COST MANAGEMENT-BASED BIM: SKILLS, IMPLEMENTATION AND TEACHING MAP

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ABSTRACT

It is widely known that the emergence of Building Information Modelling (BIM) is significantly affecting the cost management process and the role of quantity surveying professionals in the construction industry. The utilization of BIM is moving towards transforming how information is managed by and for quantity surveying professionals, especially due to the transition from 2D drawings. This chapter starts with describing the conventional cost management processes and highlighting the shortcomings of using it. Subsequently, the role of BIM to tackle those challenges through providing an autoamted quantification feature and integarting the cost estimation into the desisgn process. The integration of 4D and 5D BIM is discussed in this chapter to provide a siginfcant understanding how BIM enahanced the process of develop a budget of construction projects. This chapter also proposes an effective process to teach 5D BIM at both the undergraduate and postgraduate levels. The process is expected to enable a deep learning for students to absorb the required knowledge before starting their careers in the construction industry.

Keywords

5D BIM, Cost Management, 4D BIM, Cost Estimation, Cost Budgetting, Cost Control

1. BACKGROUND OF COST MANAGEMENT PROCESS

The cost management process is a system of managing all cost tasks within the different stages in the construction project such as planning, construction, and closeout stages (Ahmed, 1995). The cost management system should include processes to manage each stage such as cost estimation, budget, and control (Horngren et al., 2002). Moreover, Oberlender and Oberlender (1993) mentioned that cost management plan is a "project money plan" and it represents the financial forecast action for the project. They argue that cost management plan requires to implement specific tasks to articulate this plan such as estimation, budgeting, control, payment processing, and change management. These tasks must be implemented in specific orders and stages to obtain a reliable cost management plan for the project (Kerzner, 2017).

Given that the cost plan is influenced by project decisions, the cost plan should be flexible to deal with all changes and should be able to manage the data in a proper way (Potts and Ankrah, 2014). The cost management system has been defined by Shank (1989) as the framework of the project data. Such system involves some tools and techniques to direct the project stakeholders during the entire project stages such as the estimation tools to support different managerial decisions, as well as, providing a generic plan for the investment.

The most important activities in cost management process are (1) the cost plan for preparing the needed data (e.g. the price list) determining which estimation technique must be adopted in the project based on the availability of the data (Jorgensen and Shepperd, 2006), (2) cost estimation for the project design elements based on the completed design which can be extracted from tender documents (Niazi et al., 2006), (3) the cost control and accounting process throughout the construction stage such as preparing a payment invoice for the completed work (Leu and Lin, 2008), and (4) calculation of final accounts while considering the economic assessment. In addition to the cost management during the completion of the project, it should also consider the economic efficiency in its process such as measuring the life cycle cost of the building (Szekeres, 2005).

After discussing the structure of the cost management process, the next section highlights the challenges that face the three main tasks, namely, cost estimation, cost budgeting and cost control.

1.1.CHALLENGES OF TRADITIONAL PRACTICE OF COST ESTIMATION

Shane et al. (2009) state that bias in estimation is one of the most important reasons for underestimating the budget. This situation is called optimistic estimation and usually the estimator goes to this to show the client that they are more competitive than others. Procurement approach is playing a significant role in cost estimation escalation due to the lack of risk-sharing system (Harbuck, 2004). Allocating some risks to the party who cannot be able to manage them will lead to increase in the project cost as the contingency cost will not be enough to cover the consequences of risks (Love et al., 2011). Moreover, the lack of experience in dealing with the procurement approach in a proper way can lead to an increase in the cost. For example, incorrect schedule acceleration can cause a cost overrun more than expected (ECONorthwest, 2002, Weiss, 2000).

Callahan (1998) mentions that the unplanned changes in the schedule lead to changes in the project budget during the execution process. Thus, some companies adopt a strategy to review their budgets in a specific period to ensure that their projects remain on the company budget and if there is any change, these companies apply a technique which is called expenditure timing adjustments (Touran and Lopez, 2006, Hufschmidt and Gerin, 1970).

