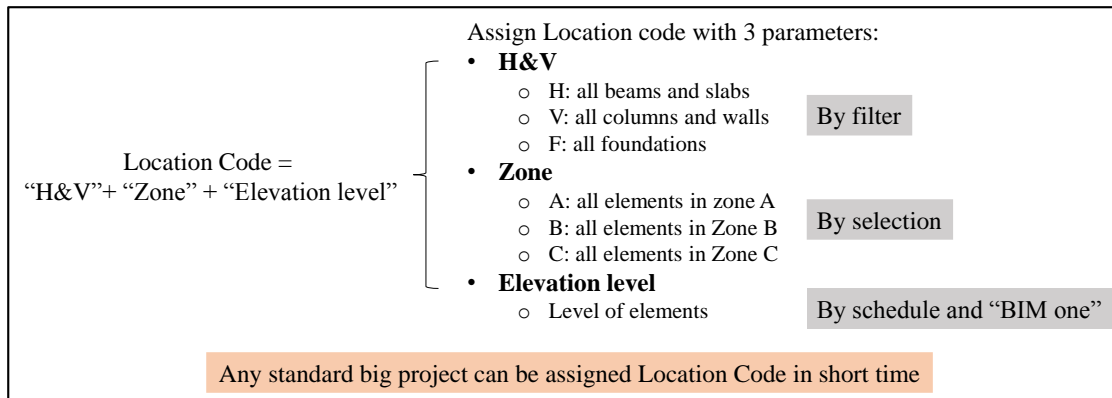


Figure 5-18: Definition of Accessorial Parameters for Assigning Location Code

H&V is to mark whether the element type is slab & beam, column & walls or foundations. Zone has three options: A, B, C. Elevation level equals to the level of elements. In Revit, it is easy to select the elements by zone with rectangular selector (refer to Figure 5-17) which means only three selections can finish Zone parameter value assigning for one project. The Zone assigning in Revit is by manual selection in Revit and it is showed in Figure 5-19. H&V can be easily assigned by filtering elements in Revit. There is an example to assign column and walls at once in Revit in Figure 5-20. There are only three categories for H&V definition:

- 1) Slab & beam (H): Choose all slabs and beams and assign “H” in “H&V” parameter
- 2) Column & walls (V): Choose all columns & walls and assign “V” in “H&V” parameter
- 3) Foundations (F): Choose all foundations and assign “F” in “H&V” parameter

Then export the multi-category schedule with “Elevation level”, “H&V”, “Zone”, “level” and “Location Code” parameters by “BIM one: Excel Import/Export” tool. In Excel, use the function of “CONCATENATE” to combine these three parameters with sequence of “H&V, Zone, and Elevation level” to form the location code, the example is in Table 5-5. Finally import the updated excel to Revit by “BIM one: Excel Import/Export” tool again. Thus all elements get right location code in Revit.

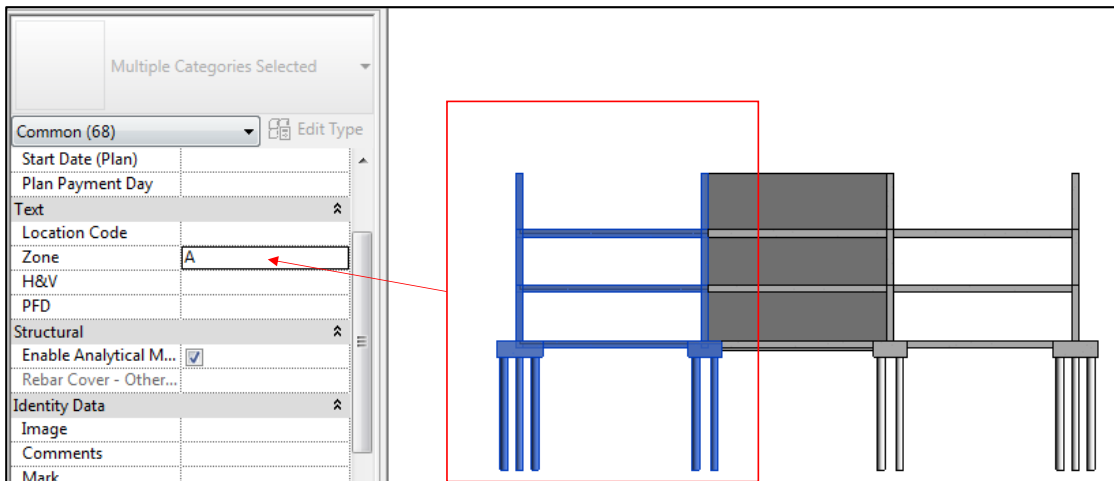


Figure 5-19: Assigning Zone Parameter Value in Revit (Zone)

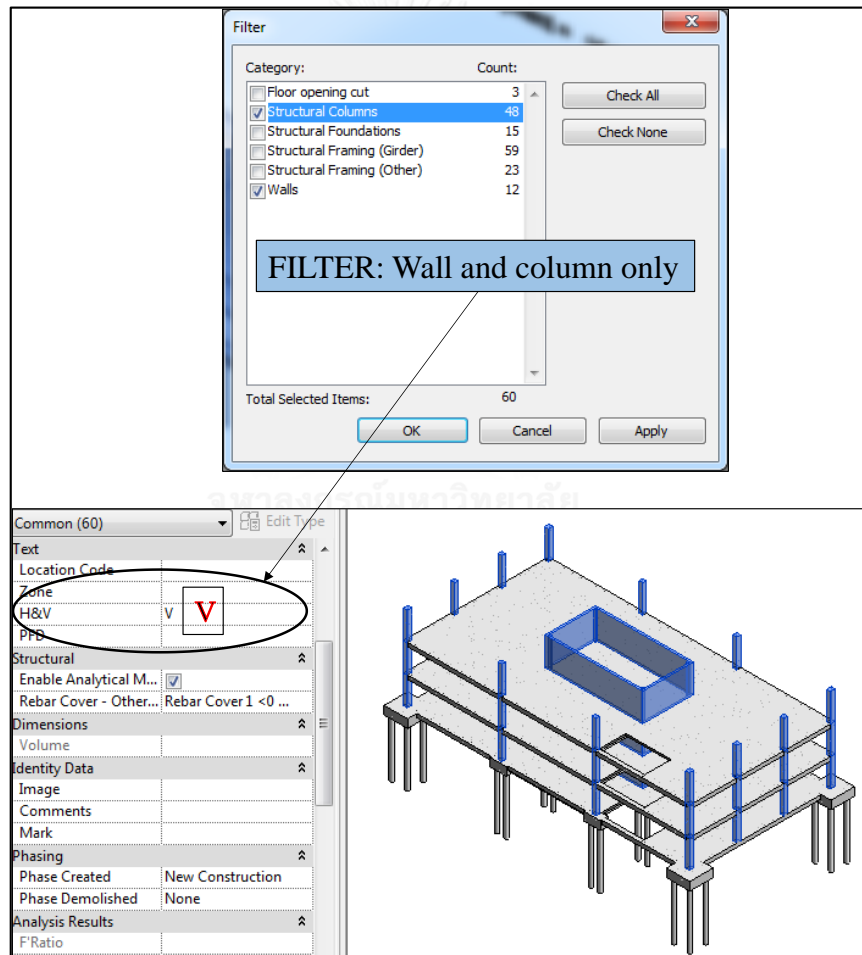


Figure 5-20: Assign "H&V" Parameter in Revit Efficiently by Filter

Table 5-5: Assign Location Code in Excel with Formula

Family and Type	H&V	Zone	Elevation level	Location Code
Concrete-Rectangular Beam: Beam 400*400	H	A	1	=CONCATENATE(B2,C2,"0",D2)
Concrete-Rectangular Beam: Beam 400*400	H	A	1	HA01
Concrete-Rectangular Beam: Beam 400*400	H	A	1	HB01
Concrete-Rectangular Beam: Beam 400*400	H	A	1	HA01
Concrete-Rectangular Beam: Beam 400*400	H	A	1	HA01
Concrete-Rectangular Beam: Beam 400*400	H	A	1	HB01
Concrete-Rectangular Beam: Beam 400*400	H	A	1	HB01
Concrete-Rectangular Beam: Beam 400*400	H	A	1	HA01
Concrete-Rectangular Beam: Beam 400*400	H	A	1	HA01
Concrete-Rectangular Beam: Beam 400*400	H	A	1	HB01

After Location Code assigned in Revit, it is time to put the schedule date in Table 5-4 to Revit. Dynamo 2 is designed to assign schedule date to Revit which is roughly like in Figure 5-21. The connection to assign schedule date between Revit and excel is the location code.

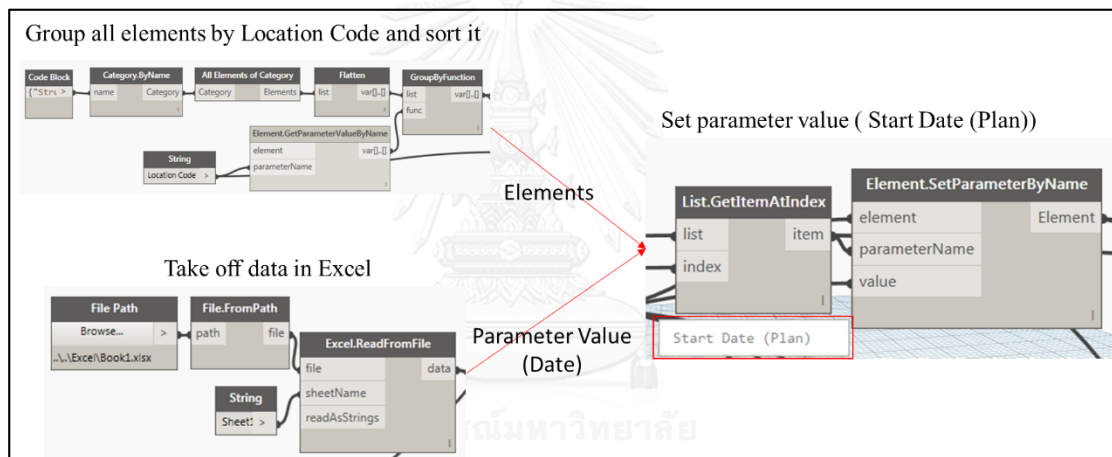


Figure 5-21: Dynamo 3: Set Schedule Plan Date Based on Location Code

All elements get its plan date of start and end by Dynamo 2. For the actual date during construction stage, the date can keep it as empty or 0 during pre-construction stage. What we need to do during construction stage is to fill the actual start and end date of the activities in schedule, the blue part in Table 5-4.

So far, the below information is input to Revit

- 1) Unit price of material,
- 2) Formula for quantity and cost,
- 3) Schedule plan with date and location code.

Primary 3D model is improved to be developed 3D model with scheduling and cost information of all elements. It is time to output to be report in in Excel. What are the

needed output documents in preconstruction stage are: BOQ by different group base (by level, by element type, by schedule activity and total), and cost plan.

5.3.4 Output: Take off the BOQ by Dynamo

This part describes what kinds of BOQ can be got from Dynamo 3 and how. BOQ contains the quantity of materials (concrete, steel and formwork), labor cost and total cost. This system takes off quantity and cost to BOQ based on time unit, element type, levels, activities, and materials.

Firstly, summarize the quantity and cost based on the level with corresponding elements type. The outcome in excel is showed in Table 5-6. It is got from dynamo by sorting based on value of parameter “Elevation level”. So the sequence of elements are based on level. Then sum every element type in every level. Here need to clarify that the original data from dynamo to excel is a list of all elements in model, so the grouping is done in excel itself. There are two type of BOQ are needed, one is group by level, another one is grouping by elements type in each level. The two BOQ are able to be got from excel by subtotal easily with list of all elements. Another BOQ is the project total cost which is designed in dynamo 3 too. The result is in Table 5-7.

Third BOQ we need is to summarize the quantity and cost based on the work package in Schedule plan which is helpful to track cost by time. So in dynamo, it groups elements by location codes and sort it by the Elevation level too. The result is showed in Table 5-8. This schedule cost BOQ is achieved by Dynamo 4: Quantity and Cost by schedule.

Table 5-6: BOQ based on Elements Type by level (Dynamo 3)

Family and Type	Volume	Concrete-C	Formwork-C	Steel-C	Labor-C	Element Cost
Family Type: 2, Family: Pile Cap-2r Pile Total	9.4	3159.9	666.3	30.8	576.6	4433.6
Family Type: 5, Family: Pile Cap-5r Pile Total	20.8	5183.2	830.0	50.5	945.8	7009.6
Family Type: 400 x 400, Family: Concrete-Rectangular-Column-F To	4.3	495.1	133.8	380.5	158.0	1167.4
Family Type: 400 x 500, Family: Concrete-Rectangular-Column-F To	2.4	206.3	50.2	126.8	65.8	449.1
Family Type: Beam 400*400, Family: Concrete-Rectangular Beam To	14.0	2124.1	358.3	3480.5	255.9	6218.9
Family Type: Beam 400*500, Family: Concrete-Rectangular Beam To	2.4	498.0	84.0	652.8	60.0	1294.8
Wall 200 Total	18.5	887.9	410.3	455.3	277.5	2031.0
Slab 200 Total	87.1	7927.9	1288.2	659.1	1219.7	11094.9
Family Type: 400 x 400, Family: Concrete-Rectangular-Column-F To	4.3	495.1	133.8	380.5	158.0	1167.4
Family Type: 400 x 500, Family: Concrete-Rectangular-Column-F To	2.4	206.3	50.2	126.8	65.8	449.1
Family Type: Beam 400*400, Family: Concrete-Rectangular Beam To	16.1	2390.4	403.2	3916.8	288.0	6998.4
Wall 200 Total	18.5	887.0	410.3	455.3	277.2	2029.8
Slab 200 Total	87.1	7927.9	1288.2	659.1	1219.7	11094.9
Family Type: 400 x 400, Family: Concrete-Rectangular-Column-F To	4.3	495.1	133.8	380.5	158.0	1167.4
Family Type: 400 x 500, Family: Concrete-Rectangular-Column-F To	2.4	206.3	50.2	126.8	65.8	449.1
Family Type: Beam 400*400, Family: Concrete-Rectangular Beam To	16.1	2390.4	403.2	3916.8	288.0	6998.4
Wall 200 Total	18.5	887.0	410.3	455.3	277.2	2029.8
Slab 200 Total	87.1	7927.9	1288.2	659.1	1219.7	11094.9
Grand Total	443.4	44295.9	8392.3	16913.6	7576.8	77178.6

Table 5-7: Total Quantity and Cost

BOQ-Total	
Volume	443.4418
Concrete-C	44295.89
Formwork area	1739.174
Formwork-C	8392.298
S'Ratio	1529.23
Steel-Q	29792.99
Steel-C	16913.59
Labor-C	7576.825
Element Cost	77178.6



Table 5-8: BOQ based on Schedule Work Package: Schedule Cost (Dynamo 4)

Location Code	Volume	Concrete-C	Formwork-C	Steel-C	Labor-C	Element Cost
FA	20.8	5183.2	830.0	50.5	945.8	7009.6
FB	4.7	1579.9	333.1	15.4	288.3	2216.8
FC	4.0	1579.9	333.1	15.4	288.3	2216.8
HA01	5.9	939.6	158.5	1539.6	113.2	2750.8
HA02	6.4	924.3	155.9	1514.5	111.4	2706.0
HA03	6.4	924.3	155.9	1514.5	111.4	2706.0
HB01	4.0	597.6	100.8	870.4	72.0	1640.8
HB02	3.1	531.2	89.6	870.4	64.0	1555.2
HB03	3.1	531.2	89.6	870.4	64.0	1555.2
HC01	93.5	9012.9	1471.2	2382.4	1350.4	14216.9
HC02	93.7	8852.2	1444.1	2173.6	1331.0	13800.9
HC03	93.7	8852.2	1444.1	2173.6	1331.0	13800.9
VA01	6.6	506.2	163.9	333.5	160.5	1164.2
VA02	6.6	506.2	163.9	333.5	160.5	1164.2
VA03	6.6	506.2	163.9	333.5	160.5	1164.2
VB01	12.0	576.0	266.4	295.7	180.0	1318.1
VB02	12.0	576.0	266.4	295.7	180.0	1318.1
VB03	12.0	576.0	266.4	295.7	180.0	1318.1
VC01	6.6	507.1	163.9	333.5	160.8	1165.3
VC02	6.6	506.2	163.9	333.5	160.5	1164.2
VC03	6.6	506.2	163.9	333.5	160.5	1164.2

5.3.5 Output: Cost Plan from Dynamo

This part describes how to get the cost plan which summarizes the cost based on time. Cost plan is got by summarizing the cost in every time unit, day is the time unit in this sample. Moreover, this cost plan is also used to summarize out the payment plan by setting the fixed date within every month and sum the cost of this period if the payment method is fixed date in every month. The outcome of cost plan is showed in Figure 5-22.

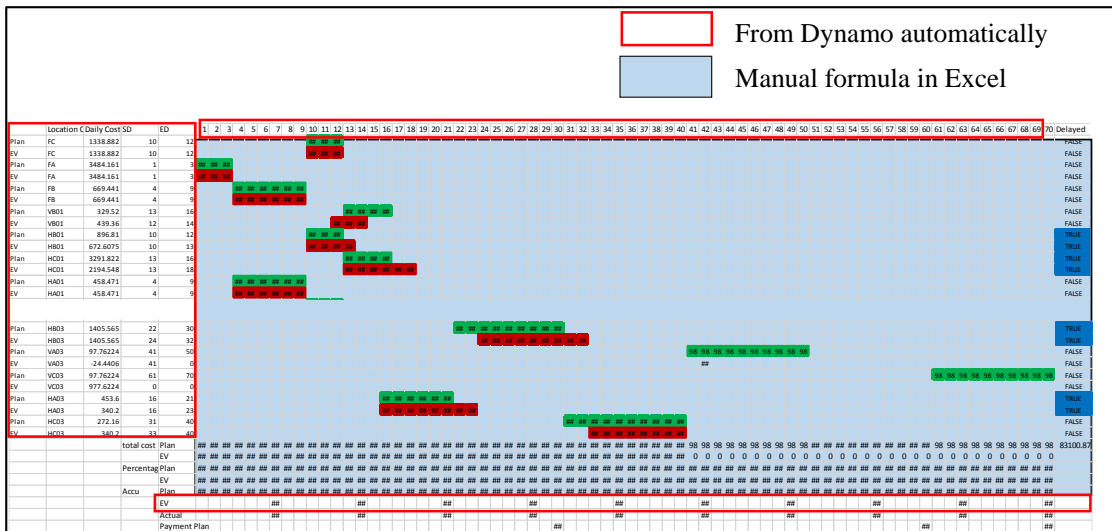


Figure 5-23: Data Path of Cost Plan

The right side is the formula for simulating the Gantt chart and it sums the total daily cost at the bottom of Gantt chart. The cost plan in Figure 5-24 curve is drawn from the accumulative cost in excel. This cost plan shows the cost trend based on progress of schedule plan.

