



A financial decision making framework for construction projects based on 5D Building Information Modeling (BIM)

Qiqi Lu, Jongsung Won, Jack C.P. Cheng *

Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong

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Abstract

Analyzing cash flows and undertaking project financing are important for contractors in managing construction projects. Traditional methods for cash flow analysis are based on the manual integration of time and cost information. However, the manual integration process can be automated by using five-dimensional building information modeling (5D BIM). Previous studies on 5D BIM have focused on estimating cash outflow rather than cash inflow analysis and project financing. This paper proposes a BIM-based methodology framework for cash flow analysis and project financing. The framework considers contract types and retainage to estimate cash inflow, and cash outflow patterns for equipment, manpower, and materials in order to more accurately measure cash outflow. Project financing scenarios can also be evaluated using the framework. Illustrative examples are demonstrated to validate the proposed framework by considering two what-if scenarios. Results show that the framework can help contractors analyze the cash flow and make appropriate decisions for different design and payment scheme alternatives in construction projects. © 2015 Elsevier Ltd. APM and IPMA. All rights reserved.

Keywords: 5D BIM; Cash flow analysis; Financial decision making; Project financing

1. Introduction

Managing and forecasting the cash inflows and outflows of a project is crucial to ensure the success of the project and the contractor (Park et al., 2005). More than 60% of construction contractor failures are mainly due to economic factors (Russell and Jaselskis, 1992). More construction companies fail due to a lack of liquidity in supporting their daily activities rather than inadequate management of other resources (Kaka and Price, 1991; Kangari, 1988; Navon, 1996; Park et al., 2005; Pate-Cornell et al., 1990; Singh and Lokanathan, 1992). Poor cash flow management may result in inadequate cash flows and thus undermine the sustainability of a project (Cui et al., 2010). Mismanagement of cash flow can result in times when cash availability is critically low, which could disrupt the project or even result in bankruptcy for the contractor.

Therefore, there have been many studies to analyze the cash flows of projects. Cash flows consist of cash inflow and outflow. Cash inflow is the result of progress payments received from the owners. Cash outflow results from the contractor's expenses such as materials, labor, equipment, subcontractor payments, and overheads. The resulting project net cash flows often involve gaps between expenses and owner payments (Kishore et al., 2011). Most previous studies were based on historical cost and schedule data. When sufficient historical cost data are available, the concepts of probability theory and statistical theory can be used for cash-flow prediction (Park et al., 2005). Integrating the scheduling and financing functions of construction project management is required to analyze cash flows (Elazouni, 2009). Construction firms use spreadsheets or other software packages to estimate project cash flows. The computerized estimation is developed with the integrated costs/schedule method, which involves a detailed project schedule with full costing based on the bill of quantities (BOQ) (Cui et al., 2010). However, scheduling and financing are not effectively integrated (Lee et al., 2011). The traditional process of

* Corresponding author. Tel.: +852 2358 8186; fax: +852 2358 1534.

E-mail addresses: qluab@ust.hk (Q. Lu), jongsungwon@ust.hk (J. Won), cejcheng@ust.hk (J.C.P. Cheng).

forecasting cost flow curves entails the calculation of production quantities for each time interval, according to the progress schedules, and then multiplying them by the estimated unit costs. This manual process has been found to be tedious and time consuming, leading to alternative automated methods being sought (Kaka, 1996; Kim and Grobler, 2013).

On the other hand, the manual process can be improved upon with technological advancements, especially building information modeling (BIM) (Kim and Grobler, 2013). A BIM model is a digital representation of physical and functional characteristics of a facility (NIST, 2012). BIM models contain a wealth of information such as material resources and can be integrated with the schedule and cost information to perform five-dimensional (5D) BIM. There are several software tools used to create 5D BIM models, such as Autodesk Navisworks, Vico Office, CostX, etc. Current 5D BIM models are mainly used for cost estimation of a project and enable various disciplines to visualize the progress of construction activities and related costs over time (Multiconsult AS, 2012; URS, 2012a, b; Vicosoftware, 2007). The current BIM-based cost estimating processes still have several limitations. For example, they cannot be used for cash flow analysis since they do not consider payment delays, retention, material orders, etc. Moreover, there have been few studies on the cash flow analysis in a project based on 5D BIM (Kim and Grobler, 2013). Kim and Grobler (2013) proposed methodologies to analyze cash flows of a project by integrating a BIM model with schedule, cost, and cash inflow payment patterns databases. However, they assumed that cash outflows are made continuously according to the completion status of individual tasks. In reality, based on the contract, some payments need to be settled at the time of ordering, while some payments are made a period after the associated tasks are completed. Therefore, they did not consider cash outflow patterns based on contracts that would provide decision making for project financing.