The complexity is inherent in the construction industry due to factors such as the location of the project or several design changes in projects. Such factors can cause difficulties in determining the properly planned cost value as the uncertainty is very high with repetitive changes in the project plans (Touran and Lopez, 2006, Callahan, 1998). Consequently, coordination problems exist between different disciplines and some information will be missing and as a result, the accuracy of cost estimation might be affected (Shane et al., 2009, Kaliba et al., 2009).

Scope changes such as changes in design components or the proposed function of some parts in the project may lead to some changes in project cost and schedule (Hussain, 2012, Khan, 2006). In case these changes are not managed properly by the owner, this can be a major change in the project scope and in many cases, the projects are executed with cost and schedule overruns (Alinaitwe et al., 2013).

Akintoye and Fitzgerald (2000) state that poor estimation procedures can cause misunderstanding in terms of the used formats, which do not provide an easy way to check, verify, and correct the estimated elements. Therefore, the procedures, formats, and methods should be understandable, and clear to enable the user to determine the cost (Reilly, 2005). Moreover, poor estimation can lead to miss some data and give unreliable results which cause an underestimation case (Azhar et al., 2008). This will affect other processes such as scheduling, and misleading inventory plan which definitely will cause cost overrun by considerable variance from the planned value (Shane et al., 2009). Poor cost estimation can affect the delivery of construction project in different aspects.

The misunderstanding of the contractual agreement plays an important role in misleading cost estimation, specifically, the misallocation of the responsibilities between the different participants can cause cost estimation issues (Zaghloul and Hartman, 2003, Ali and Kamaruzzaman, 2010, Le-Hoai et al., 2008). Moreover, the ambiguity in contract provision can be a reason for allocating the responsibilities in a wrong way such as who is responsible for implementing reworks or change orders (Touran and Lopez, 2006). The poor execution cannot be ignored as one of the most important reasons of cost overrun, as well as, the bad site management and in the lack of collaboration due to the inability for the participants' representatives to make decisions (Shane et al., 2009, Enshassi et al., 2009).

The aforementioned challenges in cost estimation lead to incorrect contingency cost (Moselhi and Salah, 2012), hence, the overall agreed budget will be unreliable. Also, the project will be affected either by misusing the contingency cost or facing a shortage in the contingency costs to cover the carried risks (Schexnayder et al., 2011).

After discussing the challenges that face the traditional cost management process, next section includes an introduction in terms of the overview of BIM-based cost management. This section shows how BIM can be used to automate the quantification process.

2. BIM AND COST MANAGEMENT

In moving towards efficient project delivery, the ultimate goal is to have a database of information that is available to all project participants, with confidence in its accuracy, universal utility, and clarity (Ashcraft, 2014, Oraee et al., 2017). The main drive for adopting BIM is to manage all project documents and stages (i.e. design, planning, and costing) in a single/dynamic context, to secure the proper exploitation of available information (Redmond et al., 2012, Merschbrock et al., 2018, Abrishami et al., 2015). BIM design elements must contain the required information in various natures, including design or management (Banihashemi et al., 2018), to acquire smartly-designed elements, rather than traditional 3D components (Fu et al., 2006, Pärn and Edwards, 2017). BIM users should be capable of acquiring all the required information from a single BIM element, to make informed decisions (Motamedi and Hammad, 2009, Shen et al., 2012, Abrishami et al., 2014). Four-dimensional modelling (4D BIM) can embed progress data in 3D model objects by adjusting the task-object relationship (Hamledari et al., 2017). Application of 4D BIM leads to streamline workflows, efficient on-site management, and assessing constructability (Hartmann et al., 2008). As for the cost management, BIM is one of the most efficient Architectural, Engineering, and