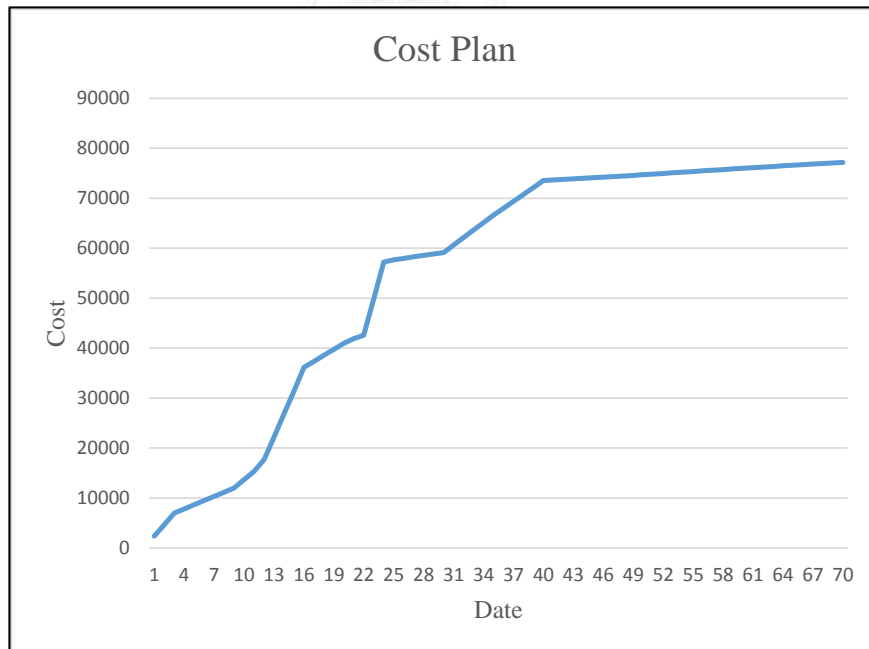


Figure 5-24: Cost Plan Curve in Excel

5.4 Construction Stage

In preconstruction stage, plan scheduling, cost and payment are prepared well and input into Revit with the alive link by dynamo. The output from preconstruction stage are: quantity takeoff, BOQ, cost plan. In construction stage, the desired output that cost manager would like to see are the three progress report, working progress, cost progress, and payment progress. In order to get these progress, construction site needs to collect the actual cost, actual scheduling date, and actual payment information and input to 3D Model in Revit. Dynamo compares the plan data and actual data to judge the progress status on scheduling, cost and payment, then the outcomes of the progress status are both in Revit and excel. The status contains delayed works, over budget works, unpaid but finished works and unapproved but finished works at the checking time during construction. These statuses are visualized in Revit with color scheme, the definition of scheme is that Blue shows delayed elements, Red shows over budget elements and Orange shows unpaid but finished elements, pink shows unapproved but finished elements in Revit.

The process (refer to Figure 5-3) is:

Step 1: record actual completed works date based on schedule work package (Location code) and calculate earn value. (Weekly checking)

Step 2: record actual cost on material and labor based on Location Code and judge the over budget works. (Weekly checking)

Step 3: record the payment applying date and approval date, judge the unpaid but finished works at payment approval date. At the same time, mark unapproved but finished elements in Revit, then show it in Revit by Dynamo. (Monthly checking)

Step 4: repeat step 1-3 until project is delivered. Get the overview S-Curve with plan cost, earn value, actual cost and actual payment.

5.4.1 Input Actual Scheduling Date

This part describes the way to record actual scheduling date and input to the system based on real working progress. In this sample, it plans to input the actual date every week to be more practicable. There are two part to input the actual scheduling date, one

is inputting date in excel: Schedule in Table 5-4 blue part. Another is inputting the date in Revit model for ongoing activity. “PFD” means partial finished date. Parameter “PFD” is designed to mark the ongoing activity which has started but not finished yet at the checking time. At every end of week, construction site should input the exact start date of activity which is started in this week, and the exact finished date of activity actually finished in this week in Column of “End Date (Actual)” in Table 5-4. Unfinished activity’s “End Date (Actual)” is put “0”. There is an example of the table of schedule with actual date until day 42 in Table 5-9, it contains some “0” which are the activities haven’t start yet at the checking date 42.

Table 5-9: Schedule Table with Partial Actual Date

Location Code	Start Date (Plan)	End Date (Plan)	Start Date (Actual)	End Date (Actual)
FA	1	3	1	3
FB	4	9	4	9
FC	10	12	10	12
HA01	4	9	4	9
HA02	12	15	11	14
HA03	16	21	16	23
HB01	10	12	10	13
HB02	16	22	15	19
HB03	22	30	24	32
HC01	13	16	13	18
HC02	23	24	20	25
HC03	31	40	33	40
VA01	10	12	10	11
VA02	16	20	15	22
VA03	41	50	41	0
VB01	13	16	12	14
VB02	21	25	23	26
VB03	51	60	0	0
VC01	17	20	15	22
VC02	26	35	28	37
VC03	61	70	0	0

On the other side, for the activity that has started but didn’t finish yet at the checking date, they should select the corresponding partial finished elements in 3D Model, and assign the current date in the parameter “PFD”. For example, at the 6th week day 42, only three columns of activity VA03 are finished, then the three columns in 3D model are selected and put 42 to “PFD”. The process is showed in Figure 5-25.

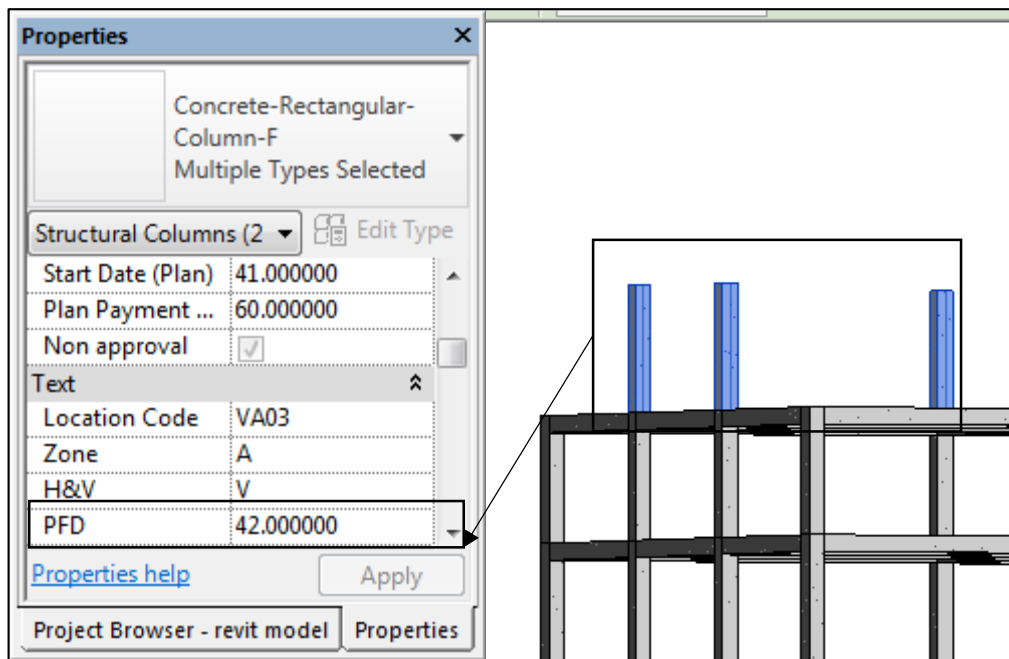


Figure 5-25: Assigning “PFD” for Ongoing Activity at Checking Date 42

The actual scheduling date in excel is automatically input to Revit by Dynamo 2. The result of the parameter value of date after assigning actual date is like in Figure 5-26, taking the first week activity as example. The finished elements gets the right actual start and end date, ongoing elements get the actual start date, PFD value, and its actual end date is 0. For the elements that haven't started get both 0 for the actual start and end date.

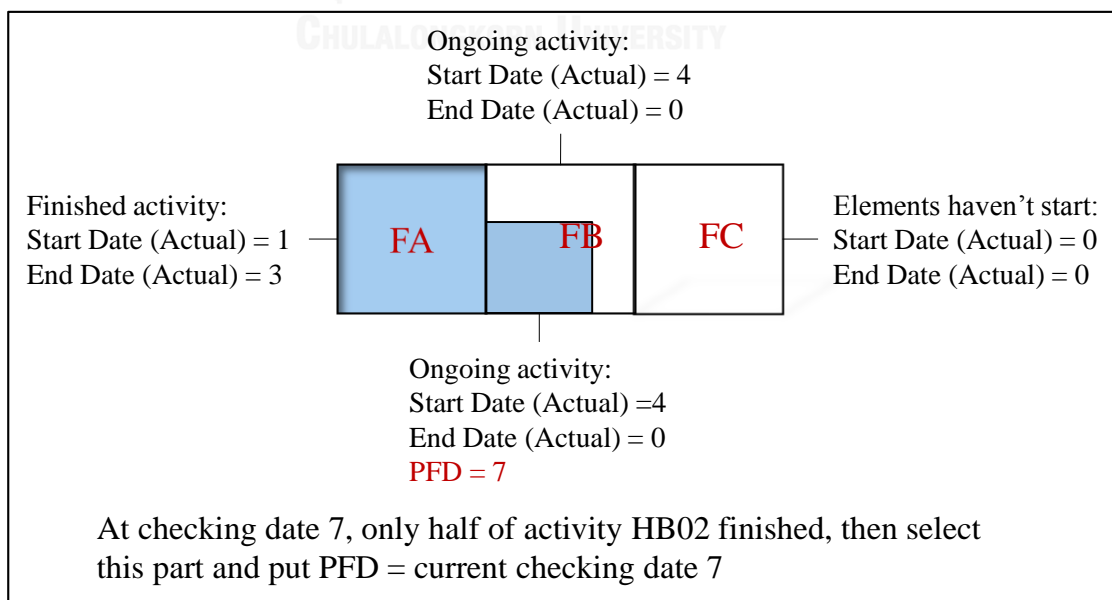


Figure 5-26: Result of the Elements' Actual Scheduling Value at First Week in Revit

5.4.2 Calculate Earn Value with Dynamo 2

This part describes the way how the system calculating the earn value with the actual scheduling date input. Earn value means the accumulative plan cost for the actual completed works. The algorithm for calculating the earn value is summarized in the Figure 5-27. At every week, the corresponding earn value is calculated in dynamo 2 once actual scheduling date is input. It takes reference from the PFD parameter value, Start Date (Actual), End Date (Actual) and element cost of elements in Revit.

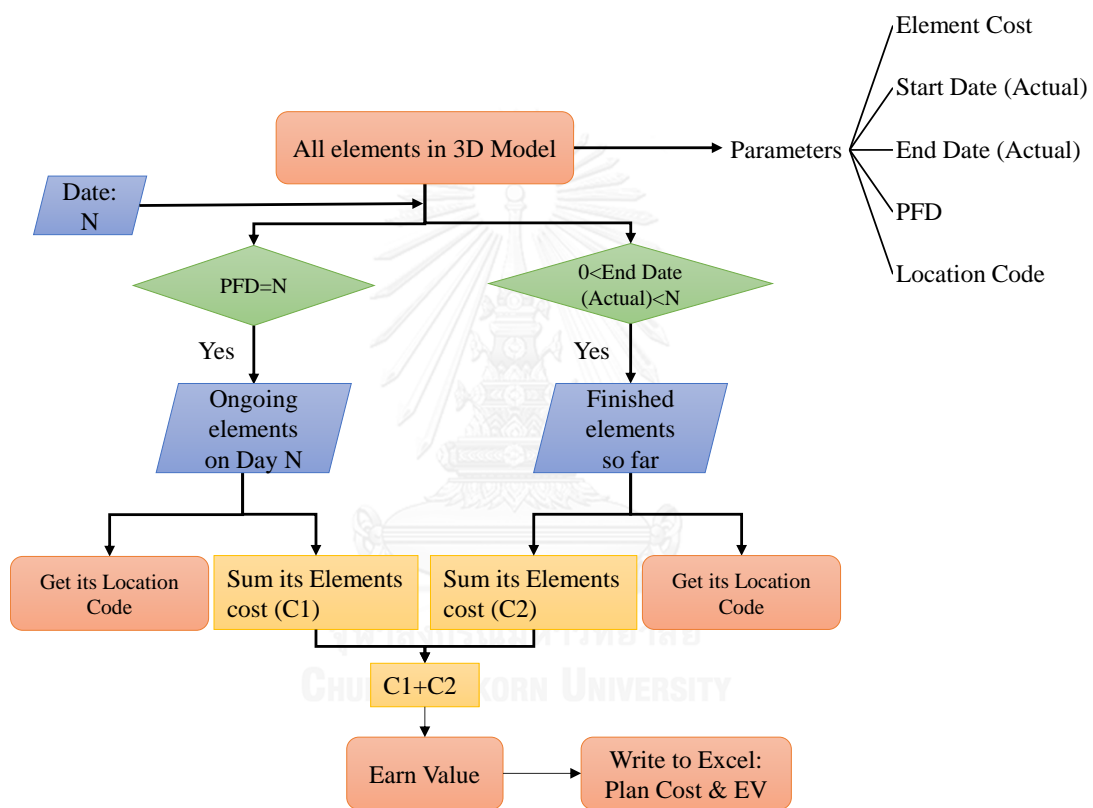


Figure 5-27: The Algorithm for Earn Value Calculation

So the actual finished works in Revit so far (before checking date N) contains the two part of works. First is the actually finished activities whose “End Date (Actual)” value is lower than checking date N but higher than 0 (filter out the elements haven’t start). Second is the elements that have started but the whole total activity haven’t finish yet, whose “PFD” is current checking date N. So there are 2 logic conditions for selecting the earned elements:

“ $0 < \text{End Date (Actual)} < N$ ”

“PFD = N”

All finished elements are selected with above logic conditions. Then earn value is the sum of all elements' Element Cost. Finally Dynamo 2 writes the earn value into the bottom of Excel 4: Cost Plan & EV in Figure 5-22.

5.4.3 Input Actual Cost

This part describes the recording tables of actual cost on material and labor. The materials contains concrete, steel and formwork. According to these recordings, total cost report over time is got form the summation of the above four recordings. In this sample, actual cost is recorded every week and they are remarked by location code as well. Finally, we can not only get the total cost of every week, but also the cost of every activity. The example of 6th week's total cost record is showed in Figure 5-28. In the total cost report, the activity's weekly cost and total activity cost are both summarized. The total cost report can be compared with schedule cost in Table 5-8 and cost plan in Figure 5-22. The example of the record of actual concrete cost is in Table 5-10, this example shows the concrete using to particular activity every weeks until 6th week.

Table 5-10: Record of actual concrete cost

Record of Actual Concrete Cost (USD)											
Location Code	Week 1	2	3	4	5	6	7	8	9	10	Sum
FA	7435										7435
FB	859	859									1719
FC		1789									1789
HA01	480	470									950
HB01		909									909
HC01		2897	7787								10684
VA01		506									506
VB01		591									591
VC01			466	30							496
HA02		924									924
HB02			8489								8489
HC02			185	719.43							904
VA02			456	40							496
VB02				596							596
VC02				50.62107	354.3475	162.4843					567
HA03			824.29	100							924
HB03				5639.413	2869.707						8509
HC03					308.096	616.192					924
VA03						101.2421					101
VB03											0
VC03											0
Sum	8775	8946	18208	7175	3532	880	0	0	0	0	

Total Cost Record (USD)												
Location Code	Week 1	2	3	4	5	6	7	8	9	10	Sum	
FA	11940	0	0	0	0	0	0	0	0	0	11940	
FB	2802	2802	0	0	0	0	0	0	0	0	5604.744	
FC	0	4360	0	0	0	0	0	0	0	0	4359.742	
HA01	1415	1375	0	0	0	0	0	0	0	0	2790.826	
HB01	0	2650	0	0	0	0	0	0	0	0	2650.43	
HC01	0	4389	10861	0	0	0	0	0	0	0	15250.17	
VA01	0	858	0	0	Actual cost of activity (send to "Schedule cost" to check over budget activity)					0	857.6224	
VB01	0	1423	0	0						0	1423.08	
VC01	0	0	788	210	0	0	0	0	0	0	997.6224	
HA02	0	2541	0	0	0	0	0	0	0	0	2541.048	
HB02	0	0	12530	0	0	0	0	0	0	0	12530.09	
HC02	0	0	541	2190	0	0	0	0	0	0	2731.082	
VA02	0	0	824	140	0	0	0	0	0	0	964.087	
VB02	0	0	0	1293	0	0	0	0	0	0	1293.08	
VC02	0	0	0	98	684	231	0	0	0	0	1013.147	
HA03	0	0	2250	398	0	0	0	0	0	0	2647.696	
HB03	0	0	0	8433	4277	0	0	0	0	0	12710.09	
HC03	0	0	0	0	902	1684	0	0	0	0	2586.048	
VA03	0	0	0	0	0	196	0	0	0	0	195.5245	
VB03	0	0	0	Actual Cost Progress					0	0	0	0
VC03	0	0	0						0	0	0	0
Sum	16157	20398.8	27793.78	12762.11	5863.047	2110.605	0	0	0	0		
Accumulative	16157	36556.14	64349.92	77112.02	82975.07	85085.68	85085.68	85085.68	85085.68	85085.68		

Figure 5-28: Record of Total Cost

The accumulative actual cost in bottom row of Figure 5-28 shows the actual cost progress based on the week time unit, which is used to draw the actual cost progress curve in Figure 5-29. Apparently the accumulative actual cost stops at 6th week which is the current time. The curve is built in Excel instead of Dynamo.