This paper proposes a methodology framework to accurately analyze cash flows (cash inflow and cash outflow) of construction projects and to support financial decision making for contractors based on 5D BIM. The framework considers quantities of equipment, quantities of manpower, and quantities of materials, project schedule, payment period, down payment, and lead time of material orders in order to calculate the actual cash outflow. The cash inflow of a project is analyzed in the proposed framework by considering cash inflow patterns as defined in contracts. Furthermore, contractors can compare various alternatives through considering the different designs, overdrafts, and interest rates and decide how to finance the overdraft costs for managing a project smoothly.

This paper is organized as follows. The next section reviews various previous studies on cash flow analyses in the architecture, engineering, and construction (AEC) industry. Section 3 introduces the proposed methodology to analyze cash flows and to support financial decision making at the project level. Examples to demonstrate the framework are illustrated in Section 4. Findings and contributions of this paper as well as future work are discussed in Section 5.

2. Literature review

Considerable research on analyzing the cash flows of a project has been conducted. In order to accurately forecast cash flow, detailed data are required. Detailed data include resources, cost estimation, bill of quantities, schedule, information about subcontractors, contract information between owners and subcontractors, and general data (Navon, 1996). Various studies developed methods to analyze the cash flow of a project with detailed data by integrating the schedule and cost. Reinschmidt and Frank (1976) proposed a model for cash flow forecasting in the early planning stage of a project by integrating the schedule and cost items manually. Sears (1981) also proposed a technique to manually integrate the schedule and cost items for cash flow analysis. However, the manual process was time-consuming. To avoid extensive manual work, each of these cost elements was assumed to be a fixed percentage of the total cost over the project's duration. For example, Ashley and Teicholz (1977) suggested a cash flow forecast based on detailed methods of cost flow and divided the direct cost into labor, materials, and equipment costs, which were specified as percentages of the total cost. However, since cost items were not calculated based on the accurate quantity of each resource, cash flows cannot be analyzed accurately. Moreover, many of the early cash flow models in the 1970s did not account for the time lag between cost payments (Navon, 1996).

Various approaches were proposed for more accurate cash flow forecasting (Boussabaine and Kaka, 1998; Kaka, 1996; Kenley and Wilson, 1986; Miskawi, 1989; Navon, 1996; Tucker, 1986). Barbosa and Pimentel (2001) developed a linear programming model by dealing with typical financial transactions, possible delays on payments, use of available credit lines, effect of changing interest rates, and budget constraints. Park et al. (2005) proposed a moving weights model considering the progress of construction work and incorporating the time lags in accordance with change orders or changes in the contractual payment conditions and credit times given by subcontractors.

However, if either the BOQ or the schedule is altered due to particular changes, the integration process is likely to be more complicated and time consuming. Therefore, researchers have proposed several systems that could support this process. Hwee and Tiong (2002) developed a computer model to forecast cash flows through analyzing risk factors. Hegazy and Ersahin (2001) proposed a cash-flow modeling and analysis system that considers cash inflows, cash outflows, and overdraft size. Lee et al. (2011) proposed a stochastic system that can handle the variability in cash-flow inputs and outputs by finding the best-fit probability distribution function and by integrating project financing and stochastic simulation-based scheduling into a single system. It appears that existing finance-based scheduling methods are valuable and effective project management tools.

The existing proposed models still require extensive manual processes by contractors. Although previous studies have proposed new algorithms for cash flow analysis, it is a daunting task for project planners to develop a time–cost integration for

cash flow analysis due to tremendous amount of information involved. Despite the fact that advanced technologies appear abundant in the areas of quantity take-off (QTO), scheduling, and cost estimation, integrating all the aforementioned tasks into one system is still lacking. A system based on modeling technologies linked to a project schedule and cost can provide such integration automatically and effectively. Three-dimensional computer-aided design (3D CAD) development in the late 1980s was an important advance in the development of construction modeling technology (O'Brien, 2000). 3D CAD technology was often used and studied to improve the design quality by creating a virtual mockup before construction. Another typical application of 3D CAD models was to coordinate the construction sequence (Griffi et al., 1990). This work quickly led to the advancement of four-dimensional (4D) CAD models (linking the schedule information with 3D CAD models) in the AEC industry. More dimensions of information, like cost information, were linked to 4D CAD models to create multi-dimensional (MD) CAD models (Feng et al., 2010; Kang and Paulson, 1998; Liston et al., 1998; Waly and Thabet, 2003). Staub and Fischer (1999) demonstrated the practical needs of integrating cost, time, and scope and proposed an approach to cost planning at the activity level in a 4D environment. Feng et al. (2010) utilized the MD CAD model to generate the time–cost integration and automate the scheduling process. Liston et al. (1998) proposed a visual decision support tool based on 4D CAD for construction planners to visually show how a proposed schedule change affects decision criteria like cost. The intelligent link of 3D CAD/BIM models with time and cost information is officially named as 5D BIM.