Construction (AEC) tools in increasing productivity on construction projects (Wang et al., 2016, Aibinu and Venkatesh, 2013, Lee et al., 2014). Colloquially termed as 5D BIM (Aibinu and Venkatesh, 2013), this capability of BIM offers the preferred technique for extracting quantities from 3D models, allowing cost consultants to incorporate productivity allowances and pricing values (Eastman et al., 2011a, Lee et al., 2014). The cost estimating process starts with exporting data from 3D models to BIM-based cost estimating software (e.g. CostX®) to prepare quantity take-off. Afterwards, the Bills of Quantities (BoQ) are generated and exported to an external database (Aibinu and Venkatesh, 2013). Prices and productivity allowances can also be added to project schedule preparation (Eastman et al., 2011a, Lee et al., 2014). Such automated quantification will shorten the quantity take-off processing time, and will automatically consider any changes in design – which is likely in fast-track projects (Wang et al., 2016, Popov et al., 2010).

5D BIM is mainly a process of retrieving the quantities from the 3D BIM model, therefore, the role of quantity surveyors/cost estimator has been changed to meet this new technology as highlighted in the next section.

3. 5D BIM AND QUANTITY SURVEYING

Quantity surveying has been a vital part of the construction process for more than 170 years (Cartlidge, 2011). From that time, the role of the quantity surveyor has been to manage cost estimation and control as well as to optimise contractual and financial trade-offs, such as in the valuation and payment of construction projects (Ashworth et al., 2013). The role of the quantity surveyor has been developed to meet the requirements of value management approaches more than the construction method, and has been implemented by developing the tools and techniques used to capture cost management parameters, such as automated measurement (de Andrade et al., 2019). Moreover, the emergence of BIM has enabled the support and delivery of facilities management tasks as well as enhancing the holistic management process. Hence, the role of the quantity surveyors has changed in parallel with BIM progress (Stanley and Thurnell, 2014). The introduction of BIM has required a change in the manner of building in terms of design, procurement strategy, as well as all other parameters to achieve the necessary collaboration and integration in the AEC industry (Aranda-Mena et al., 2009, Qian, 2012). Consequently, cost management must change to be compatible with these approaches and an effective part of this process (Hanid et al., 2011).

Most of the definitions state that 5D BIM is the preferred method for extracting the quantities from the BIM model to enable cost consultants to commence the costing process by inserting the productivity allowances and pricing values (Eastman et al., 2011a). Forgues et al. (2012) recommend that output data should be supported by another format used to complete the measurement and pricing process. The cost estimation process begins by importing the BIM 3D model to any BIM-based cost estimation software, such as Exact COST-X or Visio office, to prepare take-off of quantities (Mitchell, 2012). After that, generating the Bill of Quantities (BOQ) and exporting it to an external database where prices and the productivity allowances are added to prepare the project schedule (Eastman et al., 2011a, Forgues et al., 2012). Moreover, Hannon (2007) points out that such automated quantification will shorten the typically time-consuming process, and will automatically take account of any changes in the design development process.

In this section, the role of quantity surveyor using 5D BIM was discussed, challenges that face quantity surveyors with BIM also presented. 5D BIM faces challenges and barriers like any other new process or technology. Therefore, this is highlighted in the next section.

3.1.5D BIM IMPLEMENTATION: BARRIERS AND CHALLENGES

Sylvester and Dietrich (2010) reported that 5D BIM has changed the quantity surveyor roles from spending much time to extract the quantities from the drawings to analyse and validate the cost data to reach the optimal cost estimation value. Moreover, Shen and Issa (2010) asserted that using 5D BIM platforms reduce the generated errors of misleading manual calculations and this leads to effectively estimated durations. In general, 5D BIM introduces a comprehensive process of taking the early decision at an early design stage by offering an automated quantity take-off for all designs whether concept or detailed design (Forgues et al., 2012). Therefore, Smith (2014b) asserted that the BIM process introduces a holistic approach for all project functions such as design, management, construction, and sustainability matters simultaneously. McCuen (2008) reported that exploiting 4/5D BIM in the AEC industry leads to increase the profitability. Moreover, Franco et al. (2015) claimed that the model has proven comprehensive and durable enough to assist in all phases of the project lifecycle—from conception, through design and construction, to operations and maintenance.