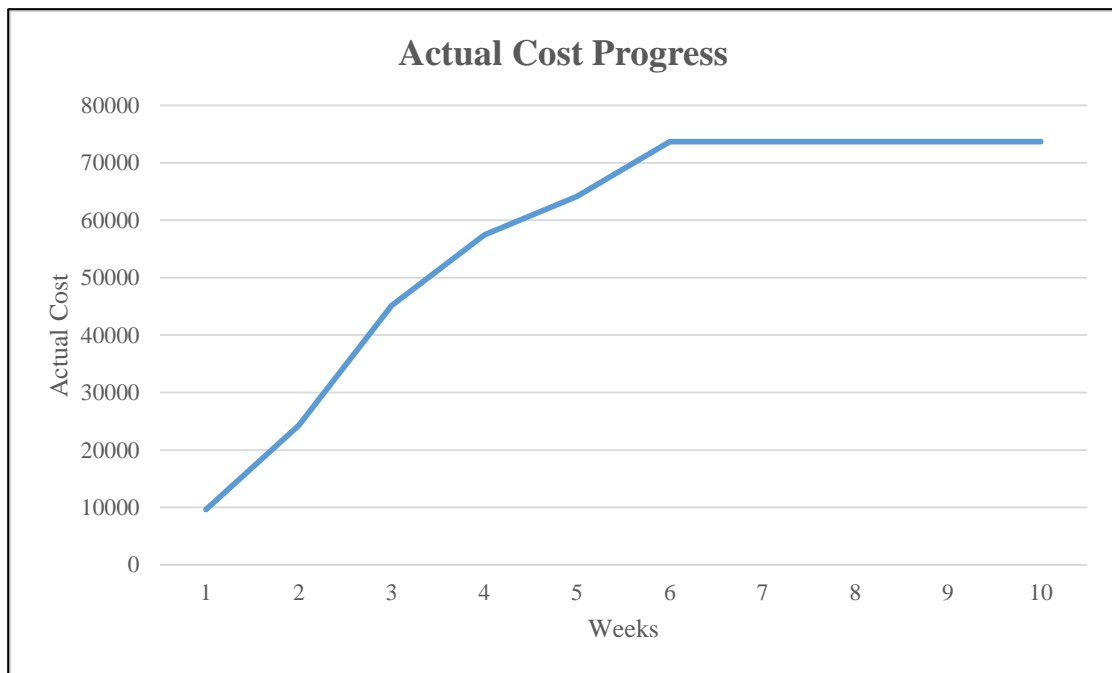


Figure 5-29: Actual Cost Progress

The sum of every activity is in last column of Figure 5-28, these data is used to compare with the schedule cost to judge the over budget activity. The comparison is showed in next part about output over budget elements in 5.4.6.

5.4.4 Payment Checking Date

This part describes the way to process the actual payment progress. There are two parts for payment progress recording, first is the payment date of applying and approval to find out the payment amount and unpaid but finished elements, second is recording the unapproved but finished elements. In this sample, the engineer is designed to check the working progress at 28th of every month and submit the application of payment to owner. The payment amount is the plan cost in BOQ of the checked and completed works. The working progress is checked based on activity, ongoing activity is not counted into the current payment. Basically, the payment approval date is 2 or 3 weeks later than the payment application date (refer to Figure 4-8), the activities completed in this time differentiation between payment application date and payment approval date are seen as unpaid but finished elements. Cost of these elements are required by cost manager, so Dynamo 6 is designed to visualize and calculate these part of elements.

To filter out the unpaid but finished elements and monitor payment, the input information is only the date of payment checking and payment approval. The details are showed in next part on dynamo 6. The example of the payment checking date record is in the Table 5-11.

Table 5-11: Record of Payment Checking Date

Payment record	
Payment Applying Date	Payment Approval Date
28	42
58	68
70	84

In the second part, the elements that unapproved but finished elements should be recorded in Revit. This is to warn the project manager that the works may have problems on quality or the changes he should pay attention. The way to record it is by selecting the unapproved elements and click the parameter “Non approval” in Revit, the example is showed in Figure 5-30.

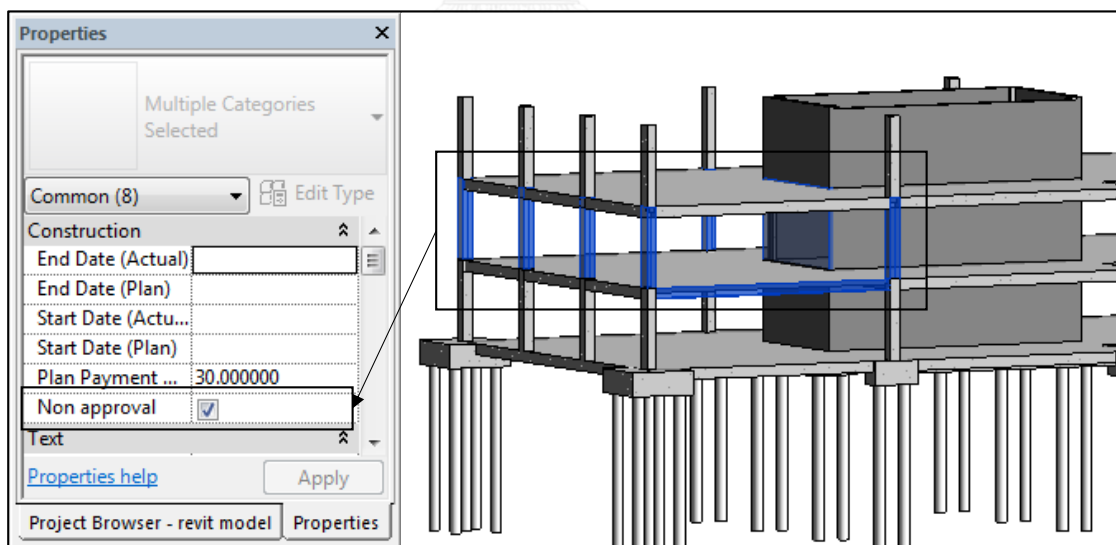


Figure 5-30: Example of Marking Unapproved but Finished Elements at Payment Applying Date

5.4.5 Output during Constructin Stage: Working Progress and Delayed Workings

This part describes the algorithm to judge the delayed elements and visualize delayed elements in Revit.

To judge the delayed elements, there are two factors are compared for judgment, time and quantity. For finished activity, compare the finished date between plan and actual. For ongoing activity, compare the completion quantity of works between plans and actual, since the ongoing activity is no finished date in Revit.

How to check each activity whether it is delayed or not? According to the scheduling date of elements in Revit (refer to Figure 5-26), every activity's actual completion percentage at checking date N is calculated below. N can be 7, 14, 21 ... and so on, the weekly date. The concept of completion percentage calculation is in Figure 5-30. It is divided to be 2 parts:

- 1) If the $0 < \text{"End Date (Actual)} < N$, the activity is completed 100%.
- 2) If the $\text{"PFD} = N$ ", then sum the "Element Cost" of these elements (C1) and get its' corresponding total cost (C2) based on Location Code (refer to Table 5-8). Then the $\frac{C1}{C2} * 100\%$ will be the completion percentage of the ongoing activity. C1 is from dynamo 2 and the percentage of completion is from formula in Excel. The result of the ongoing activity summary is Table 5-12 and the result is until the 6th week.

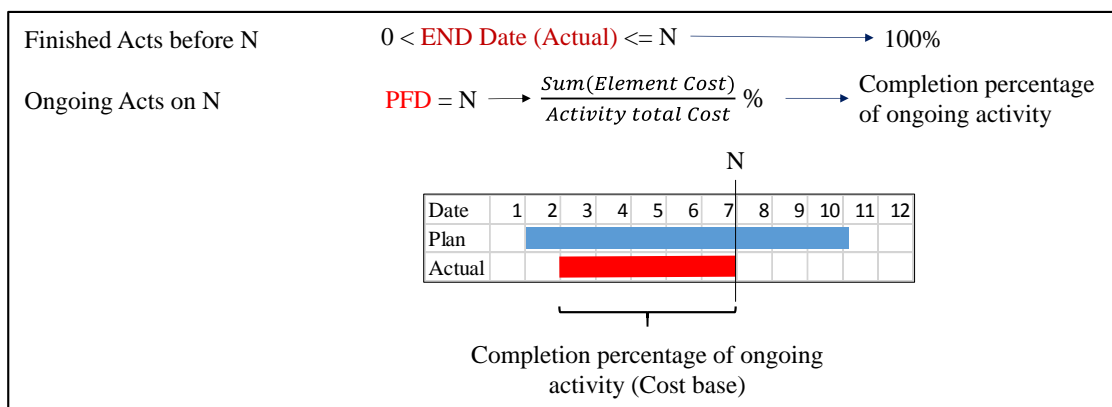


Figure 5-31: Concept of Completion Percentage Calculation

Table 5-12: Ongoing Activity's Completion percentage from Dynamo

Week	Ongoing Location Code	Earn Cost	Percentage
Week 1	HA01 Total	1583.86	58%
	FB Total	2008.32	50%
Week 2	HC01 Total	1683.60	13%
	VC01 Total	443.81	45%
Week 3	VA02 Total	532.77	54%
	HC02 Total	972.00	36%
	HA03 Total	2328.91	86%
Week 4	HB03 Total	12261.29	97%
	VC02 Total	147.94	15%
Week 5	HC03 Total	1360.80	50%
	VC02 Total	355.88	36%
Week 6	VA03 Total	221.90	23%

Based on actual completion percentage of every activity, the conditions for delayed elements are the also divided to two parts:

- 1) For the finished activity ($0 < \text{End Date (Actual)} \leq N$), the delayed activities will meet the requirement: “End Date (Actual) > End Date (Plan)” which means the activity late finished.
- 2) For the ongoing activity ($\text{PFD} = N$), if the actual completion percentage is lower than plan completion percentage will be seen as delay. Here the plan completion

$$\text{percentage is } \frac{N - \text{Start Date (Plan)}}{\text{End Date (Plan)} - \text{Start Date (Plan)}} * 100\%.$$

Equation 4: Plan Completion Percentage

The concept of how to filter out the delay elements is in Figure 5-31, it takes the 6th week as an example ($N=42$). Algorithm for the delayed elements in dynamo 2 is summarized in Figure 5-32

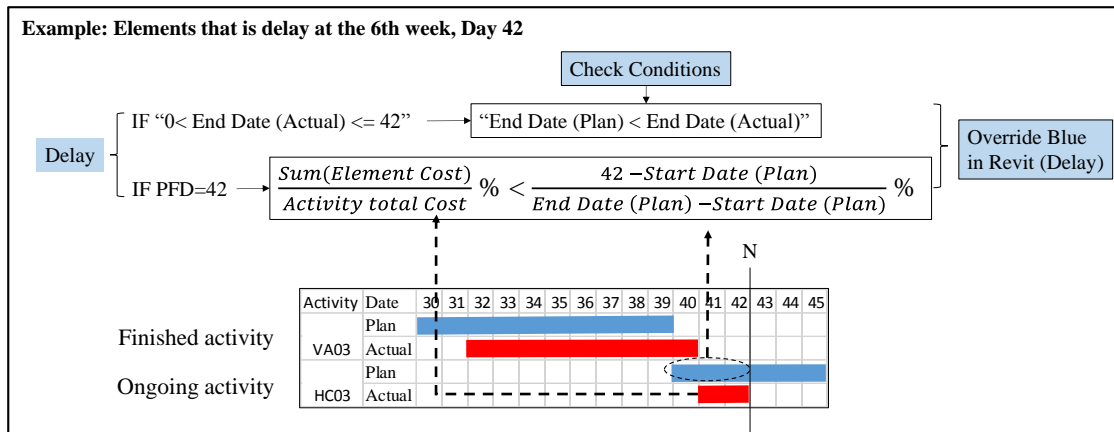


Figure 5-32: Concept for Filtering Delayed Elements (N=42)

For the actual ongoing activities earn value is based on the cost, plan completion percentage is based on the time and duration. Plan completion percentage assumes that the cost of completed works of every day are the same in duration of this activity. The algorithm in Dynamo 2 to calculate Earn Value is in Figure 5-27. This earn value means the total plan cost of completed works until the checking date N.

Diagram for getting delayed elements

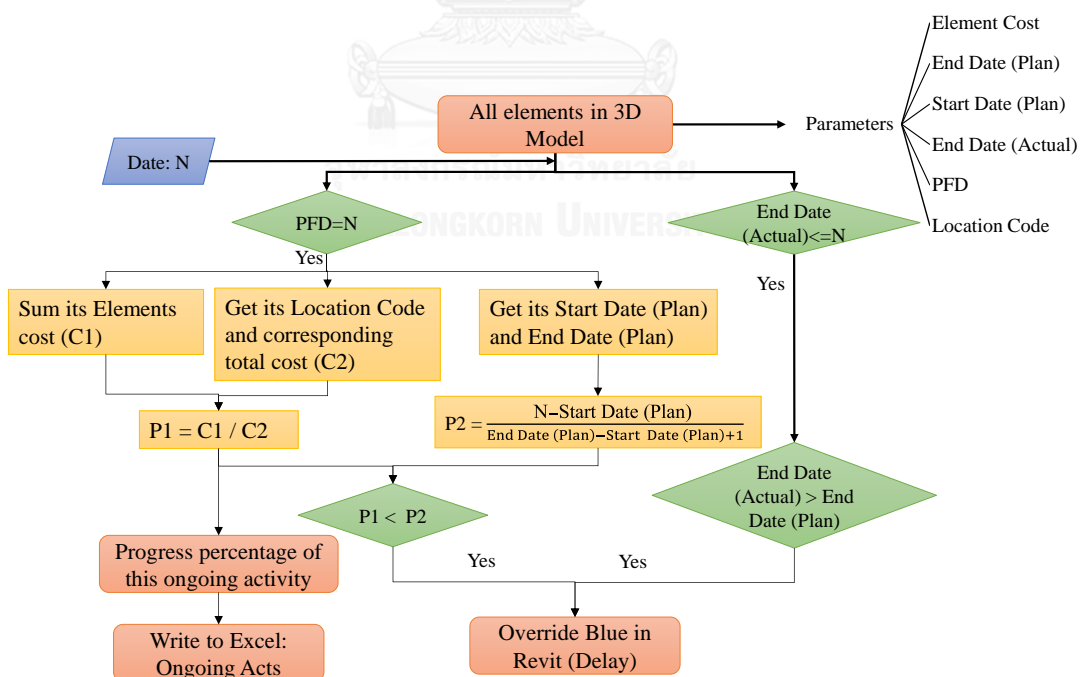


Figure 5-33: Algorithm for Filtering Delayed Elements in Dynamo 2

The output of this algorithm is the ongoing activity’s location code and corresponding element cost in Excel, and the delayed elements location code and its cost. And it

overrides delayed elements in blue color in Revit, the outcome is in Figure 5-33. Moreover, the elements that haven't start are hidden in view, the algorithm is in Figure 5-34 which is achieved in dynamo 2 as well.

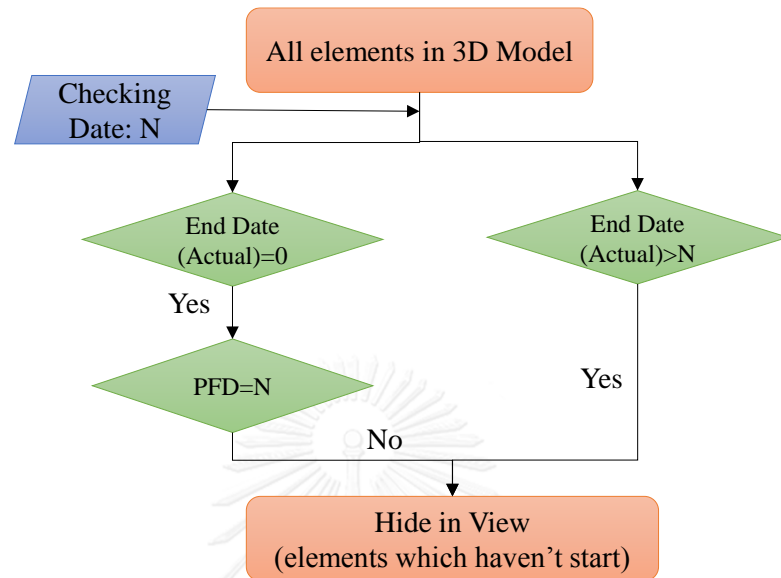


Figure 5-34: Hide the Elements that haven't Start until Date N in the 3D Model

In Excel: Delayed activities and corresponding cost										
Delayed Activities	VC01	VA02	VC02	HB01	HC01	HC02	HA03	HB03	VB02	
Delayed Activities' Earn Value	977.6224	977.6224	977.6224	2690.43	13167.29	2721.6	2721.6	12650.09	1318.08	

In Revit: Delayed elements are displayed in Blue

The elements that haven't started are hidden in View
The displayed model are the current working progress

Figure 5-35: Output of Working Progress and Delayed Elements (Historical)

In Figure 5-34, it shows the delayed elements until day 42, the 6th week in blue color. And the model only show the started elements until day 42.

Another working progress that project manager would like to know is the elements that currently delay instead of all elements that have delayed so far. So the same function but except the work package that finished already at the checking date, here the delayed elements called current delay. The outcome of current delay is showed in Figure 5-36.

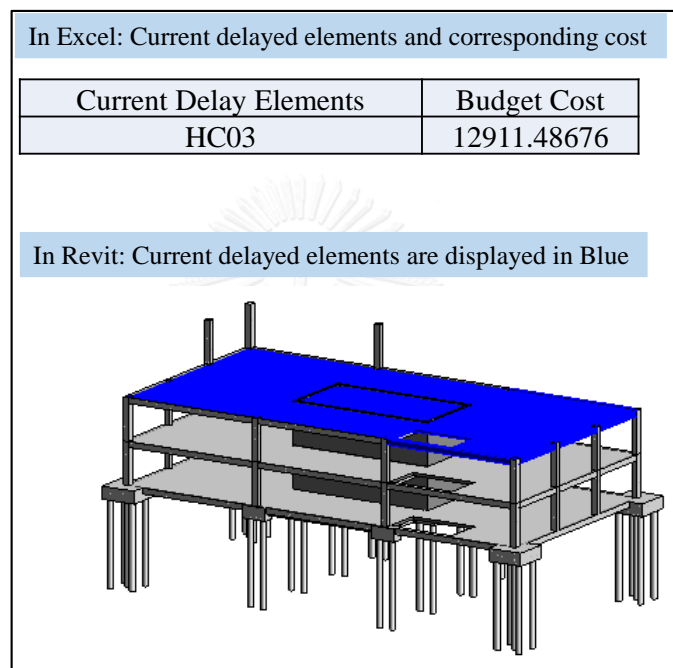


Figure 5-36: Output of Current Delayed Works

In order to make the delayed and working progress more visible in Excel, the ongoing activity's completion percentage in Table 5-12 and the delayed activity in Figure 5-34 are transferred in Gantt chart of cost plan sheet in excel, the specification is in Figure 5-35. In this figure, the delayed activities are highlighted in blue from Figure 5-34, and yellow activity is ongoing activity at the current checking date (day 21). Green Gantt chart bar is plan progress and Red is Earned progress. The data of location code, start date and end date on both plan and actual are output from Dynamo 2, but the Gantt chart is drew in Excel, ongoing activity and delayed activity are highlighted by Excel too.