Construction projects are now becoming more complicated and more materials are needed. In addition, as the project proceeds, changes become more frequent. A more efficient and automatic financial decision making support and cash flow analysis should be conducted. Some technological advancement, like 5D BIM, can provide advantages over traditional methods of quantity surveying by quick updates of both schedule and budget, improved visualization of construction details, and risk identification in advance (Stanley and Thurnell, 2014). Contractors can optimize the schedule by integrating quantities of materials provided by the BIM model with the productivity rate of construction crews and predict the accurate project cost at different project time (Kala et al., 2010; Sattineni and Macdonald, 2014; Smith, 2014; Vicosoftware, 2007). Apart from cost and schedule estimation, 5D BIM can also facilitate specific aspects (Kim et al., 2014; Wong et al., 2014). For example, Wong et al. (2014) utilized 5D BIM technology to promote pro-active carbon mitigation and improve on-site safety. Kim et al. (2014) proposed a 5D product model for highway alignment design reviews. On the contrary, there are few studies on analyzing cash flow based on the BIM model. Kim and Grobler (2013) proposed a method to analyze cash flows based on automated processes, including QTO, scheduling, and cost estimating, by using BIM. Through the automated process, time and effort in analyzing cash flows could be reduced from weeks to minutes. However, current approaches to 5D BIM assumed

that cash outflows are made continuously according to the completion status of individual tasks. In practice, some payments need to be settled at the time of ordering while some payments are made in batches after the associated tasks are completed. Moreover, BIM-based financial decision making for project financing was not considered. With BIM models, contractors are able to quickly compare diverse cash flow scenarios for each model, which is potentially useful for value engineering decisions and bidding strategies (Kim and Grobler, 2013). This indicates the need for a comprehensive framework based on 5D BIM which can analyze cash inflow and actual cash outflow and support project financing for construction projects.

3. The proposed 5D BIM framework for financial decision making

The structure of the proposed 5D BIM framework for project-level cash flow and financial decision making is explained in this section. As described in Fig. 1, the framework consists of four modules: (1) 5D model preparation, (2) cash inflow calculation, (3) cash outflow calculation, and (4) project financing.

3.1. 5D model preparation

As shown in Fig. 1, in order to prepare a 5D BIM model, four main steps are needed. They are (1) BIM model generation, (2) Quantity take-off (QTO) extraction, (3) schedule data and QTO list integration, and (4) Cost data and schedule-loaded QTO list integration. A BIM model contains full geometric and semantic information and can be exported to a 5D software platform to generate a QTO list. By linking the QTO list with the external schedule database, the schedule-loaded QTO list is generated. By integrating the schedule-loaded QTO list with the external cost database, the cost-loaded project schedule (cost-loaded timeline) can be estimated. The cost-loaded timeline file can then be imported to the 5D platform to create a 5D BIM model and conduct 5D simulation.

3.1.1. BIM model

BIM is a digital representation of the physical and functional characteristics of a facility (NIST, 2012), which contains geometric and semantic information as the basis of 5D simulation. Semantic information provides material information, while geometric information provides accurate QTO of objects. The contractor will be able to utilize the framework to automate the cash flow analysis as soon as they receive a BIM model. The accuracy and level of detail (LoD) of the cash flow analysis depends on the LoD of the BIM model and the accuracy of the external databases, including schedule and cost information. Cash flow can be analyzed at any stage of the project based on the updated BIM model which can reflect the current changes and of high LoD. Consequently, as the project proceeds, the accuracy of cash flow analysis can be increased as more information is available.