Nassar (2011) argued that the estimation process is more than listing the design objects and the prices, thus only using BIM is not adequate in the cost management process. Therefore, linking cost estimation programs and BIM design platforms is important to accomplish the entire cost management process. Stanley and Thurnell (2014) reported that exploiting BIM estimation software produce an accurate cost estimation and give the estimator reliable indicators to inform future projects. Nevertheless, McCuen et al. (2011) claimed that it is not necessary that the derived information from BIM model is completely precise. On the other hand, the data transfer between several platforms causes waste in data which reduces the accuracy of the information (Azhar et al., 2012). Moreover, Sunil et al. (2017) reported that BIM leads to enhanced cost estimation and control of tasks and this affects directly the role of cost managers and increase their abilities and way of making decisions. Moreover, BIM increases the involvement of quantity surveyors in different project tasks and eliminates the traditional QS isolation working environment which reduces the availability of information. Nonetheless, the integration and coordination between different models are not adequate, thus the QS is still responsible to articulate the cost report semi-manually via linking several models such as 3D design model, 5D platform to extract quantities and Excel sheet to determine the prices by exporting the derived quantities (Smith, 2014a). On the other hand, the integration between cost estimation and schedule is processed manually by the QS which makes this process complicated and takes a long time (Sunil et al., 2017). Moreover, Cho et al. (2012) also claimed that the project data is used by a set of spreadsheets, and estimating software, therefore, there is not a single/dynamic platform to conduct the entire cost management without any other supporting programs.

There is no balance in the relationship between the amount of information required for cost estimation and the data added by designers (Kiviniemi et al., 2007). Moreover, the pricing format is not considered in BIM models, but it is required by the quantity surveyors to modify the BOQ model for each project in terms of their breakdown structure (Wu et al., 2014).

The lacuna is caused by the traditional approach of working in separate environments, whereby each discipline is implemented by using a different model. This results in the confusion that what cost estimation model should be followed (Stanley and Thurnell, 2014), Consequently, the project core team member usually loses countless hours in adapting one model to meet the needs of the cost process (Meadati, 2009). Boon and Prigg (2012) contend that a balance of the information between the different disciplines, such as the architecture and QS information, must be considered.

Stanley and Thurnell (2013) state that the nature of the construction industry is the reason for the late or less efficient implementation of 5D 5D BIM. To address this, the 5D 5D BIMsoftware companies should consider collaboration regarding the workflow of the cost data throughout the project stages or between the different participants who lead, to make the cost management process effective and efficient (Olatunji et al., 2010).

Different challenges that face 5D BIM implementation were discussed in this section. Next section includes explanation how BIM is employed to develop the cash-out plan (curve).

4. BIM AND CASH FLOW

Interdependencies between the cost (5D BIM) and schedule (4D BIM) are obvious because the integration between cost and schedule processes in a single system is necessary to establish appropriate control. However, in practice, the two parameters are still separate given that the schedule is represented by Work Breakdown Structure (WBS), whilst the costs are identified by Cost Breakdown Structure (CBS) (Fan et al., 2015). Hence, during the budgeting stage, the integration between the WBS and CBS becomes complex, thus leading to potential errors and mismatch (Jung and Woo, 2004).

Fan et al. (2015) state that the initial steps to integrate 4D BIM and 5D BIM are first the creation of the project schedule and BIMs, and then the next step is the cost estimation of all BIMs. Subsequently, the generated cost items need to be linked with the project schedule (4D BIM), and the BIM element linked to the schedule. However, this process has some shortcomings when it comes to implementation, particularly linking the BIM schedule to the generated cost. In sum, the BIM elements should be linked directly to the cost items to avoid the complicated process of integrating these elements with the schedule.

Kim (1989) developed a costing system model to manage cost estimation, budgeting control. However, the proposed model, called basic construction operation, indicated the lowest level in construction operation, and this level has linked to three sources, namely, WBS, CBS, and design files. The proposed system has been criticised by Rasdorf and Abudayyeh (1991) as it requires a high level of details as well as refining each operation to reach sub-task, that is, the system is not practical and applicable in AEC industry.