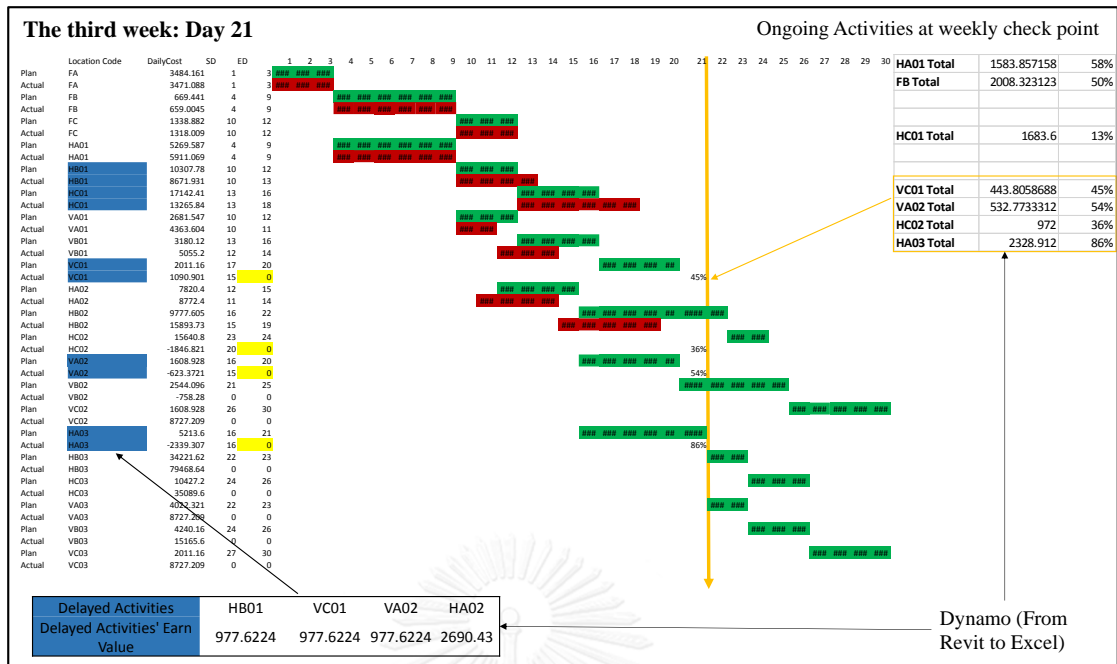


Figure 5-37: Result of Working Progress in Excel

5.4.6 Output during Construction Stage: Over Budget Workings

This part describes how to judge the over budget elements by comparing plan cost and actual cost. It shows the table for comparison between plan cost and actual cost. Visualization of over budget elements in Revit is given. Here the over budget visualization contains 5 parts separately which are concrete cost over budget, formworks over budget, steel cost over budget, labor cost over budget and total cost over budget. According to the different objects' over budget visualization, cost manager is able to compare the 5 over budget visualization to figure out the resource and reason of over budget part on materials or labors. From actual cost recording, the data is already recorded by materials type and labor separately, so the 5 visualization is possible and easy to get by comparing plan and actual data.

Actual cost from record is compared with plan cost to judge the over budget elements. Object of plan and actual cost is work package (Location Codes), mentioned above in Table 5-8 for plan cost and in Figure 5-28 for actual cost. The comparison excel for over budget is in Table 5-13. Dynamo 5: "Over budget" judges out the over budget work package and overrides Red in Revit model at the same time which is showed in Figure 5-36. The sample is until the day 42, 6th week.

Table 5-13: Comparison Excel for Over Budget Work Package

Location Code	Volume	Element Cost	Over budget Acts
FA	20.79	10452.48	1487.07
FB	4.68	4016.65	1588.10
FC	4.04	4016.65	343.10
HA01	5.89	2750.83	40.00
HA02	6.40	2706.05	-165.00
HA03	6.40	2706.05	-58.35
HB01	6.02	2690.43	-40.00
HB02	90.19	12650.09	-120.00
HB03	90.19	12650.09	60.00
HC01	91.55	13167.29	2082.89
HC02	6.60	2706.05	25.03
HC03	6.60	2706.05	-120.00
VA01	6.60	977.62	-120.00
VA02	6.60	977.62	-13.54
VA03	6.60	977.62	-782.10
VB01	12.00	1318.08	105.00
VB02	12.00	1318.08	-25.00
VB03	12.00	1318.08	-1318.08
VC01	6.60	977.62	20.00
VC02	6.60	977.62	35.52
VC03	6.60	977.62	-977.62

The corresponding elements with the red cell are over budget. The rule is “Actual Cost > Element Cost (in Excel: Schedule Cost)”. In the last column of Table 5-13, the negative data contains the activity haven’t be completed, so the actual cost haven’t recorded so far which is much lower than the plan cost. In Figure 5-36 the elements that haven’t start are hidden in view which follow the same rule in Figure 5-33.

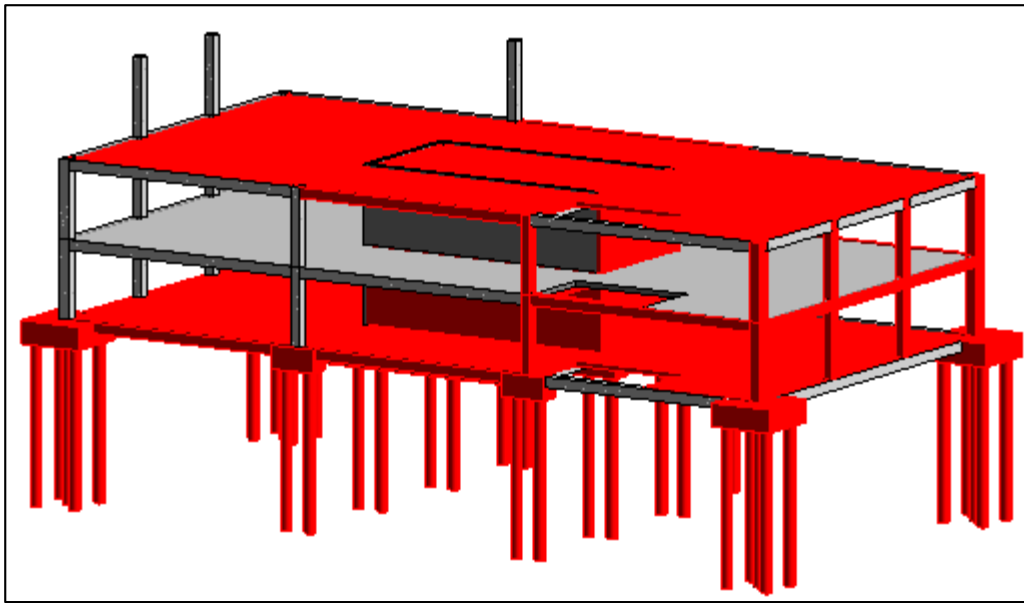


Figure 5-38: Result of over Budget Elements in Revit (until 6th week)

Based on the same rules, the visual programming in Dynamo for over budget elements is designed to visualize every material type's and labor's over budget status separately. The table of the data for comparison on all materials and labor is in Table 5-14. The plan data is from BOQ in preconstruction stage (Table 5-8) and the actual cost is from the actual cost recordings (refer to Table 5-10). Actual cost in this table is the recordings until date 42, so actual cost of the work package that haven't start are 0.

Table 5-14: Over Budget Elements Comparison Table(including Materials and Labor)

Over Budget Elements Comparison Table										
Location Code	Concrete-C	Formwork-C	Steel-C	Labor-C	Element Cost	Actual Concrete Cost	Actual Formwork Cost	Actual Steel Cost	Actual Labor Cost	Actual Total Cost
FA	5183.2	830.0	50.5	945.8	7009.6	5100.0	800.0	50.0	900.0	6850.0
FB	1579.9	333.1	15.4	288.3	2216.8	1500.0	300.0	22.0	300.0	2122.0
FC	1579.9	333.1	15.4	288.3	2216.8	323.2	800.0	700.0	230.0	2053.2
HA01	939.6	158.5	1539.6	113.2	2750.8	949.6	168.5	1549.6	123.2	2790.8
HA02	924.3	155.9	1514.5	111.4	2706.0	924.3	155.0	1459.5	120.0	2658.8
HA03	924.3	155.9	1514.5	111.4	2706.0	924.3	152.7	1461.6	109.1	2647.7
HB01	199.9	33.7	327.5	24.1	585.1	200.0	30.0	370.0	50.0	650.0
HB02	727.7	122.8	1192.4	87.7	2130.6	2000.0	39.6	820.4	0.0	2860.0
HB03	727.7	122.8	1192.4	87.7	2130.6	750.0	130.0	1180.0	100.0	2160.0
HC01	9410.6	1538.3	2611.3	1398.3	14958.5	8800.0	1250.0	3060.0	1480.0	14590.0
HC02	8655.7	1411.0	1537.5	1307.4	12911.5	8300.0	1550.0	1800.0	1350.0	13000.0
HC03	8655.7	1411.0	1537.5	1307.4	12911.5	8852.2	1404.1	2133.6	1291.0	13680.9
VA01	506.2	163.9	333.5	192.9	1196.6	506.2	123.9	293.5	120.5	1044.2
VA02	506.2	163.9	333.5	192.9	1196.6	496.2	173.9	343.5	150.5	1164.2
VA03	506.2	163.9	333.5	192.9	1196.6	100.0	60.0	80.0	30.0	270.0
VB01	576.0	266.4	295.7	300.0	1438.1	591.0	296.4	325.7	210.0	1423.1
VB02	576.0	266.4	295.7	300.0	1438.1	596.0	216.4	330.7	150.0	1293.1
VB03	576.0	266.4	295.7	300.0	1438.1	0.0	0.0	0.0	0.0	0.0
VC01	507.1	164.3	334.0	193.4	1198.8	540.0	220.0	220.0	220.0	1200.0
VC02	506.2	163.9	333.5	192.9	1196.6	700.0	136.4	210.0	210.0	1256.4
VC03	506.2	163.9	333.5	192.9	1196.6	0	0	0	0	0

Visual programming in Dynamo for over budget compares every materials and labors cost between plan and actual data based on work package level. The outcome of this Dynamo in Revit is showed in Figure 5-39. Form the 5 visualization comparison, cost manager can locate the total cost over budget elements and target the specific material or labor that cause the total cost budget. For example in Figure 5-39, the elements in blue circle, it shows only steel cost is over budget while the other materials and labor cost are not over budget. So that the reason of this total cost over budget of this circle part is because of steel instead of concrete, formworks, or labor. Cost manager will focus the steel cost of this part instead of wasting time on formwork cost, concrete cost and labor cost. This comparison narrowed down the range of irrelevant possible reasons for analysis which improves the efficiency of problems detection.

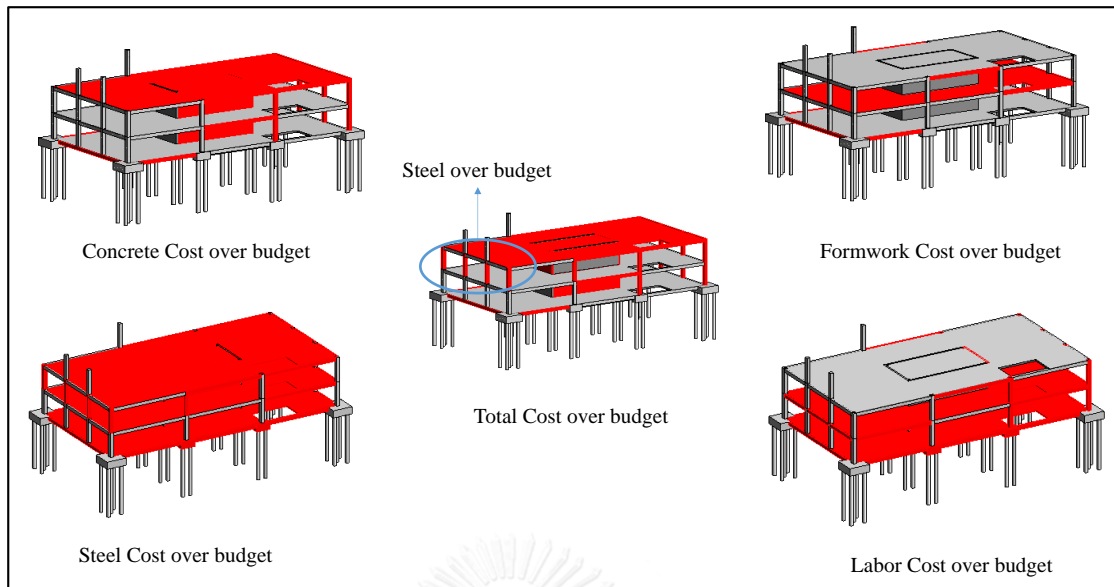


Figure 5-39: Outcome over Budget Visualization Comparison (including Materials and Labor)

5.4.7 Output during construction stage: payment progress status

This part describes the algorithm to visualize the unpaid but finished elements and unapproved but finished elements in Revit and export the corresponding cost in Excel. The reason of existence of the unpaid but finished elements is because there is a time difference between payment applying date and payment approval date as describes in Figure 5-37. It assumes that the contractor gets the payment at the payment approval date, and the payment amount is the cost of finished activity until the payment applying date. Ongoing activity is not included and checked by engineer at the payment applying date.

The date is recorded in Table 5-11 which is required by dynamo to decide the unpaid but finished elements. The algorithm of Dynamo 6 for unpaid but finished elements is summarized in Figure 5-37. The unpaid but finished elements at the checking date are override in orange in Revit, showed in Figure 5-38. Dynamo 6 also calculates the unpaid but finished elements' cost that grouped by location code in Excel.

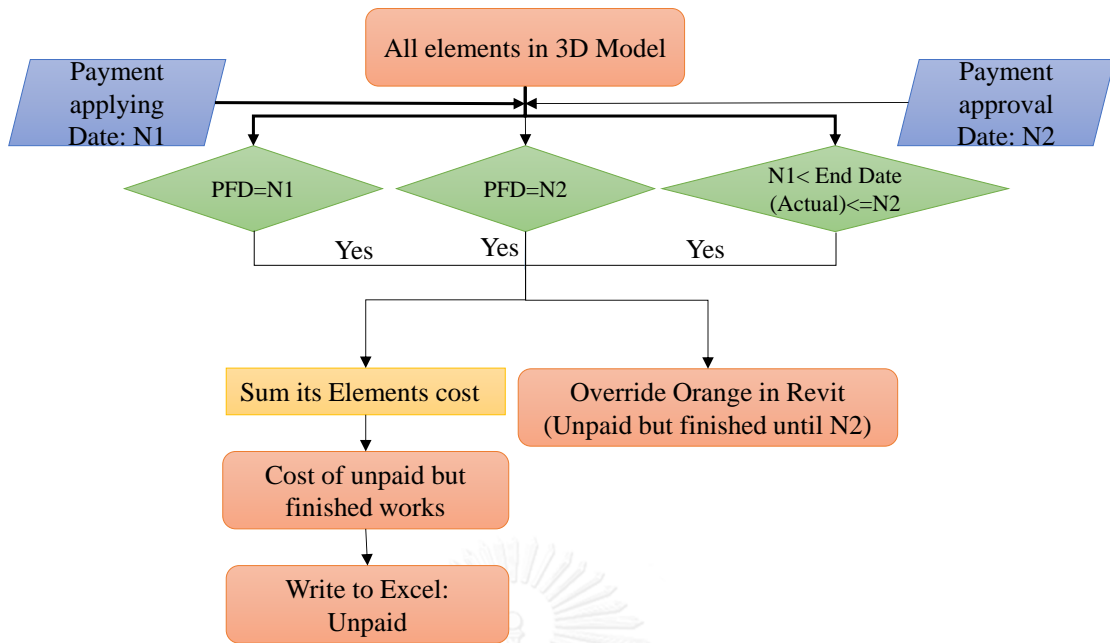


Figure 5-40: Algorithm for the Unpaid but Finished Elements

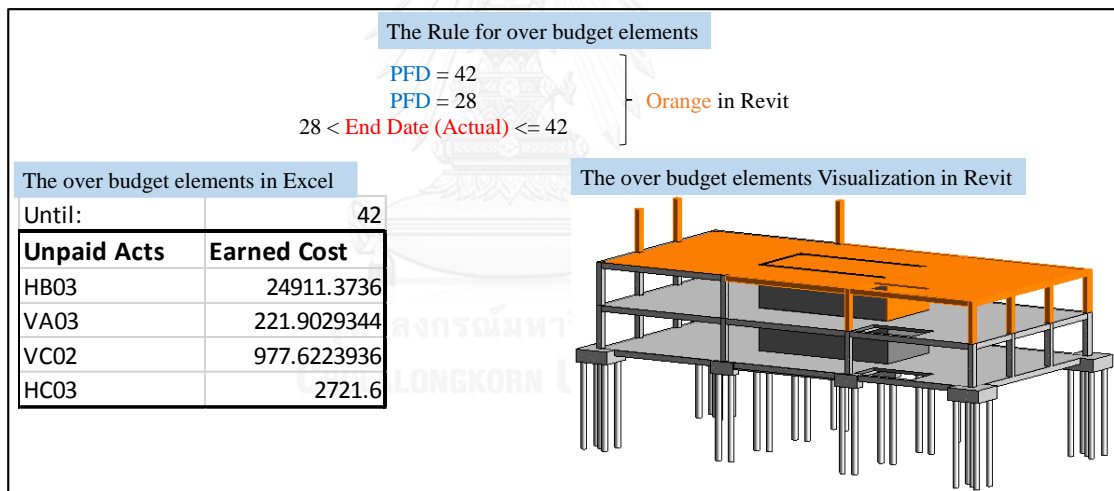


Figure 5-41: Result of the Unpaid but Finished Elements in Excel and Revit

For the unapproved but finished elements, project manager has to mark the elements that unapproved but finished in Revit like the way that showed in Figure 5-30. By algorithm in Dynamo, it checks the parameter “Non approval” value which is “yes” to override pink color in Revit. Because the elements that finished but unapproved by engineer for payment, so the payment amount is the contract cost of approved part only which is excluded the unapproved part. In real cases, the payment amount is took from the contract BOQ instead of the bidding BOQ, so here we assume the contract BOQ which is adjusted from bidding BOQ that we get from the 3D model. The contract BOQ

assumption is in Table 5-15. This contract BOQ is assumed to calculate the actual payment amount, the contract cost is adjusted a little bit from the BOQ (Table 5-8) from the system which is the BOQ for internal budget.

Table 5-15: Contract BOQ (From Assumption)

Contract BOQ	
Work Package	Contract Cost
Work Package	7200
Foundation zone A	2500
Foundation zone B	2200
Foundation zone C	2500
1st Fl. beam&Slab Zone A	2500
1st Fl. beam&Slab Zone B	2500
1st Fl. beam&Slab Zone C	700
1st Fl. column&structural Wall Zone A	2200
1st Fl. column&structural Wall Zone B	2200
1st Fl. column&structural Wall Zone C	15500
2nd Fl. beam&Slab Zone A	12000
2nd Fl. beam&Slab Zone B	13000
2nd Fl. beam&Slab Zone C	1200
2nd Fl. column&structural Wall Zone A	1200
2nd Fl. column&structural Wall Zone B	1200
2nd Fl. column&structural Wall Zone C	1300
3rd Fl. beam&Slab Zone A	1300
3rd Fl. beam&Slab Zone B	1400
3rd Fl. beam&Slab Zone C	1200
3rd Fl. column&structural Wall Zone A	1200
3rd Fl. column&structural Wall Zone B	1200
3rd Fl. column&structural Wall Zone C	76200

The formula for actual payment amount is below, including the payment process which refers to Figure 4-8.