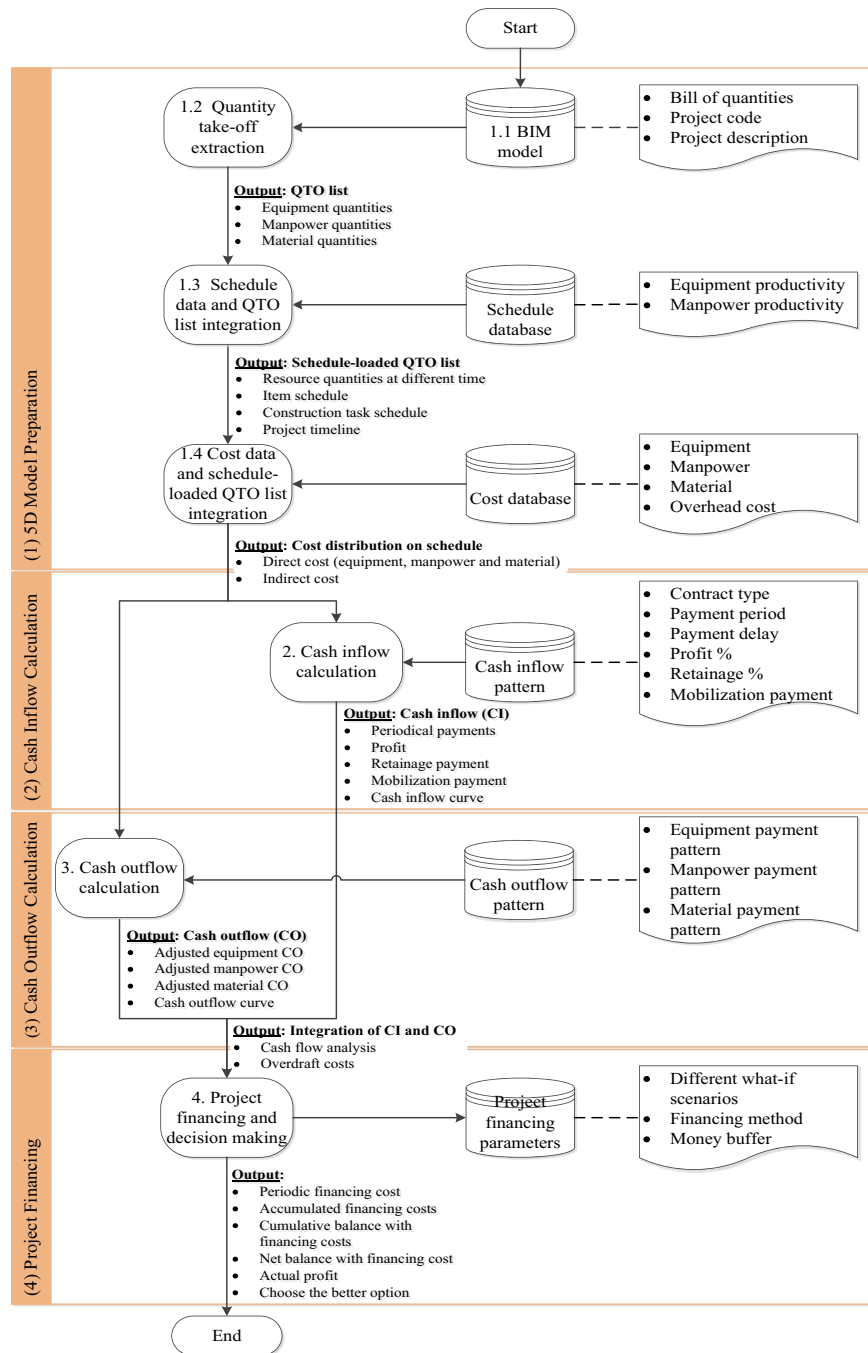


Fig. 1. The proposed 5D BIM framework for cash flow analysis and financial decision making.

3.1.2. Quantity take-off (QTO) extraction

Many software tools like Vico Office, Autodesk Quantity Takeoff, Autodesk Navisworks, etc. support extracting object quantity take-offs from a 3D BIM model. Fig. 2 shows the workflow to calculate QTO of a project. Many dimensions of component quantities, such as length, width, thickness, area, and volume, can be estimated by existing software platforms. Once the quantities are extracted, it is also important to make sure that the quantities are in the right units since they will be exported as the basis for scheduling and cost estimating. The preferred units for each component and resource are defined by the industry/company

standard, and they can be stored in the Quantity Surveyor (QS) databases, including the schedule database and cost database. Following the QS databases and adding resources into each element, the resource quantities, including materials, manpower, and equipment, can be calculated. The generated QTO file can be exported into many common formats, like extensible markup language (XML) and Microsoft Excel, for further analysis.

3.1.3. Schedule data and QTO list integration

The QTO list with resource information extracted from the BIM model can then be linked to the external schedule database

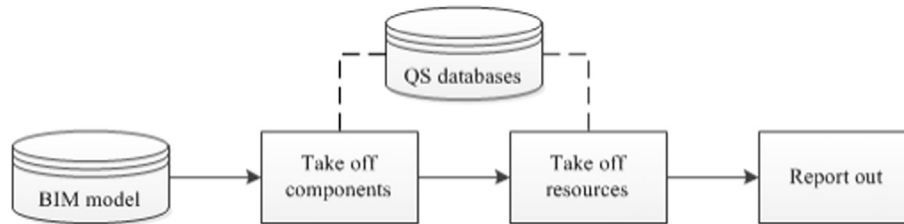


Fig. 2. The workflow of quantity take-off.

to calculate the project schedule. Fig. 3 shows an example of BIM-based scheduling and explains the related terminologies. The schedule database includes equipment and labor productivity which allows estimating the duration for each work item by linking them to the QTO list. Several work items can constitute a construction task. A schedule-loaded QTO list is generated by manually adding the logistic sequence among different tasks. The project timeline, which only contains the duration of each task, can also be calculated by removing all other information, such as item and resource quantities and schedule.