Since the classification of construction works is vital to reliable budget, Kang and Paulson (1998) developed a classification system based on four categories, namely, facilities, Spaces, elements, and operations. Subsequently, the cost and schedule will be considered for each level in each category for a construction project, however, the proposed classification system is not suitable for quantity take-off in cost estimation process (Wang et al., 2016). Therefore, the challenge of detailed cost estimation with consistent WBS hierarchy persists in the AEC industry, particularly when using the work-packaging (WP) method which relies on the cost/schedule control system criteria (C/SCSC) in the package level. However, this is not efficient due to the construction operations involves long hierarchy levels to reach the sub-task level (Moder et al., 1983). Even though the method assigns the cost to WBS regardless of CBS, Rasdorf and Abudayyeh (1991) assert that it needs some improvements to make it applicable to complex projects.

Yang et al. (2007) developed a model to integrate the budget (override the resources) directly to the schedule in daily proportion to develop BCWS. In this model, each activity will be weighted daily as a ratio relative to the schedule, and this ratio will be used to measure the progress,. However, the shortcoming of this model is that daily scale in construction projects may be impractical. Cho et al. (2012) developed a model which is entitled a 5W1H (What, When, Where, Who, Why, and How) to solve the challenge of integrating cost/schedule in a construction project. More specifically, the planner can follow the operation as multi-function within multi-level such as What (would be a column), How (framework), and answers of other questions give more details to enable the integration.

According to Eastman et al. (2011b), there is no fully functional BIM cost management software, therefore the quantity surveyor should link between different platforms to carry out the main three tasks, namely estimation, budgeting and control. Even though Lawrence et al. (2014) developed a model to update the estimated cost automatically based on design changes, the entire estimation will be unreliable due to plenty of missed information which is not embedded in the design. Moreover, Wang et al. (2016) developed a model to integrate cost/schedule-based BIM, the developed model links between the BIM design object, cost item, activity, and area (zone/floor). Even though, the proposed model used BIM in formulating project budget, the process does not support the automation.

After discussing how BIM is utilised to develop the cost budgeting. Given, BIM supports completing tasks automatically, therefore, next section shows the existing attempts to integrate 4D and 5D to develop cost plan.

5. 4D/5D BIM AUTOMATION

Integrating BIM into daily construction activities will facilitate automatic updating of all site information, and as such, can result in enhancing productivity and strengthening relationships amongst stakeholders, and increasing trust in site-collected data (Omar and Dulaimi, 2015). As such, El-Omari and Moselhi (2011) asserted that using unsystematic procedures in collecting site data can lead to a huge loss of information with unreliable results. 4D BIM automation will enhance the quality of the collected data and reduce human interference in the data collection process (Hartmann et al., 2008, Hamledari et al., 2017). Similarly, 5D BIM provides an effective methodology for cost data collection and analysis of construction projects (Wang et al., 2016, Aibinu and Venkatesh, 2013, Lee et al., 2014, Popov et al., 2010). Furthermore, Lee et al. (2014) recommended that BIM cost systems should participate in decision making, rather than merely generating BoQs.

Automated data collection methods have intensively improved, through various kinds of technology like barcoding, radio frequency identification, 3D laser scanning, photogrammetry, multimedia, and pen-based computers (El-Omari and Moselhi, 2011, Turkan et al., 2012, Turkan et al., 2013). Eastman et al. (2011a), on the other hand, argues that there is no comprehensive BIM-based cost management platform that can perform all cost-related processes, namely estimation, budgeting, and control. Collected data is hence not effectively used across the construction industry, and research studies are shifting to explore the means towards analysing data in efficient ways (Wang et al., 2016, Hosseini et al., 2018).

This section provided a clear view regarding the existing attempts to develop the cash-out plan through integrating 4D and 5D automatically.