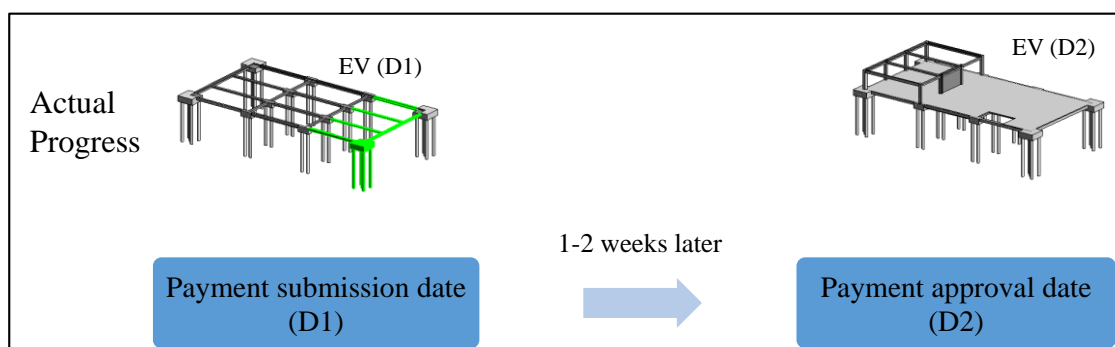


Figure 5-42: Payment Checking Process for System

Formula to calculate payment amount is showed below.

Payment Amount = $\frac{\text{Earn Value}(D1)}{\text{Total budget}}$ * total contract cost- Earn Value (non-approval)

Equation 5: Payment Amount of this System

The payment amount is put in output spreadsheet of S-Curve in Figure 5-44 which is calculated and output by visual programming in Dynamo. The outcome of unapproved but finished elements is in Figure 5-43.

Unapproved but finished elements					
Location Code	Concrete-C	Formwork-C	Steel-C	Labor-C	Element Cost
VA02	423.7	141.6	270.1	166.6	1002.0
HA02	132.8	22.4	217.6	16	388.8
Sum					1390.8

In Revit: unapproved but finished elements are in Green, unpaid but finished elements are in Orange

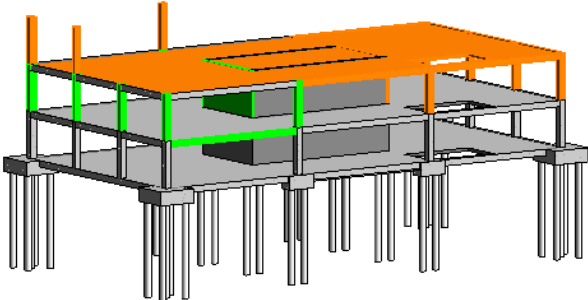


Figure 5-43: The Outcome of Unapproved but Finished Elements (Payment Progress)

5.4.8 S-Curve

This part is a summary of above information in Excel but it is aided by Dynamo as well. It is summarized the plan cost, accrual cost, Earn value and actual payment in one curve, S-curve. The S-curve reveals the overview project progress on working, cost and payment with data details in Figure 5-41. The resources data is exported from Dynamo 7: “S-Curve” to excel, and curve is drew in Excel instead of dynamo automatically.

In S-Curve sheet, it shows the delayed activity and completion percentage of the ongoing activity from above output of dynamo 2. S-Curve in Figure 5-41 is made in the Excel base on the accumulative plan cost, actual cost, earn value and payment (bottom 5 line in Figure 5-39) in real time.

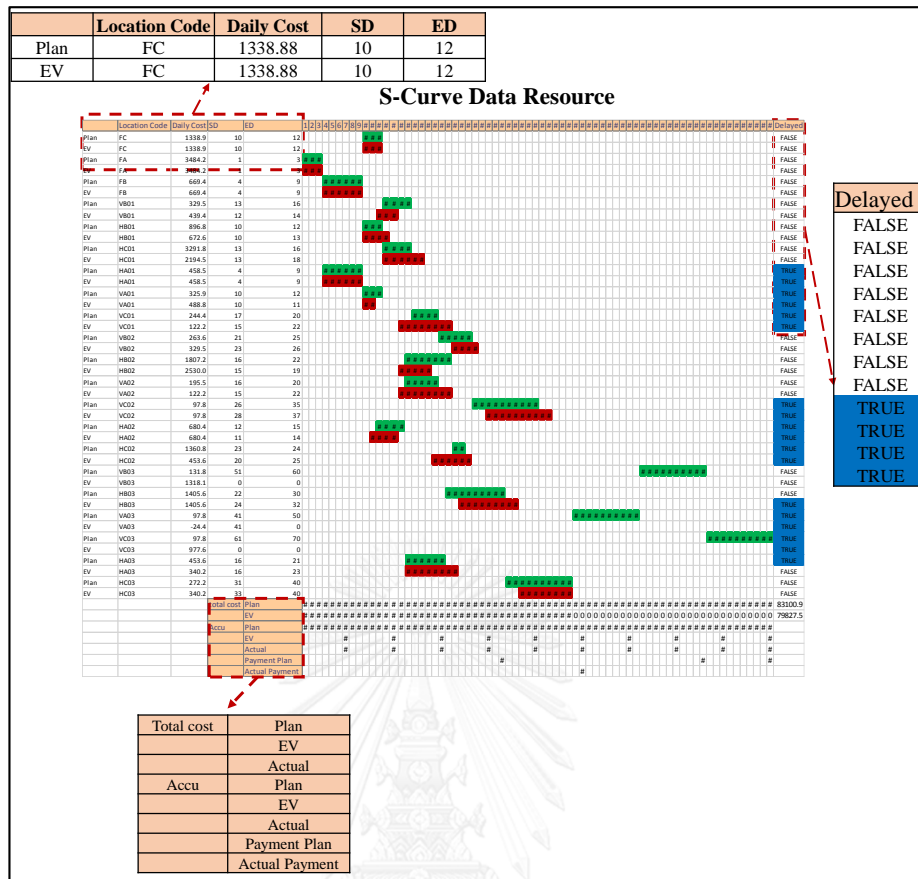


Figure 5-44: S-Curve Data Resource

In this figure, the data from dynamo automatically contains:

- 1) First column: Plan, EV
- 2) Second column: Location Code
- 3) Third column: Daily Cost
- 4) Forth column: SD(Start Date)
- 5) Fifth column: ED(End Date)
- 6) First line: head title and range of date
- 7) Last 4th lines: Accumulative EV

The data from formula in Excel:

- 1) The Gantt chart part: the formula in cell is to show the right daily cost in right duration cell and show the color to stimulate the Gantt chart, enabling the progress visible.

- 2) The bottom line: Total Plan Cost, the formula in cell sum the actual daily cost.
- 3) The bottom line: Total EV is from summing EV's daily cost in Gantt chart part.
- 4) The most right column: Delayed activity is checking from Excel: "Checking activity" from Figure 5-34. If the column "Location Code" contains the delayed activity's location code will be highlighted in Blue.

The summary of Platform where the S-Curve data resource from is in Figure 5-40.

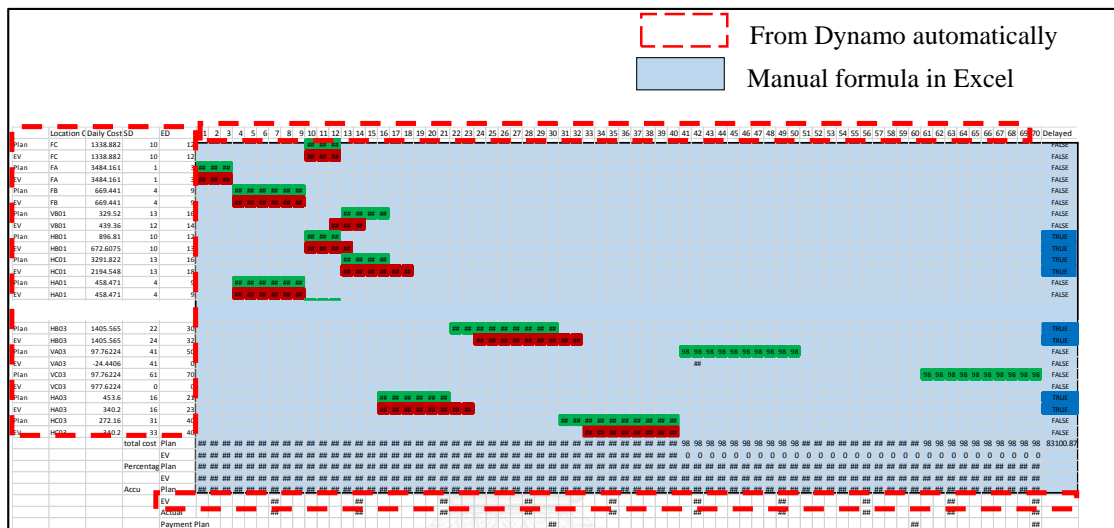


Figure 5-45: Path of Date Resource in S-Curve Sheet

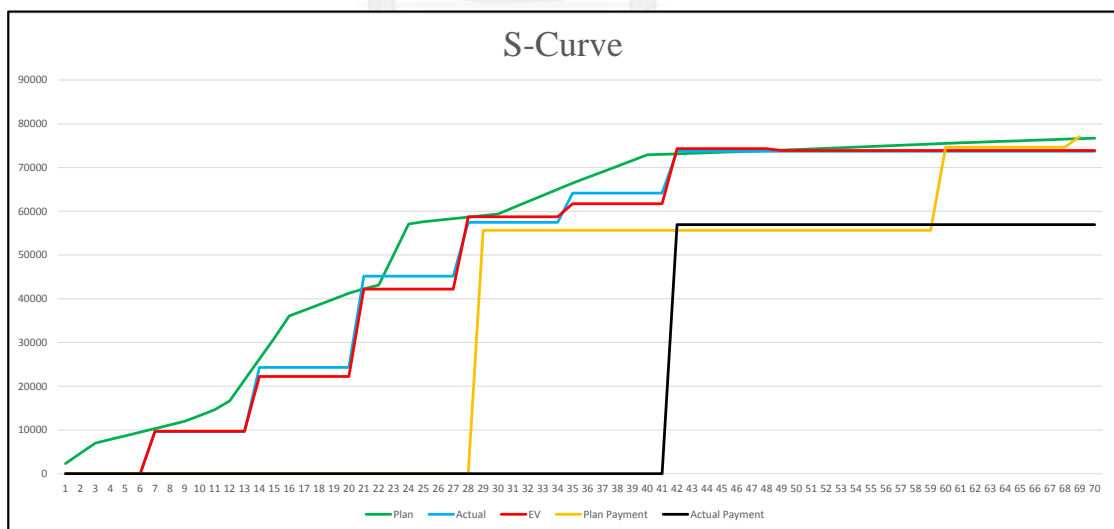


Figure 5-46: S-Curve (until day 42)

As we can see from the S-Curve, the Plan cost grows slowly at the last period, and at the day 42, the first actual payment is occurs which is later 2 weeks than the plan

payment date 28. And the Earn Value, actual cost are checked weekly, the payment checked every month. So the time unit is different among these cost index.

With this S-Curve and the visualization in Revit with three critical progress status: working progress visualization, actual cost status visualization, payment status visualization, the cost manager can have a good look on the current cost status of project.

5.5 Validation and Verification

This part is designed to test whether the output from 5D BIM system is correct or not. The main output tested are quantity takeoff, BOQ, working progress status, cost progress status, payment status. The testing uses 2 methods: Validation and Verification. Validation attempts to confirm that this system is an accurate representation of the real system. In this part, manual calculation in Excel represents the results of real system to compare with result from 5D BIM system for validation of this system. Verification is to assure that the parameters and logical structure of the system represents correctly. In this part, the parameter values in the system are changed to check whether the results from system match with the expected changes or not. In summary, the concept of validation is comparing manual calculation result and system's result. The concept of verification is checking whether the results of system with different input parameter values match the expected results or not, it is internal comparison. Manual calculation of Quantity takeoff and BOQ on the sample model in Figure 5-2 is applied to validate the quantity and cost from 5D BIM system. And for the other progress status in Revit which is not obtained by current practice, it takes verification method. It is verified by changing input data in Excel to check whether the result in Revit changes synchronously or not.

Validation part: quantity takeoff, BOQ, earn value and delayed elements

Verification part: Earn value, delayed elements, over budget elements and unpaid but finished elements

In summary, the validation and verification test about the accuracy of quantity takeoff, BOQ, earn value and delayed elements (working progress status), over budget elements (cost progress status), and unpaid but finished elements (payment status) from 5D BIM system.

5.5.1 Validation on Quantity Takeoff and BOQ

This part manually calculates the quantity of every materials and labor based on the same formula in 5.3.2 which is for 5D BIM system. Total cost of every type of elements are calculated and summarized one by one to be the quantity takeoff backup in appendix 2. Later on, break down the project by floors to get the BOQ to compare with the result from dynamo in Table 5-6. And the comparison result is in table Table 5-14. In this table, pink is from manual calculation and blue is from the 5D BIM system (refer to the Table 5-6).

Table 5-16: Comparison on BOQ based on Element Type between Manual Calculation and 5D BIM System

BOQ Comarison (based on element type)											
Element Type	Manual Concret-C	System Concrete-C	Manual Formwork-C	System Formwork-C	Manual Steel-C	System Steel-C	Manual Labor-C	System Labor-C	Manual Total Cost	System Total Cost	Difference
Foundation											
Pile -2	3154.9	3159.9	667.1	666.3	30.7	30.8	575.7	576.6	4428.5	4433.6	0.1%
Pile -5	5192.0	5183.2	830.4	830.0	50.6	50.508	947.4	945.835	7020.4	7009.6	-0.2%
Floor 1											
Column 400 x400	505.3	495.1	136.6	133.8	388.4	380.5	161.3	158.0	1191.6	1167.4	-2.0%
Column 400 x500	210.6	206.3	51.2	50.2	129.5	126.8	67.2	65.8	458.4	449.1	-2.0%
Beam 400*400	2124.8	2124.1	358.4	358.3	3481.6	3480.5	256.0	255.9	6220.8	6218.9	0.0%
Beam 400*500	498.0	498.0	84.0	84.0	652.8	652.8	60.0	60.0	1294.8	1294.8	0.0%
Wall 200	875.5	887.9	404.9	410.3	449.4	455.3	273.6	277.5	2003.5	2031.0	1.4%
Slab 200	7927.9	7927.9	1291.6	1288.2	659.1	659.1	1219.7	1219.7	11098.3	11094.9	0.0%
Floor 2											
Column 400 x400	505.3	495.1	136.6	133.8	388.4	380.5	161.3	158.0	1191.6	1167.4	-2.0%
Column 400 x500	210.6	206.3	51.2	50.2	129.5	126.8	67.2	65.8	458.4	449.1	-2.0%
Beam 400*400	2390.4	2390.4	403.2	403.2	3916.8	3916.8	288.0	288.0	6998.4	6998.4	0.0%
Wall 200	875.5	887.0	404.9	410.3	449.4	455.3	273.6	277.2	2003.5	2029.8	1.3%
Slab 200	7927.9	7927.9	1291.6	1288.2	659.1	659.1	1219.7	1219.7	11098.3	11094.9	0.0%
Floor 3											
Column 400 x400	505.3	495.1	136.6	133.8	388.4	380.5	161.3	158.0	1191.6	1167.4	-2.0%
Column 400 x500	210.6	206.3	51.2	50.2	129.5	126.8	67.2	65.8	458.4	449.1	-2.0%
Beam 400*400	2390.4	2390.4	403.2	403.2	3916.8	3916.8	288.0	288.0	6998.4	6998.4	0.0%
Wall 200	875.5	887.0	404.9	410.3	449.4	455.3	273.6	277.2	2003.5	2029.8	1.3%
Slab 200	7927.9	7927.9	1291.6	1288.2	659.1	659.1	1219.7	1219.7	11098.3	11094.9	0.0%
									77216.7	77178.6	0.0%

From this result, the result is acceptable which doesn't differentiate too much. The differences between manual result and BIM result can be explained with the intersection between elements in Revit. There is an example to interpret the difference on volume and also formwork area.

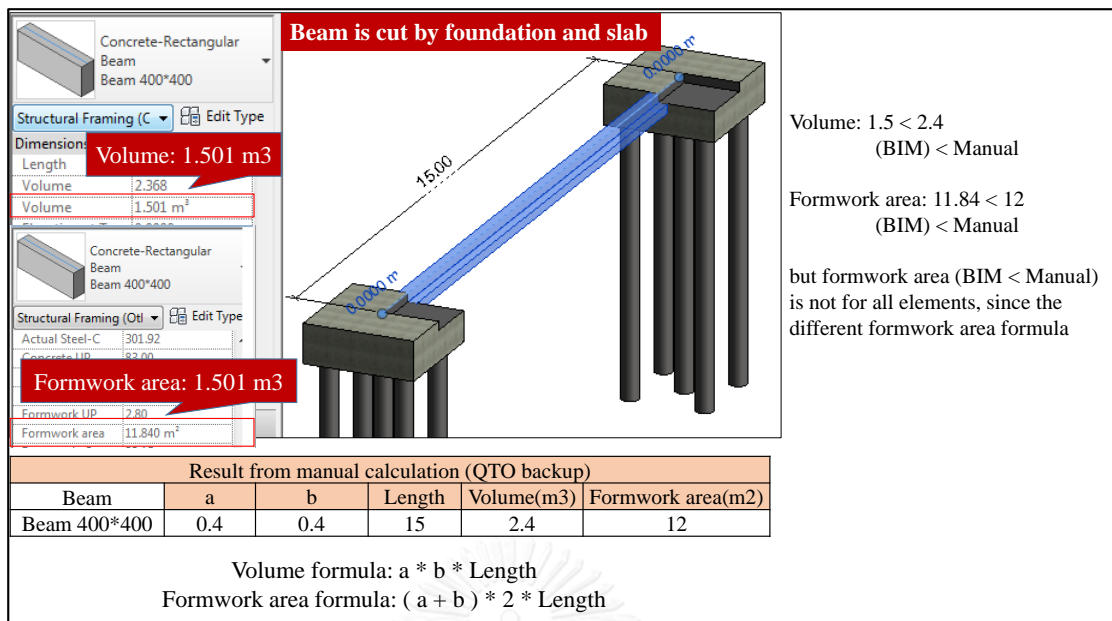


Figure 5-47: Example of Different Result on Quantity Takeoff between BIM System and Manual Calculation

The beam in Figure 5-42 is cut by foundation and slab which changes the length and volume of this beam, so the volume is lower than the manual calculation ($a*b*\text{Length}$). Because the elements are always cut when they meet other elements in model and it is same like situation in real construction site. So the BIM result on volume is always the exact volume of elements which is referred to concrete and labor cost form the formula. For the formworks area, the formula for formwork area are different from element type to type. So the formworks area may higher than the manual calculation for other elements type. Thus if the result difference is in 5%, the result is accepted.