3.1.4. Cost data and schedule-loaded QTO list integration

By linking the schedule-loaded QTO list with the external database, including equipment, manpower, and material cost, the direct cost distribution on the project schedule can be estimated. Some other cost items like material hoists, tower cranes, and scaffolding, which cannot be directly linked to each building component, should be added as well. Some indirect costs like supervision, cleanup fees, bonds or insurance, etc. should also be included to calculate the total project cost. The timeline file can then be updated to include the cost information and imported to a 5D software platform to create the 5D BIM model and thereby conduct 5D simulation. However, the 5D BIM model does not provide the cash inflow nor reflect the actual cash outflow of a project, since it is based on the contractor's expected daily consumption on the construction site, rather than considering income patterns and the actual payments by a contractor. Therefore, cash inflow and cash

outflow patterns should be considered in order to accurately analyze the cash flow of a project.

3.2. Cash inflow calculation

The contract type and payment scheme may have an influence on the cash inflow. This paper focuses on the unit price contract, because it requires precise measurement of field quantities which can be provided by the BIM model. Other types of contracts can be incorporated by changing the cash inflow payment patterns in the framework. A unit price contract consists of a specified set of measurable work items. A guide quantity of work items is often provided for contractors to quote prices. The subtotal for each work item is the unit price multiplied by the guide quantity, while the total contract price is the sum of the individual work item subtotals. The total contract price is the contractually obligated price that will be paid for the project. Therefore, the total contract price is the total cash inflow for the project. The unit price for each work item should reflect the relevant direct cost and the percentage profit. Based on a unit price contract, the contract price as well as the total cash inflow for the project can be formulated by Eq. (1):

$$CI = \sum_{w=1}^W (UP_w \times Q_w) \quad (1)$$

where CI is the total cash inflow; W is the number of work items; UP_w is the unit price the contractor quoted for work item

From Quantity-takeoff (QTO) List				From Schedule Database		Calculate the schedule				
Task ID	Work Item ID	Work activity Title	Resource category	Primary quantity (A)	Productivity (B)	Working days (=A/B)	Predecessor ID	Expected start	Expected end	
Task →	4	Level 1: Columns (Concrete)				9	3	04/04/2011 8:00	04/15/2011 17:00	
Work Item →	4.1	Level 1: Columns (Concrete)-10x10					3	04/04/2011 8:00	04/07/2011 17:00	
Resource →		4.1.1	Rebar #3	Material	2000 pd			04/04/2011 8:00	04/04/2011 17:00	
Resource →			Rodman	Manpower		2000 pd/day	1			
Resource →		4.1.2	Formwork	Material	500 sf			04/06/2011 8:00	04/06/2011 17:00	
Resource →			Formwork Carpenter	Manpower		500 sf/day	1	4.1.1		
Resource →		4.1.3	Concrete 3000 psi	Material	5 cy			04/07/2011 8:00	04/07/2011 17:00	
Resource →			Concrete Pourer	Equipment		5 cy/day	1	4.1.2		
Resource →			Concrete Pumping Equipment	Manpower						
Work Item →	4.2	Level 1: Columns (Concrete)-18x18					6	4.1	04/08/2011 8:00	04/15/2011 17:00
Resource →		4.2.1	Rebar #4	Material	4000 pd			04/08/2011 8:00	04/11/2011 17:00	
Resource →			Rodman	Manpower		2000 pd/day	2			
Resource →		4.2.2	Formwork	Material	1000 sf			04/12/2011 8:00	04/13/2011 17:00	
Resource →			Formwork Carpenter	Manpower		500 sf/day	2	4.2.1		
Resource →		4.2.3	Concrete 3500 psi	Material	10 cy			04/14/2011 8:00	04/15/2011 17:00	
Resource →			Concrete Pourer	Equipment		5 cy/day	2	4.2.2		
Resource →			Concrete Pumping Equipment	Manpower						
Note: 04/05/2011 public holiday; 04/09/2011, 04/10/2011 weekends										

Note: 04/05/2011 public holiday; 04/09/2011, 04/10/2011 weekends

Fig. 3. Example of BIM-based scheduling and the related terminologies.

w and is calculated using Eq. (2); and Q_w is the quantity for work item w .

$$UP_w = UC_w \times (1 + P\%_w), w = 1, 2, \dots, W \quad (2)$$

where $P\%_w$ is the profit percentage of work item w , UC_w is the unit cost of work item w , which is the sum of equipment, material, and manpower cost divided by the work item quantity as represented by using Eq. (3):

$$UC_w = \frac{CO_w^{EQ} + CO_w^{MP} + CO_w^{MT}}{Q_w}, w = 1, 2, \dots, W \quad (3)$$

where UC_w is the unit cost of work item w ; CO_w^{EQ} is the equipment cost of work item w ; CO_w^{MP} is the manpower cost of work item w and CO_w^{MT} is the material cost of work item w ; and Q_w is the quantity for work item w .