6. TEACHING MAP OF 5D BIM

To teach 5D BIM to undergraduate or postgraduate students, the teaching process should be systematic to enable students to absorb the required theoretical knowledge before moving to the practical and sophisticated applications. The following steps should be followed to prepare/adopt 5D BIM in educational institutes:

- **Teaching cost management process:** Cost management comprises of three main tasks (i.e. cost estimation, budget and control), which should be fully comprehended by students before moving to learn 5D BIM. This is to enable students to understand how 5D BIM can contribute to conduct these tasks and what the limitations are.
- **Teaching the traditional practices of cost estimation:** 5D BIM contributes mainly to automate extracting the BoQ from the 3D BIM model. Therefore, a student should be aware how traditional methods are used to implement the same process. This should be accompanied with teaching different cost estimation methods such as analogous and reserve estimation methods.
- **Teaching 5D BIM implementation process:** after students understand all essential theoretical knowledge, the 5D BIM then can be introduced systematically through (1) teaching the process of retrieving cost information from the 3D BIM model, (2) teaching how the retrieved cost data (i.e. BoQ) can be used to estimate the whole project

cost, and (3) teaching how the estimated cost can be used with other BIM documents such as 4D BIM to develop the project budget.

- **Teaching the advanced 5D BIM integrations with other technologies:** given BIM can be integrated with several technologies such as immersive technologies and blockchain, it will be useful to show how 5D BIM can be enhanced by using these technologies such as automating all payments to enhance the transparency among project parties.

Figure 1 shows the process of preparing and teaching 5D BIM. The process is divided into three main stages, namely, prerequisites of teaching 5D BIM, teaching 5D BIM, 5D BIM with other technologies.