The BOQ based on schedule activity is calculated too by counting the number of every element type of every activity. The cost resource is supported by above quantity takeoff backup appendix 2. It is compared with the result in Table 5-8 from dynamo. The comparison result is in Table 5-15. From the last column in this table, it shows the difference between manual calculation and BIM system cost. There is no difference over 5% which means the result is acceptable and the result of Schedule cost form BIM system is validated.

Table 5-17: Comparison on BOQ based on Schedule Activity

Location Code	Components	length	number	Manual cost		System cost (schedule cost)	Difference
FA	pile -5		4	7020.4	7020.4	7009.6	0.2%
FB	pile-2		4	2214.3	2214.3	2216.8	-0.1%
FC	pile-2		4	2214.3	2214.3	2216.8	-0.1%
HA01	beam 400*400	10	4	1555.2	2721.6	2750.83	-1.1%
	beam 400*400	15	2	1166.4			
HA02	beam 400*400	10	4	1555.2	2721.6	2706.05	0.6%
	beam 400*400	15	2	1166.4			
HA03	beam 400*400	10	4	1555.2	2721.6	2706.05	0.6%
	beam 400*400	15	2	1166.4			
HB01	beam 400*400	10	2	777.6	1640.8	1640.80	0.0%
	beam 400*500	10	2	863.2			
HB02	beam 400*400	10	4	1555.2	1555.2	1555.20	0.0%
HB03	beam 400*400	10	4	1555.2	1555.2	1555.20	0.0%
HC01	beam 400*400	10	5	1944	14208.69	14216.92	-0.1%
	beam 400*400	15	2	1166.4			
	Slab 200		1	11098.29			
HC02	beam 400*400	10	4	1555.2	13819.89	13800.93	0.1%
	beam 400*400	15	2	1166.4			
	Slab 200		1	11098.29			
HC03	beam 400*400	10	4	1555.2	13819.89	13800.93	0.1%
	beam 400*400	15	2	1166.4			
	Slab 200		1	11098.29			
VA01	Column 400x400	3	6	595.7952	1167.715	1164.16	0.3%
	column 400x500	3	2	229.2192			
	wall 200	5.2	1	342.7008			
VA02	Column 400x400	3	6	595.7952	1167.715	1164.16	0.3%
	column 400x500	3	2	229.2192			
	wall 200	5.2	1	342.7008			
VA03	Column 400x400	3	6	595.7952	1167.715	1164.16	0.3%
	column 400x500	3	2	229.2192			
	wall 200	5.2	1	342.7008			
VB01	wall 200	10	2	1318.08	1318.08	1318.08	0.0%
VB02	wall 200	10	2	1318.08	1318.08	1318.08	0.0%
VB03	wall 200	10	2	1318.08	1318.08	1318.08	0.0%
VC01	Column 400x400	3	6	595.7952	1167.715	1165.31	0.2%
	column 400x500	3	2	229.2192			
	wall 200	5.2	1	342.7008			
VC02	Column 400x400	3	6	595.7952	1167.715	1164.16	0.3%
	column 400x500	3	2	229.2192			
	wall 200	5.2	1	342.7008			
VC03	Column 400x400	3	6	595.7952	1167.715	1164.16	0.3%
	column 400x500	3	2	229.2192			
	wall 200	5.2	1	342.7008			

So that cost and quantity calculation from BIM system are validated by manual calculation. And result shows that BIM system is more precise than manual calculation on result of volume. Volume refers to concrete cost and labor cost by formula, so total cost from BIM system is more precise and reliable than manual calculation too.

BOQ from BIM system is validated and it proves BIM system is more precise. Moreover, the BIM system calculation on BOQ is much faster than manual calculation as well.

So far, the BOQ and QTO have been validated which means the quantity and cost data in 5D BIM system can be trusted. So the BOQ and QTO data from 5D BIM system will be used to verify the other output from 5D BIM system in the following verification.

5.5.2 Verification and Validation on Earn Value and Delayed Elements

This part validates and verifies the earn value and delayed elements output from 5D BIM system. There are two tests designed:

- 1) Test 1: Validate the accuracy of earn value, ongoing activity and delayed activity by comparing with manual calculation.
- 2) Test 2; Verify the flexibility of 5D BIM system by changing activity's actual finished date and ongoing activity's finished quantity, checking whether the result changes synchronously or not.

4.5.1.1 Test 1: Validation: Compare with manual calculation on earn value and delayed activity

Firstly, the manual works and 5D BIM system use the same schedule named schedule 1. The actual start and end are until date: 14. And schedule 1 is manually transferred to be Gantt chart in Excel, the Gantt chart is showed in Figure 5-43.

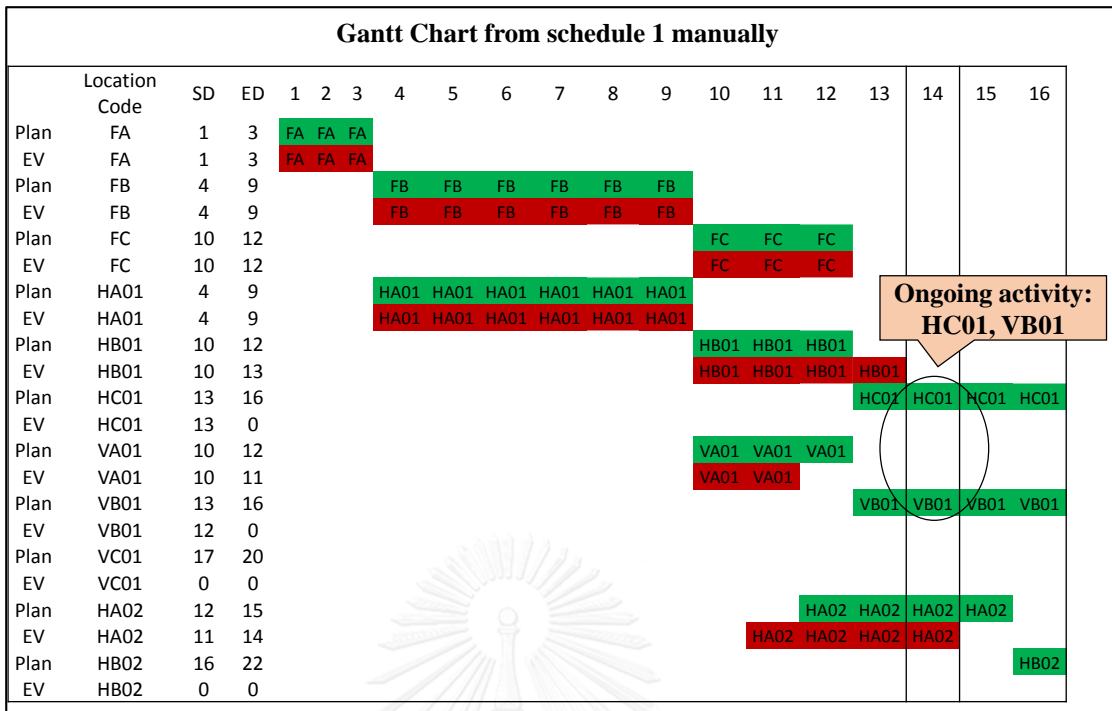


Figure 5-48: Test 1: Gantt chart of Schedule 1

This Gantt chart contains location code, start date and end date. Row of plan corresponds plan start date and plan end date, while the row of EV corresponds actual start date and actual end date. At the right zone of Gantt chart bar, green represents plan activity duration, red represents actual activity duration. Ongoing activity is input in Gantt chart.

From Figure 5-43, it shows the ongoing activity can be HC01 and VB01. And Moreover, the delayed activity includes HB01 for sure in Gantt chart. Then select the ongoing works' elements within activity HC01 and VB01 in Revit and put 14 as the value of "PDF" parameter which marks the ongoing elements. Then calculate the quantity and cost of these elements from manual quantity takeoff backup (validated already). The summary of components and cost of ongoing elements are in Figure 5-44.

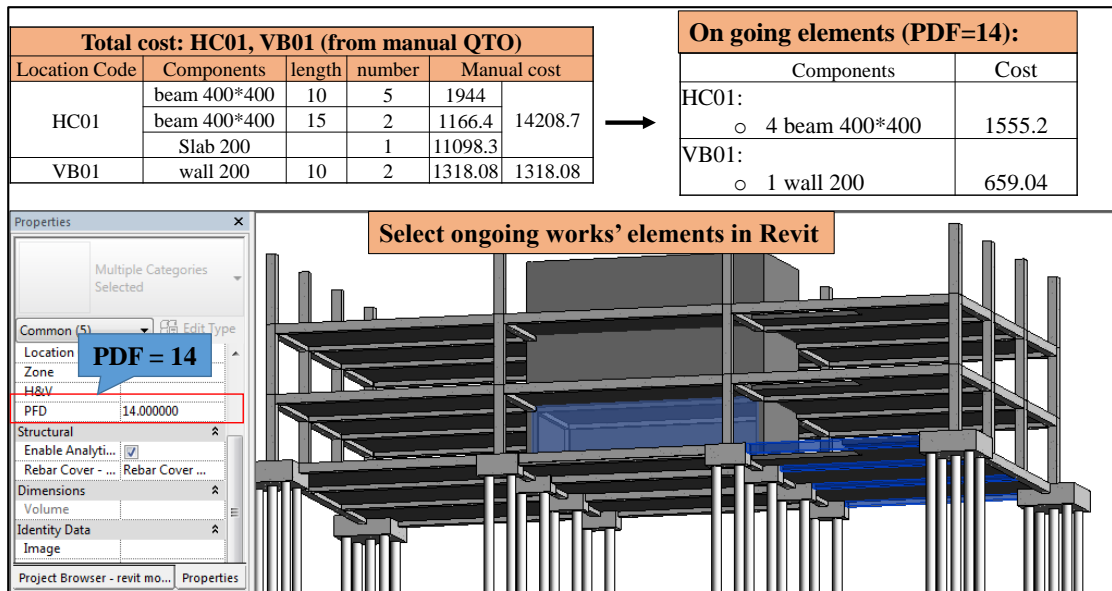


Figure 5-49: Test 1: Ongoing selection in Revit and Corresponding Manual Calculation Result

Checking ongoing activity (HC01, VB01) is delayed or not in manual calculation:

From manual calculation, the earned value of ongoing activity is in table “on going elements (PDF=14)” of Figure 5-44. Earn cost of activity HC01 is 1555.2 and VB01 is 659.04. From schedule plan in Figure 5-43, HC01 should finish 50% (based on the duration) which is $14208.7 * 50\% = 7104.4$ (from Figure 5-44). And actual earn value of HC01 is 1555.2 (< 7104.4) which means HC01 is delayed as ongoing activity. The same rule to calculate VB01, VB01 is not delayed. So delayed activity contains: HC01, HB01 from manual calculation.

The result of 5D BIM system is in Figure 5-45, it contains comparison with manual calculation.

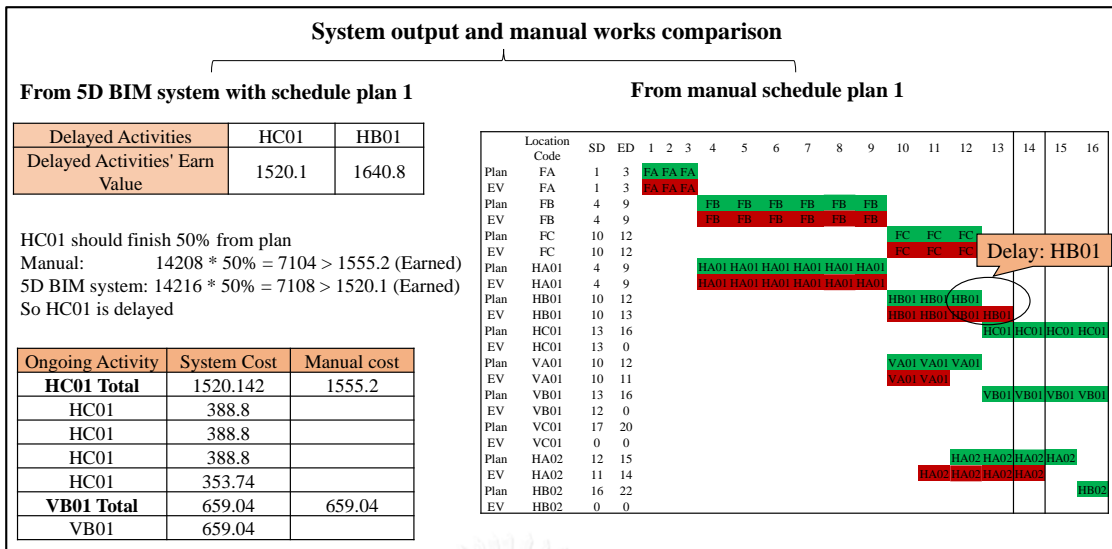


Figure 5-50: Comparison between Manual Works and 5D BIM System on Delayed Activity and Ongoing activity

According to Figure 5-45, Output of delayed activity and ongoing activity from 5D BIM system are matched with the manual result: HC01, HB01.

Total earn value comparison result is in Figure 5-46. The manual earn cost is calculated from the above manual quantity takeoff. The result in Figure 5-46 shows that there are small difference on the earn value between 5D BIM system and manual result, the difference is caused by the elements intersection in model which is discussed above. And the difference is within the acceptable range mentioned above (5%). Finally, the result of earn value and delayed, ongoing activity from 5D BIM system are validated successfully.

	location code	Earned cost(manual)	System EV
Finished works before day 14	FA	7020.4	21888.1 21884.1
	FB	2214.3	
	FC	2214.3	
	HA01	2721.6	
	HB01	1555.2	
	VA01	1226.6	
Ongoing works at day 14	HA02	2721.6	
	HC01	1555.2	
	VB01	659.04	

Figure 5-51: Result of Comparison on Total Earn Value between 5D BIM System and Manual Calculation

4.5.1.2 Test 2: Verify earn value and delayed elements from 5D BIM system by changing the actual finish date and quantity of ongoing activity

This test postpones one activity's actual end date in schedule and change one ongoing activity's finished quantity. Then check whether the result from 5D BIM system match the changes or not.

The schedule after changing is called schedule 2. The schedule used in test 1 is schedule 1. Schedule 1 and schedule 2 are used to compare to verify the earn value and delayed elements output from 5D BIM system. The changes made in schedule 2 are:

Change 1: postpone actual end date of VA01 from 11 to 13

Change 2: adding one more slab to be finished elements of ongoing activity HC01

With this changes, compared with output from schedule, the expected changes for the result of 5D BIM system are:

- 1) HC01 is not delayed,
- 2) VA01 is delayed,
- 3) Total earn value increase of 11094 which is cost of increased elements (slab), ongoing activity increase one more element which is in HC01.

The changes are showed in Figure 5-47. Gantt chart of schedule 2 is manually got in excel, showed in Figure 5-48.

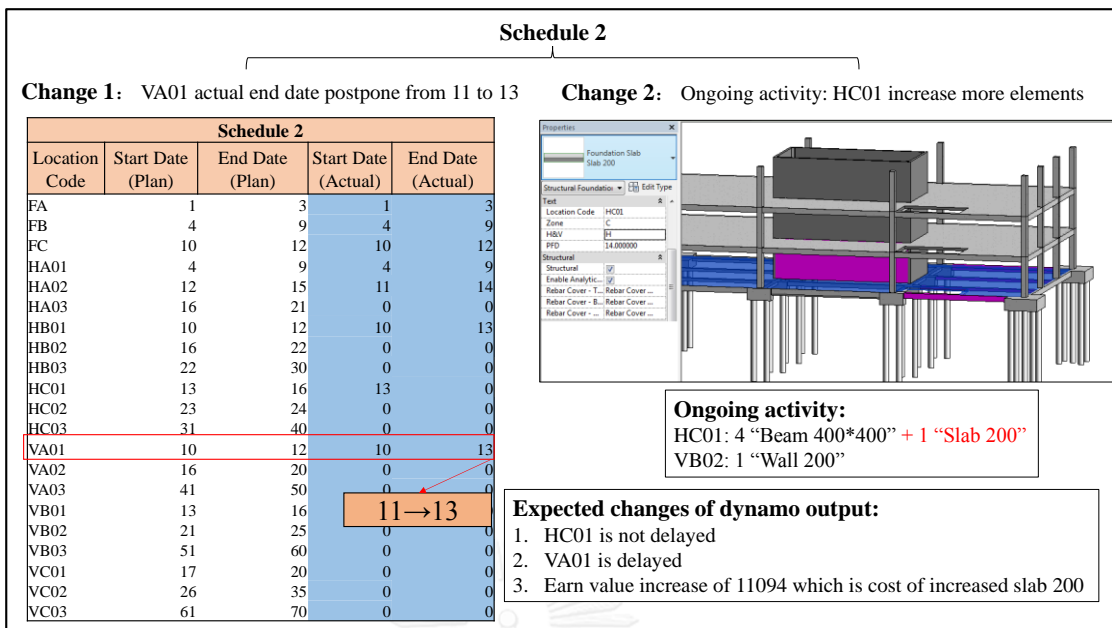


Figure 5-52: Changes Made in Test 2 between Schedule 1 and Schedule 2

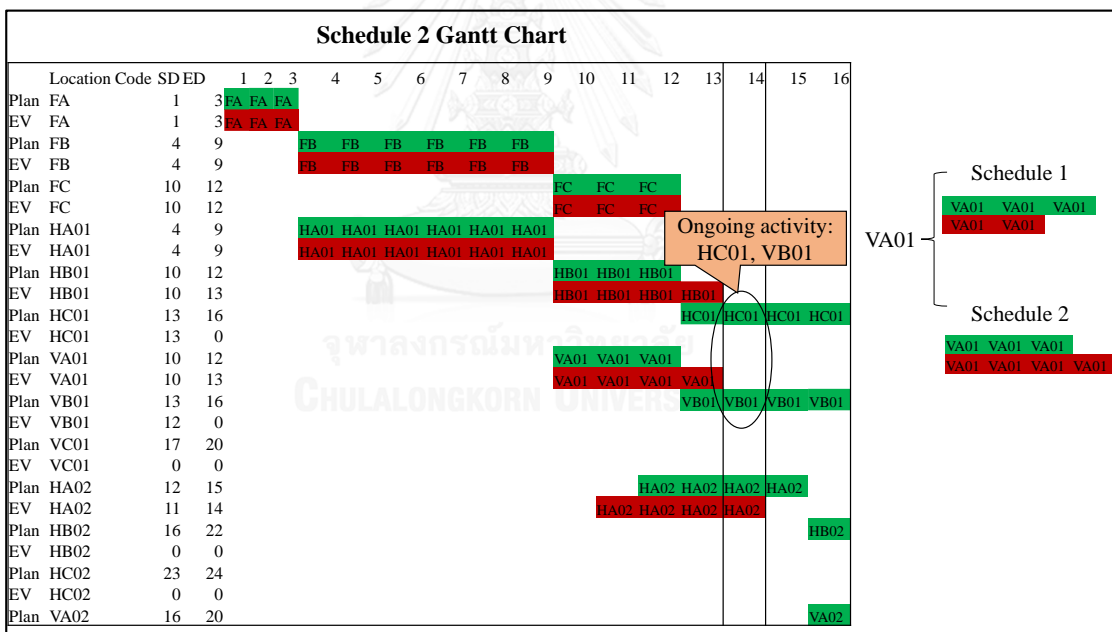


Figure 5-53: Gantt Chart of Schedule 2 (manually in Excel)

Ongoing activities are still HC01, and VB01 from the Gantt chart of schedule 2 in Figure 5-48. There is no change on ongoing activity but there is change on quantity of ongoing activity which doesn't show by current practice but 5D BIM system shows.