It is not reasonable to expect the contractor to finance the project to completion. Consequently, the contract typically calls for the project owner to make periodic payments to the contractor for the items completed with less retainage to be held by the owner until completion of the project. The periodic payments from the client constitute the cash inflows for the project, while the contractor's various expenses of the project result in the cash outflows. The time difference between two periodic payments (T^{pay}) should be defined in the contract. In addition, the time lag between payments and expenses (T^{lag}) is common in the construction industry. In other words, the payment is not realized until a period after the corresponding expense occurs. As illustrated in Fig. 4, the owner can make monthly payments ($T^{pay} = \text{one month}$), with a two-month delay ($T^{lag} = \text{two months}$). Therefore, the cash inflow curve lags behind the cash outflow curve. The total cash inflows are the total cash outflows with profit applied. It is common for owners to hold a certain percentage of the payments as retainage money in the contract to ensure the contractor completes the project on time and with high quality. The retainage percentage can be a constant, like 10% of each period payment, or can be changed as the project proceeds. There are several common methods used to pay the retainage. For example, at each milestone point, the previous retainage could be paid by the client. Another scenario is that all the retainage is paid back in the final payment (Fig. 4).

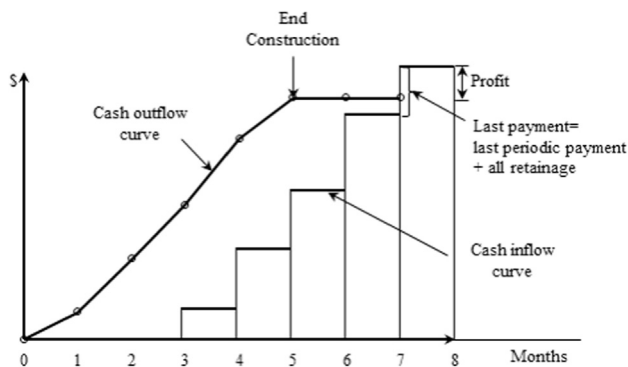


Fig. 4. Cash inflow curve and cash outflow curve.

Cash inflow amount and point can be defined as follows:

$$CI^m = \begin{cases} \left[\sum_{w=1}^W (UP_w \times Q_w^m) \right] \times (1 - R\%_m), m = 1, 2, \dots, M-1 \\ \left[\sum_{w=1}^W (UP_w \times Q_w^m) \right] \times (1 - R\%_m) + R, m = M \end{cases} \quad (4)$$

$$R = \sum_{m=1}^M \sum_{w=1}^W (UP_w \times Q_w^m \times R\%_m) \quad (5)$$

$$t^{CI^m} = m + T^{lag}, m = 1, 2, \dots, M \quad (6)$$

where CI^m means the cash inflow for month m ; Q_w^m is the quantity of work item w finished in month m , which can be provided by the updated BIM model; $R\%_m$ is the retainage percentage ($R\%$) for month m and changes with the project proceeds; M is the number of months the project lasts; and R represents the total retainage the owner holds and is calculated based on Eq. (6). As formulated in Eq. (5), all the retainage are paid to the contractor in the last payment. Cash inflow point is calculated by Eq. (7), where t^{CI^m} is the cash inflow point for CI^m , while T^{lag} represents the time lag between expense and payment. If $T^{lag} = 2$, for example, CI^1 happens at the end of month 2 and CI^m happens at the end of month $m + 1$.

3.3. Cash outflow calculation

5D BIM model can only reflect the daily expenditure on the construction site; it cannot show the actual cash outflow of the contractor, since some down payments should be paid to the supplier at the time of ordering. The remaining part will be realized in a period after the associated construction activities are completed. In order to calculate the actual cash outflow amount and timing of the resources, the actual payment patterns of the equipment, material, and manpower cost should be analyzed. However, subcontractor payment patterns are not considered in the framework. Since most of the construction work is performed by subcontractors, the costs for the subcontractors account for a large portion of general contractor's cost. In addition, the retention burden from the client can be transferred to the subcontractors which can help the contractor improve the cash flow status. However, the payment pattern for subcontractors is almost the same as that of materials. For example, the down payment of the material supplier is similar to retention of the subcontractor.

The actual payment patterns of the equipment, material, and manpower should be inputted by the contractor to calculate the adjusted cash outflow. Lists of the required information are explained in the next sub-sections.