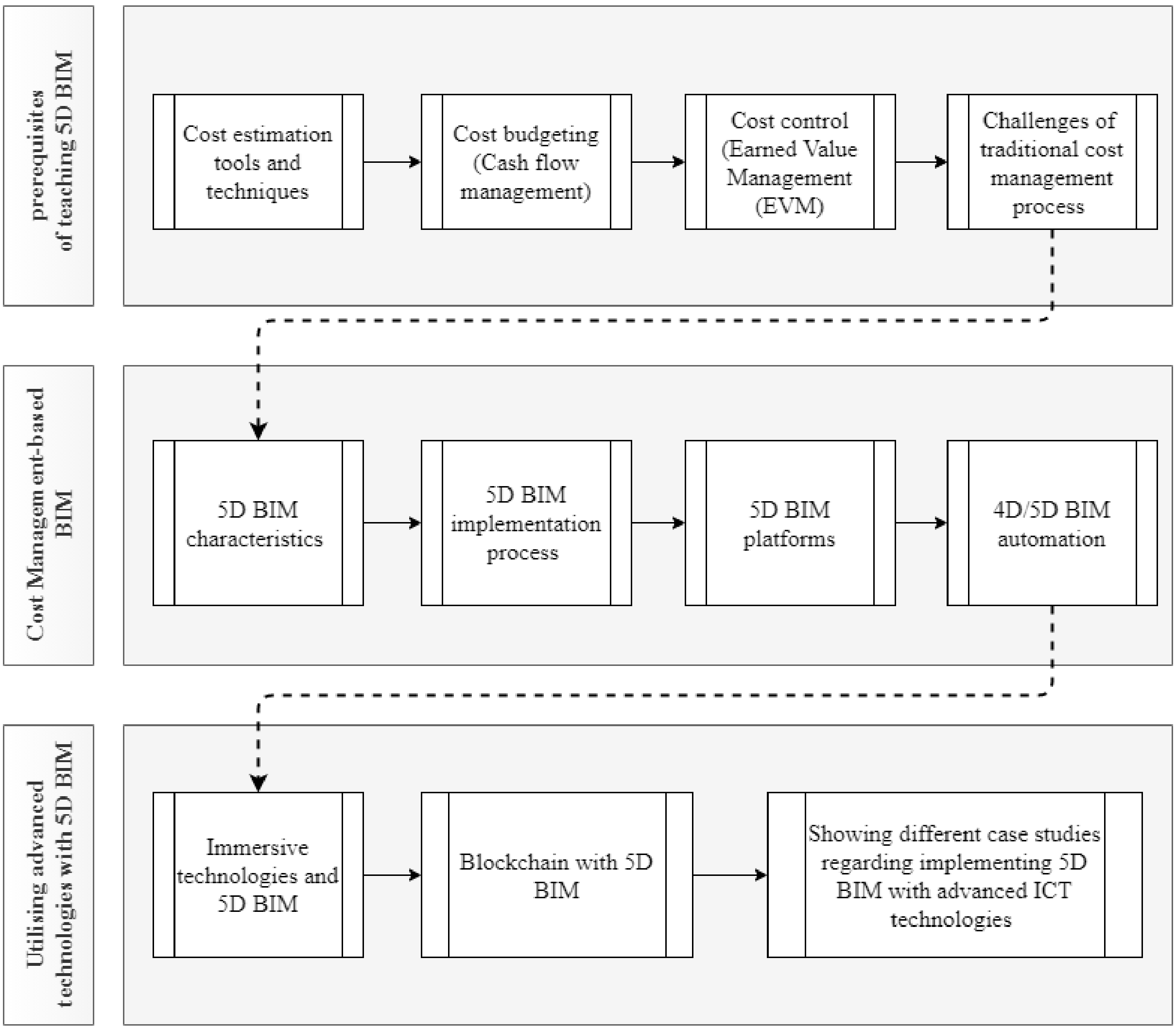

Figure 1. The process of preparing and teaching 5D BIM.

7. CONCLUSION

The aim of this chapter was to review the application of 5D BIM for cost management and establish a teaching map for educators. The cost management system is a framework that comprises of a set of tools and techniques to implement specific tasks such as estimation, budgeting, control, payment processing and change management. The most important activities in cost management system are to prepare the cost plan, perform the cost estimation, perform the cost control, and provide the calculation of final accounts. In particular, cost estimation is an important element of construction project planning and it is known to be an iterative process. Uncertainty, which is defined as controllable and uncontrollable factors that may occur during the project, is the major root cause of poor cost estimation. For example, changes in the scope of the project and bias may lead to inaccurate cost estimation. Also, ambiguous contractual agreements play an important role in inaccurate cost estimation. From its establishment, BIM is perceived to contribute to the cost management system and the role of quantity surveying. More specifically, 5D BIM offers extracting quantities from 3D models. The cost estimating begins by exporting data from 3D models to BIM-based cost estimating software, and the preparation of BoQs. Such automated quantification reduces the time needed for the quantity take-off. The role of quantity surveying has changed in a way that the focus is on analyzing and validating the cost data rather than spending time to extract quantities. Also, BIM helps quantity surveyors to be involved in different tasks of the project and eliminating the traditional QS isolation working environment. However, the coordination of building information models developed by different trades is a challenge and as a result, quantity surveyors need to articulate the cost report semi-manually by linking several models. The conventional approach of developing models in isolation make BIM ineffective for use by quantity surveyors.

Recognizing the interdependencies between the cost (5D BIM) and schedule (4D BIM) is important to control the cash flow. However, the integration of Work Breakdown Structure and

Cost Breakdown Structure is a complex task. Several solutions have been proposed to tackle this challenge in BIM, such as creating the project schedule with BIM models and then performing the cost estimation of all design elements. It has been also proposed to automate the data collection methods to further integrate 5D BIM into daily construction activities and reduce the human interfaces in data collection. However, the analysis of such data is a challenge and requires further studies.

This chapter also proposes a teaching map for 5D BIM consisting of four steps. The first step is about teaching the three main tasks of cost management process (i.e. cost estimation, budget and control), teaching the traditional practices of cost estimation, teaching 5D BIM implementation process (i.e. retrieving cost information from the 3D BIM model, how the retrieved BoQ can be used to estimate the whole project cost, how the estimated cost can be used with other BIM documents) and teaching the advanced 5D BIM integrations with other technologies.

Questions

- What is the cost management process?
- What are the 5D BIM characteristics?
- How the role of quantity surveyor changed with 5D BIM?
- What are the challenges of 4D/5D BIM automation?
- How BIM is utilized to develop the cost budgeting?

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