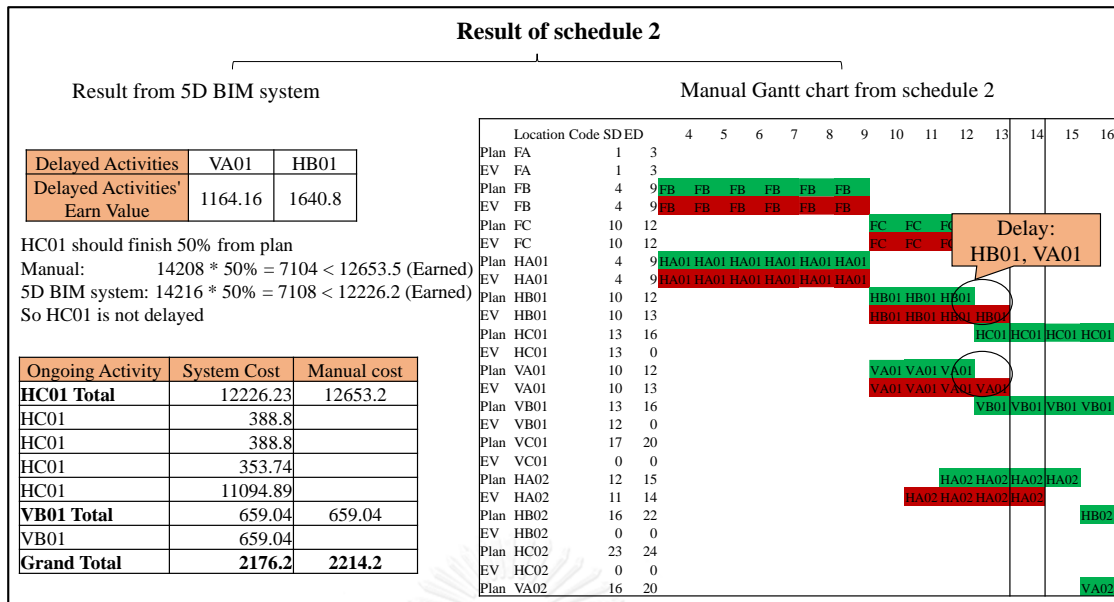


Figure 5-54: Comparison on Result of Schedule 2 from 5D BIM System and Manual Calculation

The result from 5D BIM system with schedule 2 is in Figure 5-49. It shows the same result of expected changes: HC01 is not in delayed table while the VA01 is in delayed table. This is the extra ongoing elements and delayed elements validation.

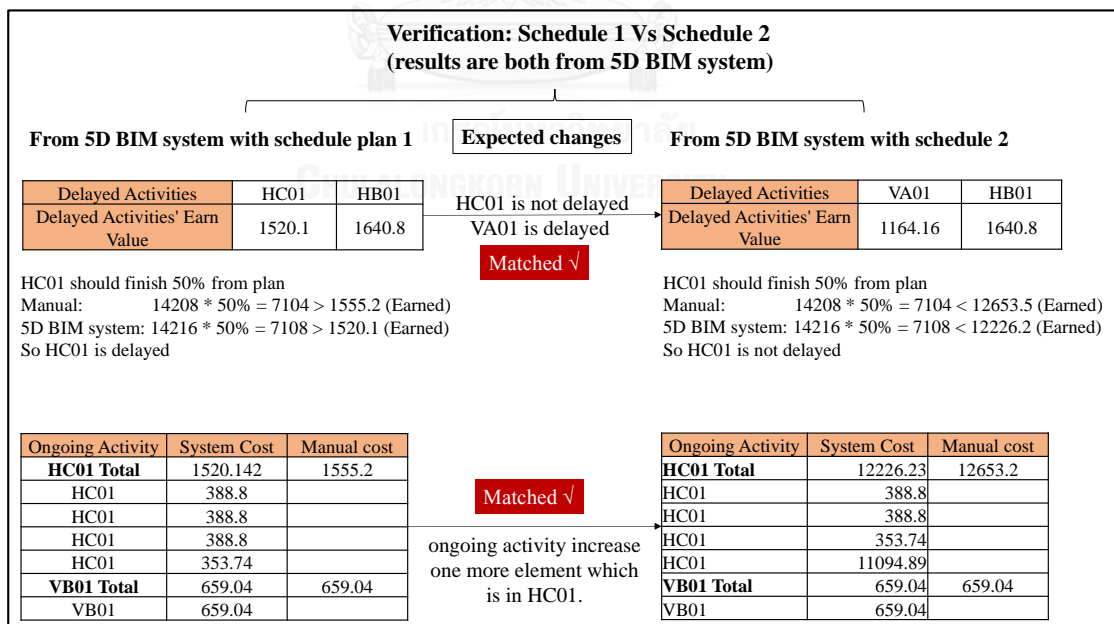


Figure 5-55: Verification on Delayed and Ongoing Elements from 5D BIM System between Schedule 1 and Schedule 2

The comparison of 5D BIM system results between schedule 1 and schedule 2 is in Figure 5-55. This figure shows that the changes on result form schedule 2 compared with schedule 1 are:

- 1) HC01 is not in delayed activities table
- 2) VA01 is delayed in delayed activities table
- 3) Ongoing activity table increases one elements in HC01, the earn cost of increased element is 11094.

These changes match with the expected changes exactly based on the result form 5D BIM system.

Verification on Earn Value: Schedule 1 Vs Schedule 2					
Earn Value comparison from schedule 1			Earn Value comparison from schedule 2		
location code	Earned cost(manual)	System EV	location code	Earned cost(manual)	System EV
FA	7020.4	32927.6	FA	3791.9	43986.9
FB	2214.3		FB	2618.0	
FC	2214.3		FC	2618.0	
HA01	2721.6		HA01	2721.6	
HB01	1555.2		HB01	1555.2	
VA01	1226.6		VA01	1226.6	
HA02	2721.6		HA02	2721.6	
HC01	1555.2		HC01	12653.5	
VB01	659.04		VB01	659.04	
			<div style="background-color: red; color: white; padding: 2px; display: inline-block;">Matched ✓</div> Expected change: Total earn value increase of 11094 which is cost of increased elements (slab) Slab 200: 11094.9		

Figure 5-56: Result of Verification on Total Earn Value between Schedule 1 and Schedule 2

Finally result of verification on total earn value is in Figure 5-51. The result from system between schedule 1 and schedule 2 matches the expected changes: increased earn value is 11094 which is the cost of slab 200, the added ongoing activity. Each schedule's total earn value between 5D BIM system and manual calculation are compared as well for earn value extra validation.

In summary, the accuracy of output from 5D BIM system: Earn Value, delayed elements, and ongoing activity are validated and verified. 5D BIM system can exactly

output the right earn value, delayed elements and ongoing elements. 5D BIM system considers not only the finished activity but also the ongoing activity to check delayed activity at the checking time point.

5.5.3 Verification: Over Budget Elements

This verification checks whether the 5D BIM system shows the right over budget elements or not by changing the actual cost of one activity from within budget status to over budget status, and then comparing the results in Revit between changes before and change after.

The changes made on actual cost record is in Figure 5-52.

Scenario 1: actual cost of VA01 is 1044 which is within budget

Scenario 2: actual cost of VA01 is 1200 which is over budget.

Expected difference between scenario 1 and scenario 2: this activity VA01 is changed from within budget status to be over budget status.

Scenario 1				Scenario 2			
Actual cost record in Scenario 1				Actual cost record in Scenario 2			
Location Code	Element Cost	Actual Cost	Difference	Location Code	Element Cost	Actual Cost	Difference
FA	7009.6	6996.5	-13.1	FA	7009.6	6996.5	-13.1
FB	2216.8	2315.2	98.4	FB	2216.8	2315.2	98.4
FC	2216.8	2246.8	30.0	FC	2216.8	2246.8	30.0
HA01	2750.8	2791	40.0	HA01	2750.8	2790.8	40.0
HB01	1640.8	1601	-40.0	HB01	1640.8	1600.8	-40.0
HC01	14216.9	4739	-9477.9	HC01	14216.9	4739.0	-9477.9
VA01	1164.2	1044	-120.0	VA01	1164.2	1200.0	35.8
VB01	1318.1	1423	105.0	VB01	1318.1	1423.1	105.0
VC01	1165.3	0	-1165.3	VC01	1165.3	0.0	-1165.3
HA02	2706.0	2659	-47.3	HA02	2706.0	2658.8	-47.3
HB02	1555.2	0	-1555.2	HB02	1555.2	0.0	-1555.2
HC02	13800.9	0	-13800.9	HC02	13800.9	0.0	-13800.9
VA02	1164.2	0	-1164.2	VA02	1164.2	0.0	-1164.2
VB02	1318.1	0	-1318.1	VB02	1318.1	0.0	-1318.1
VC02	1164.2	0	-1164.2	VC02	1164.2	0.0	-1164.2
HA03	2706.0	0	-2706.0	HA03	2706.0	0.0	-2706.0
HB03	1555.2	0	-1555.2	HB03	1555.2	0.0	-1555.2
HC03	13800.9	0	-13800.9	HC03	13800.9	0.0	-13800.9
VA03	1164.2	0	-1164.2	VA03	1164.2	0.0	-1164.2
VB03	1318.1	0	-1318.1	VB03	1318.1	0.0	-1318.1
VC03	1164.2	0	-1164.2	VC03	1164.2	0.0	-1164.2

Changes: VA01 from within budget to be over budget

Expected changes in Revit: VA01 change from original color to be red color (represents over budget)

Figure 5-57: Differences on 2 Scenarios

5D BIM system takes 2 scenarios to get results, showed in Figure 5-53. The over budget elements changed as expected that activity VA01 (the columns and walls of floor 1 in zone A) changed from original color to red color which means the VA01 changes from within budget status to over budget status. The result proves that the visualization of over budget elements follows the information in excel.

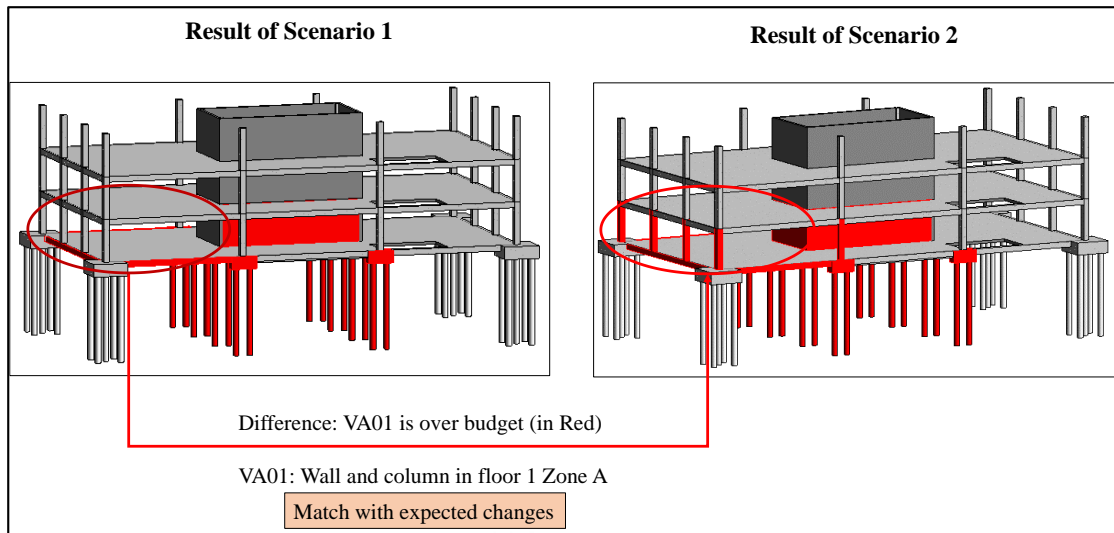


Figure 5-58: Result of 2 Scenarios on Actual Cost Records from 5D BIM system
 In summary, the 5D BIM system is validated to visualize the right over budget elements in Revit successfully.

5.5.4 Verification: Unpaid but Finished Elements

This verification is designed to check whether the 5D BIM system visualize the right elements that unpaid but finished in Revit by changing payment approval date. Payment applying date and payment approval date determines the quantity of unpaid but finished elements. Thus, there are two payment cases in this test to compare, showed in Figure 5-54. The schedule for the two cases are the same to control variable, showed in Table 5-16.

Payment case 1		Payment case 2	
Payment Applying Date	Payment Approval Date	Payment Applying Date	Payment Approval Date
28	35	28	42
			↑ Bring payment forward 1 week: from 42 to 35

Figure 5-59: 2 Payment Cases for Testing Unpaid but Finished elements visualization by 5D BIM System

Table 5-18: Schedule for 2 Payment Cases

Schedule for Two Payment Cases				
Location Code	Start Date (Plan)	End Date (Plan)	Start Date (Actual)	End Date (Actual)
FA	1	3	1	3
FB	4	9	4	9
FC	10	12	10	12
HA01	4	9	4	9
HA02	12	15	11	14
HA03	16	21	16	23
HB01	10	12	10	13
HB02	16	22	15	19
HB03	22	30	24	32
HC01	13	16	13	18
HC02	23	24	20	25
HC03	31	40	33	40
VA01	10	12	10	11
VA02	16	20	15	22
VA03	41	50	41	0
VB01	13	16	12	14
VB02	21	25	23	26
VB03	51	60	0	0
VC01	17	20	15	22
VC02	26	35	28	37
VC03	61	70	0	0

In Table 5-16, it needs to be emphasized out that, the schedule should stop at payment applying date for each payment case. It means result of payment case 1 shows the unpaid but finished elements until date 35, and payment case 2 shows the unpaid but finished elements until date 42.

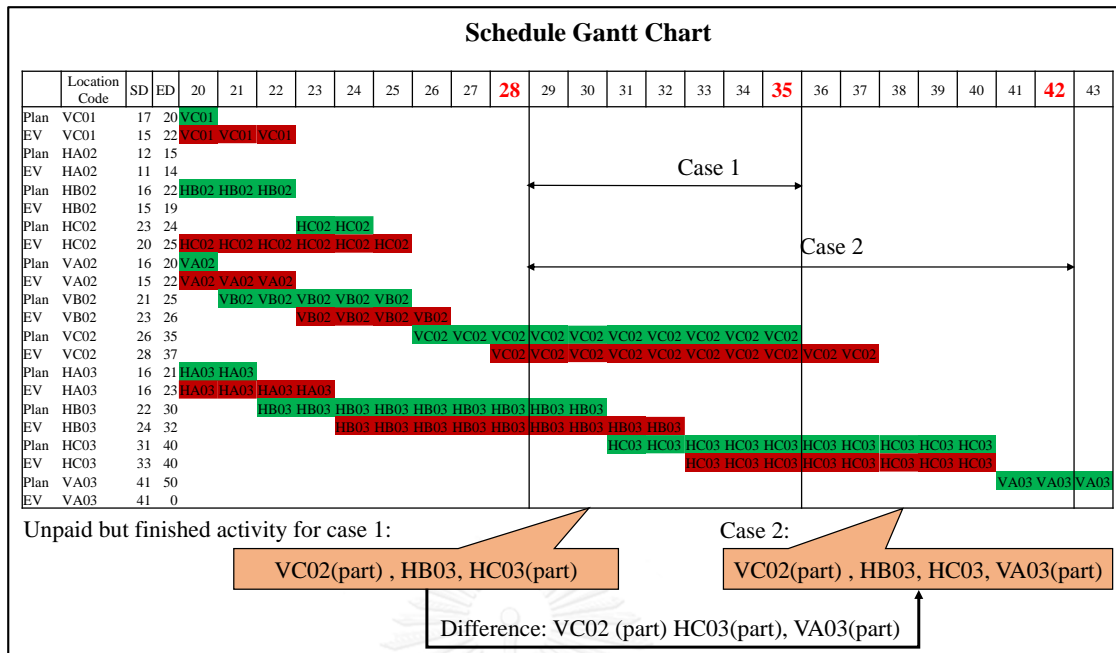


Figure 5-60: Manual Gantt chart from Schedule

From manual Gantt chart of schedule in Figure 5-55, it shows the unpaid but finished elements for payment case 1 are:

VC02 (part), HB03, and HC03 (part).

For payment case 2, the unpaid but finished elements are:

VC02 (part), HB03, HC03 and VA03 (part).

Differences of result between 2 Payment cases:

VC02 (part), HC03 (part), VA03 (part),

The differences are expected to change in Revit from hidden status to be orange color which means changing from elements that haven't start to be the elements that unpaid but finished. In fact, the differences are the elements finished during date 35 to 42 which is the time difference of the payment approval date between the 2 payment cases. The result of 2 payment cases from 5D BIM system is showed in Figure 5-56. The difference between results of the two payment cases are matched with the expected changes: HC03, VA03 (part) and VC02 (part) are changed in Revit from hidden status to be the in orange color.

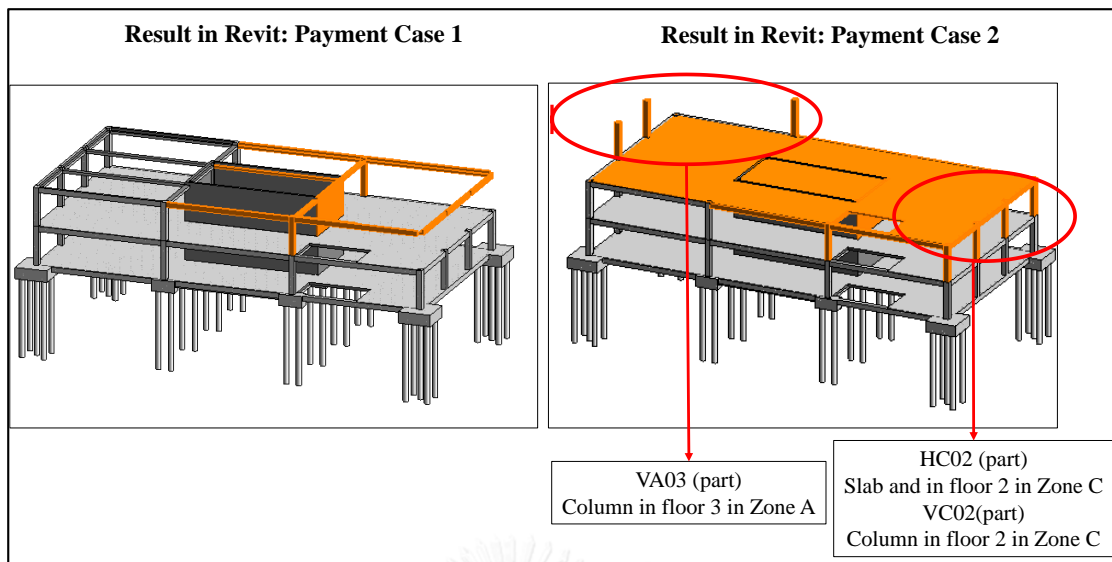


Figure 5-61: Result of Unpaid but Finished Elements Test between 2 Payment Cases
 Finally the result of unpaid but finished elements test between 2 payment cases proves that the 5D BIM system visualizes the right elements of unpaid but finished in Revit and calculates the right element cost in Excel.

So far, these functions of the 5D BIM system are validated to be correct, including the quantity takeoff, BOQ, cost plan, and earn value and delayed elements. And these functions are verified: earn value and delayed elements, over budget elements, unpaid but finished elements. All process and output from 5D BIM system to monitor cost and payment are validated and verified to be correct.

5.6 Summary

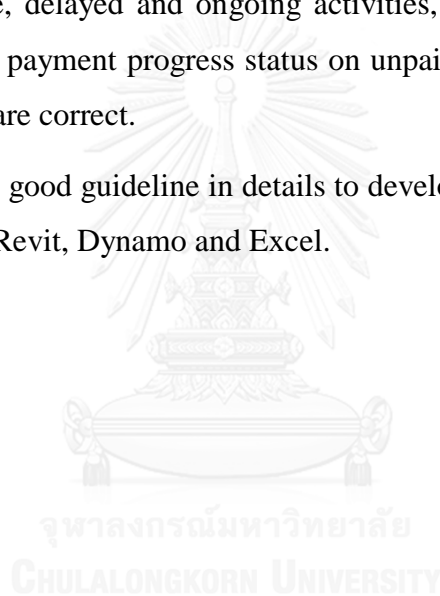
This chapter develops 5D BIM system with a structure 3D model in Revit as a sample. It describes the whole process to monitor cost and payment by 5D BIM system, including the input documents, processing, and output. This system monitors cost and payment by collaborating among the three tools which are Revit, Dynamo and Excel. Dynamo designs the visual programming to link the cost and payment progress data in Excel to corresponding elements in Revit automatically and visualize the status on working progress, cost progress and payment progress.

Whole process separates to two stages, preconstruction stage and construction stage. In preconstruction stage, output from system are BOQ, cost plan and payment plan. During preconstruction, the 3D model has been developed with scheduling, cost and

payment information linked. In construction stage, the way how to input actual data of scheduling, cost and payment are summarized. The final output from system are 3 critical progress status report, including the visualization in Revit and detailed data in excel correspondingly, including working progress status, cost progress status and payment status.

Finally, the outputs from the system are validated by manual calculation in Excel. The validation outputs are quantity takeoff, BOQ, Earn value and working progress report on delayed, ongoing and finished elements. The other outputs are verified by testing with couple of input parameter values. Verified outputs includes: working progress reports on earn value, delayed and ongoing activities, cost progress report on over budget activities, and payment progress status on unpaid activities. The result proves that all these outputs are correct.

This chapter outline a good guideline in details to develop 5D BIM system to monitor cost and payment by Revit, Dynamo and Excel.



CHAPTER 6

CONCLUSION

6.1 Conclusion

The current practice on cost and payment monitoring still separates the cost and model information which makes the cost and payment hard to be tracked over construction time. Moreover, the BIM implementation in Thailand has not developed enough in construction industry. Through the problems on cost and payment monitoring, this research comes up with a 5D BIM system to monitor cost and payment progress by integrating cost and payment with 3D model visualization over time. With this system, the cost and payment progress with current working progress can be tracked automatically and get the corresponding cost and payment data in Excel.

To achieve this objective, firstly current practices about cost and payment monitoring are explored by interviewing cost and BIM engineers who are working currently in Bangkok. There are 6 company's representatives are interviewed, they are from 4 contractors, 1 consultant, and 1 development company. Secondly, based on the result of interview and characteristics of BIM, the 5D BIM system was developed with 3 tools: Revit, Dynamo and Excel. The system development describes the detailed process to monitor cost and payment from preconstruction to construction stage, until obtaining outcome of cost and payment progress status.

This interview obtained the current process of monitoring cost and payment. To monitor cost and payment, the plan cost and payment over scheduling has to be obtained as the baseline in preconstruction stage. So in preconstruction stage, the process begins from taking off quantity first, calculating cost for BOQ, scheduling, making cost plan, and planning payment at the end. Construction stage starts from recording actual working progress, actual cost and actual payment, then compares the actual data with plan data from preconstruction stage. Current status of working progress, cost progress and payment progress are figured out from the comparison. During this process, current practices provide a good guideline to monitor cost and payment over time. At the same time, the problems are found in the current process of cost and payment monitoring. It takes time and effort to calculate the cost plan which contains many recalculations. Earn

value is hard to calculate since the plan cost is not linked with building components exactly. Finally the progress status on cost and payment are not visible. With the result from interview, the comparison and discussion on these difference provided relatively optimal options for 5D BIM system to process the needed documents to monitor cost and payment.

Based on the result and discussion of interview, 5D BIM system was developed. A simple structural model in Revit was built first to guide the system development step by step. In preconstruction stage, the price of materials and labors, schedule plan were in Excel. Dynamo transferred the data from excel to Revit and calculated quantity and cost, then wrote it to Excel back. The scheduling, cost and payment were attached in 3D model in preconstruction stage. In construction stage, actual scheduling, cost and payment data were recorded and input to system. Based on 3D model plan data attached in preconstruction stage, Dynamo calculated corresponding cost and wrote to Excel as cost and payment progress report. On the other side, Dynamo visualized delayed elements, over budget elements, unpaid but finished elements and unapproved but finished elements in 3D model in a color scheme. Finally verification and validation were applied to check the accuracy of the output from 5D BIM system, the result of verification and validation proves that the output from 5D BIM system are correct.

In a summary, these are the benefits of 5D BIM system compared with current practices on cost and payment monitoring. Firstly, this system generates cost plan efficiently by proposing a different way to link cost and schedule to every components of building in Revit 3D model. Secondly, this system provides another way to record current working progress (actual completed works) by combining start/finish checking by work package in Excel and selecting partial completed elements in Revit model. By this mean, it makes the way to measure working progress easier and more understandable, and it calculates earn value more precisely in element level. Thirdly, separated visualization of over budget between material and labor cost enables cost manager to analyse location in 3D model and the reason of over budget. Fourthly, payment visualization not only visualize the elements that finished but unpaid by owner, and also presents elements that finished but unapproved due to the quality problems. It helps to warn project manager about works that have problems and helps to locate problem part easier. On

the other side, corresponding budget cost of unpaid and unapproved works is calculated automatically to Excel as well. Finally, the research integrated the whole process to monitor cost and payment over construction progress which guides the cost and payment monitoring in a new way based on 5D BIM concept.

6.2 Research Contribution

This research proposed a 5D BIM system to monitor cost and payment with visualization by Revit, Dynamo and Excel. The contribution of this system in two fields which are academic field and practical field are summarized below.

6.2.1 Academic Contribution

In academic field, it is the new way to integrate the cost and schedule with 3D model by visual programming in Dynamo to monitor cost and payment over construction progress. This research contributes to have a systematic process to integrate cost and schedule in preconstruction stage and monitor cost and payment in construction stage. Using the color scheme in Dynamo to visualize and differentiate different status on working progress, cost progress and payment status is proposed in this research which is a new idea for progress visualization. So in the process level, there are four critical contributions compared with existed system and practices. First is the linkage of cost, schedule and 3D model promotes an integrated way and automatic way to generate cost plan in preparation stage. Secondly, this system is able to measure working progress in an easier way and keep the outcome precise too. Thirdly, this system proposes separate visualization on every material cost, labor cost and total cost to detect over budget reason. Moreover, the visualization of over budget is able to locate the elements which have cost problems. Finally, this system visualize the unpaid and unapproved elements with corresponding budget cost in excel. It can locate unapproved elements in 3D model to warn project manager for more attention.

To get improvement above, the critical factor is the customized visual programming in Dynamo. So in technical part, this research contributes to design the visual programming in Dynamo to connect the whole process to achieve cost and payment monitoring.

In technical level, visual programming in Dynamo for the system is designed to achieve various functions to improve the automation and efficiency which is the technical contribution of this research. The contributed programming designed are summarized below.

First technical contribution is visual programming that can link price that corresponding to elements in Revit 3D model automatically and calculate cost and quantity of materials on every elements automatically in Revit 3D model with formula. With this programming, it allows to update cost of project automatically when there is a change on some material and labor price.

Second technical contribution is visual programming that can link schedule date to corresponding elements in Revit 3D model by specific work breakdown structure in schedule plan. This is an automatic way to equip components of building with its schedule date which is helpful big project scheduling efficiently.

Third technical contribution is visual programming that can create BOQ of basic reinforcement concrete structure works, including material and labor cost, to excel and it can present cost plan in excel with the linkage of cost, schedule and 3D model.

Fourth technical contribution is visual programming that can calculate earn value and visualize delayed elements in 3D model. At the same time, this programming calculate budget cost of delayed elements to excel as well.

Fifth technical contribution is visual programming that can visualize over budget elements on material cost, labor cost and total cost separately.

Final technical contribution is visual programming that can calculate cost of unpaid and unapproved elements in 3D model and can export budget cost of unpaid and unapproved elements in Excel with automatic calculation.

6.2.2 Practical Contribution

In practice field, this system is mainly contributed to contractors to monitor cost and payment in 5D BIM concept. For cost manager as contractor, they could track cost and payment during construction stage with 3D model in a visible way. And the

visualization of status of working progress, cost progress and payment progress helps them to have a better understanding and control on project cost and payment progress. Besides contributing to monitor cost and payment more efficiently and visualize the progress, there are other contributions to participants of project from this 5D BIM system. For cost estimator, the 3D model and cost attachment in preconstruction stage contributes them to have a faster cost estimation automatically. For engineer and construction site manager who are responsible to record and check working progress, the system provides an easier and visible way to mark and calculate quantity and cost of completed works by marking it in 3D model directly. For owner, the visualization of progress status enables them to have a visible view on project progress. For the communication, the 5D BIM system improve the efficiency of collaboration between head office and construction site with 3D model and actual cost's real time recording.

6.3 Limitation and Future Study

6.3.1 Limitation

According to the development of 5D BIM system, there are three limitations during this process. Firstly, the cost in this system includes the cost that can be attached to the components of building. However, there are some cost that can not be attached to 3D model, such as cost of earth excavation. Secondly, this system requires the user to have some manual operation such as running Dynamo and draw some graph in Excel manually. Next, this system requires 3D modelling in Revit highly follows the standards of modelling which determines the accuracy of quantity and cost output from system. Finally the format of date in system is number instead of date which limits the flexibility of setting holidays for schedule.

As for the limitation on this research, the current practices interviewed only 6 companies, the result cannot be generalized for all contractors' practices.

6.3.2 Future Study

5D BIM system has further potential to be more efficient to calculate the cost and payment over progress both in preconstruction and construction stage. There are recommendations for further research.

First, the system can be expanded to architecture and MEP part into 3D model, so that the system can monitor cost and payment of whole project. Because of the time limitation and knowledge limitation on Dynamo visual programming, this system takes structure model only.

Based on the three limitations above, the standards of 3D modelling in Revit is required to be explored and regulated. The materials can be built in Revit to get the precise quantity of materials instead of the ratio. Lastly, the date in system can be improved to be date format instead of number format.

Thirdly, the real and big project is recommended to validate this system to be more practicable and flexible. During the validation with big project model, it must be high potential on concept of this system to monitor cost and payment more efficient and practicable.

Finally, it is suggested to improve this system to be an application, so that the operation would be more user friendly. For example, making the structure and table title fixed, the user just input data and get the result. The output of the system is suggested to be standard, such as exporting the image of progress visualization and corresponding cost of activity together as a report. All these inputs and outputs can be highly automatic.

APPENDIX 1: Interview Questions

1. What's the process to monitor the cost during construction in your company?
2. What's the hierarchy of BOQ in your company? It is categorized by materials or the structure of building or others?
3. What's the hierarchy of the schedule plan? It is categorized by the construction methods or the structure of the building or the other standards?
4. How do you develop the cost plan? (Hierarchy of WBS and BOQ etc.) Do you combine schedule plan with BOQ?
5. How do you calculate and record the Earn Value? Compare the real quantity and plan quantity, how to measure the real progress?
6. Do you separate the material cost, labor cost and equipment cost? Or you combine them together within one items.

E.g. Combined: 1st floor: material cost, labor cost and equipment cost——total cost

Separated: Material cost is in WBS or BOQ, Labor cost for all project, Equipment cost for all project.

7. How do you update cost plan when there is a change on cost plan, for example, you order a new material to replace the original material.
8. What's the structure of the table for daily or weekly cost report?

Description	A	B	C	D = A + B + C	E	F	G = E + F	H	I = G/D
	Original Budget Cost	Approved by Change Order Cost	Growth Cost	Budget at Completion Cost	Cumulative to Last Period Cost	This Period Cost	Cost to Date Cost	Estimated at Completion Cost	Percent Complete %
DIRECT ENGINEERING									
Architectural	\$9,799		\$2,900	\$12,699	\$0	\$0	\$0	\$12,699	0.0%
Civil	\$4,055		\$3,674	\$7,729	\$217	\$1,366	\$1,583	\$7,729	20.5%
Electrical	\$17,203		\$2,929	\$20,132	\$1,327	\$529	\$1,856	\$20,132	9.2%
Mechanical	\$44,330		\$1,324	\$45,654	\$7,207	\$2,099	\$10,206	\$45,654	22.4%
Structural	\$11,278		\$14,086	\$25,364	\$159	\$0	\$159	\$25,364	0.6%
Subtotal	\$86,665	\$0	\$24,913	\$111,578	\$8,910	\$4,894	\$13,804	\$111,578	12.4%

9. Do you use Unifomat or Masterformat or other standard format for WBS or BOQ?
10. How often update the work progress and input the actual cost.
11. How to get actual cost of material, actual quantity of material you order. Do you track the details on the material quantity going? E.g. if you order 1000 concrete, how do you track or assign these concrete to the activities, such as column, beam, slab. You pay supplier at once with big amount, but you need to trace cost of material consumption every day.
12. How do you record owner payment? How about the structure of the table to calculate or record the payment?
13. What are the problems you meet when communicate with owner in terms of cost and payment. E.g. owner want to know what the works you have done with the cost that you have spent during this period.
14. How to compare the actual cost and plan cost. (Do you need to compare the unit price of every material, or the works cost e.g. actual cost on 5fl construction, that the works in schedule plan. Including material cost, equipment cost and labor cost)
15. What kind of outcome you want to be shown with cost monitoring or control. E.g. S-curve, one component cost or materials, elements status on payment, update the unit price one time in every related place.
16. The value engineering. If owner want to check the scene that if change part of column as another concrete type, how the cost will be affected. It is new appearance, the cost and the plan changes

APPENDIX 2: Manual QTO backup

Name	Pile Cup				Pile				Total Quantity				Total Cost						
	a	b	h	Volume(m3)	Formwork area(m2)	R	H	Quantity	Volume	Formwork area	Volume(m3)	Formwork area(m2)	Steel ratio(kg/m3)	Steel Q(kg)	Concrete UP/m3	Steel UP/kg	Formwork UP/m2	Labor UP/m3	Total cost
Pile-2	1.8	0.8	0.9	1.296	6.12	0.2	6.3	2	0.79128	15.8256	2.87856	21.9456	0.89	2.5619184	137	1.5	3.8	25	553.56288
Pile-5	2.49	0.89	5.518089	15.0645	15.0645	0.2	6.3	5	0.79128	39.564	9.474489	54.6285	0.89	8.43229521	137	1.5	3.8	25	1755.104

Slab	Rough				Hole				Total Quantity				Total Cost				
	a	b	h	Volume	a	b	h	Volume	Area	Volume	Formwork area	Steel Ratio	Steel Q	Concrete UP/m3	Steel UP/kg	Formwork UP/m2	Labor UP/m3
Slab 200	30	15	3	4.8	3	15	0.2	435.6	87.12	454.8	0.89	387.684	91	1.7	2.84	14	11098.295

Beam	Volume(m3)		Length	Formwork area		Steel ratio/m	Steel-Q(kg)	Concrete UP	Steel UP/kg	Formwork UP/m2	Labor UP/m3	Total cost
	a	b		a	b							
Beam 400*400	0.4	0.4	10	8	13.6	136	83	1.6	2.8	10	388.8	
Beam 400*400	0.4	0.4	15	12	13.6	204	83	1.6	2.8	10	583.2	
Beam 400*500	0.5	0.4	10	10	13.6	136	83	1.6	2.8	10	431.6	

Column	Volume(m3)		Length	Formwork area		Steel ratio/m	Steel-Q(kg)	Concrete UP	Steel UP/kg	Formwork UP/m2	Labor UP/m3	Total cost
	a	b		a	b							
Column 400x400	0.4	0.4	2.8	4.48	6.8	19.04	94	1.7	2.54	30	99.2992	
Column 400x500	0.4	0.5	2.8	5.04	6.8	19.04	94	1.7	2.54	30	114.6096	

Wall	Volume(m3)		Thickness	Formwork area		Steel ratio/m2	Steel-Q(kg)	Concrete UP	Steel UP/kg	Formwork UP/m2	Labor UP/m3	Total cost
	a	h		a	h							
Wall 200	10	3	0.2	60	3.52	105.6	48	1.4	2.22	15	659.04	
Wall 200	5.2	3	0.2	31.2	3.52	54.912	48	1.4	2.22	15	342.7008	

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APPENDIX



VITA