3.3.1. Equipment payment pattern

There are many suppliers providing the different equipment facilities needed in a project. Each supplier provides at least one type of equipment, while the same equipment facility can only be supplied by one equipment supplier throughout the project

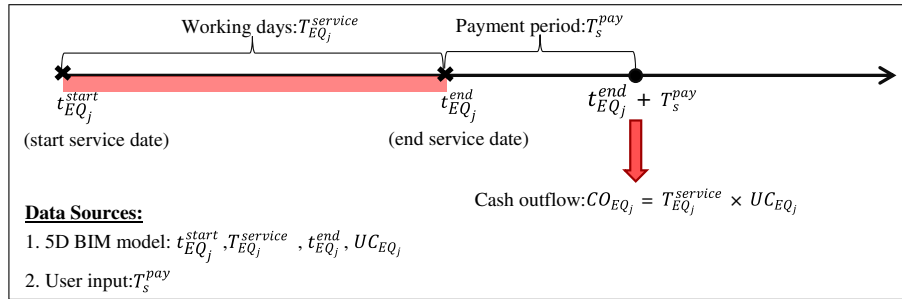


Fig. 5. Equipment cash outflow pattern.

schedule. Each supplier has the same payment period requirement for the different equipment facilities it provides. The unit cost may be different for different equipment facilities. Fig. 5 shows the equipment cash outflow pattern. Suppose there are S suppliers providing J equipment facilities (EQ) for the project. EQ_j starts service on the construction site at start service date ($t_{EQ_j}^{start}$). The contractor pays the supplier s for the equipment i service after a payment period (T_s^{pay}) since the end service date of EQ_j ($t_{EQ_j}^{end}$). The actual cash outflow amount (CO_{EQ_j}) and point of EQ_j ($t_{EQ_j}^{CO}$) can be represented by Eq. (8) and Eq. (9), respectively:

$$CO_{EQ_j} = T_{EQ_j}^{service} \times UC_{EQ_j} \quad (8)$$

$$t_{EQ_j}^{CO} = t_{EQ_j}^{end} + T_s^{pay} \quad (9)$$

where $T_{EQ_j}^{service}$ denotes working days within the service period of EQ_j ; UC_{EQ_j} represents the unit cost of EQ_j ; $j = 1, 2, \dots, J$, while J is the number of equipment facilities; and $s = 1, 2, \dots, S$, while S is the number of equipment suppliers.

3.3.2. Manpower payment pattern

In the framework, the manpower cost is qualified in monetary value, and is paid each payment period. The amount of payment to each manpower team is calculated based on

working days within the payment period or based on their work quantities. For example, a concrete pouring team is paid based on how many cubic yards of concrete they finish in a specific period of time.

As shown in Fig. 6, the manpower team k (MP_k) starts their service at start service date ($t_{MP_k}^{start}$) and ends at end service date ($t_{MP_k}^{end}$) after a service period ($T_{MP_k}^{service}$). At the end of each payment period ($T_{MP_k}^{pay}$), the contractor pays the team based on their work completed for the previous period. For example, at the end of first payment period, the contractor pays MP_k an amount of salary which equals the work quantities ($Q_{MP_k}^1$) they finished within the first payment period multiplied by unit cost of the manpower team k (UC_{MP_k}). The number of payments (N_k) the contractor pays to MP_k is calculated by dividing the total service period ($T_{MP_k}^{service}$) by the payment period ($T_{MP_k}^{pay}$). Eq. (10) and Eq. (11) represent how to calculate the cash outflow amount ($CO_{MP_k}^n$) and point ($t_{MP_k}^{CO^n}$) of the cash outflow for MP_k , respectively:

$$CO_{MP_k}^n = Q_{MP_k}^n \times UC_{MP_k} \quad (10)$$

$$t_{MP_k}^{CO^n} = t_{MP_k}^{start} + n \times T_{MP_k}^{pay} \quad (11)$$

$$N_k = T_{MP_k}^{service} / T_{MP_k}^{pay} \quad (12)$$

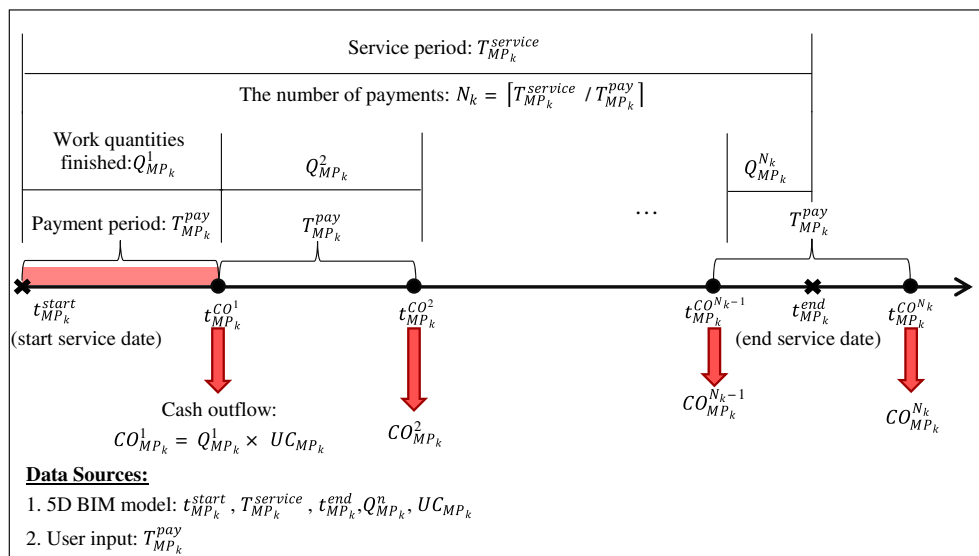


Fig. 6. Manpower cash outflow pattern of manpower team k (MP_k).

where $k = 1, 2, \dots, K$, while K is the number of manpower teams; and $n = 1, 2, \dots, N_k$, while N_k is the number of payments the contractor pays to MP_k .

3.3.3. Material payment pattern

There are S^* material suppliers providing L materials in a project. One supplier may provide several materials, while one material could only be provided by one supplier. One material may contain several orders. One order may be divided into several deliveries to the construction site. When an order is placed, down payment is given to the supplier. The remaining payment of this order is realized in the payment period, like one month after the arrival date of the first delivery of the order. The time difference between order placement date and the first arrival date is called lead time. There may be some time buffer between arrival date and start use date of an order. For example, the time buffer for concrete may equal zero.

Based on this information, material cash outflow patterns can be defined. Fig. 7 depicts the cash outflow pattern of order r ($O_{l,r}$) of material l (MT_l). The order is made at the order placement date ($t_r^{placement}$) with the quantity of order r of material l ($Q_{l,r}$). At order placement date, down payment of the order r of material ($DP_{l,r}$), which is calculated by Eq. (13), is paid to the supplier s^* . Therefore, the order placement date is also the down payment date ($t_{l,r}^{DP}$). After a lead time ($T_{MT_l}^{lead}$), the first delivery of $O_{l,r}$ arrives on the construction site. After a time buffer ($T_{MT_l}^{buffer}$), the newly arrived materials are used on the construction site. The remaining payment ($RP_{l,r}$) of $O_{l,r}$ is calculated by using Eq. (14) and realized after a payment period ($T_{s^*}^{pay}$) passing from the arrival date of the first delivery ($t_{l,r}^{arrival 1}$). Eq. (15) to Eq. (17) are used to calculate the arriving date of the first delivery ($t_{l,r}^{arrival 1}$), the starting use date of this order ($t_{l,r}^{start}$), and the remaining payment point ($t_{l,r}^{RP}$) of order r ($O_{l,r}$) of material l (MT_l), respectively.

$$DP_{l,r} = Q_{l,r} \times UC_{MT_l} \times D\%_{s^*} \quad (13)$$

$$RP_{l,r} = Q_{l,r} \times UC_{MT_l} \times (1 - D\%_{s^*}) \quad (14)$$

$$t_{l,r}^{arrival 1} = t_{l,r}^{DP} + T_{MT_l}^{lead} \quad (15)$$

$$t_{l,r}^{start} = t_{l,r}^{DP} + T_{MT_l}^{lead} + T_{MT_l}^{buffer} \quad (16)$$

$$t_{l,r}^{RP} = t_{l,r}^{DP} + T_{MT_l}^{lead} + T_{s^*}^{pay} \quad (17)$$

where UC_{MT_l} represents unit cost of material l (MT_l), while $D\%_{s^*}$ denotes down payment percentage of supplier s^* ; $r = 1, 2, \dots, R_l$, while R_l is the number of orders of MT_l ; $l = 1, 2, \dots, L$, while L is the number of materials used in the project; and $s^* = 1, 2, \dots, S^*$, while S^* is the number of material suppliers for the project.

Sometimes, several orders for the same material are required on the construction site. After the material in one order is fully consumed, material arriving later in the next order starts to be used. However, the cash flow pattern of several orders of the same material is a repetition of that of one order. As illustrated in Fig. 8, there are R_l orders of material l (MT_l). Assume MT_l is consumed continuously on the construction site, therefore, the end use date of order $O_{l,1}$ ($t_{l,1}^{end}$) is the start use date of 2nd order $O_{l,2}$ ($t_{l,2}^{start}$). A buffer time ($T_{MT_l}^{buffer}$) before start use date is the arrival date of $O_{l,2}$ ($t_{l,2}^{arrival}$). A lead time for MT_l ($T_{MT_l}^{lead}$) before the arrival date is the down payment point ($t_{l,2}^{DP}$) as well as the order placement date ($t_{l,2}^{placement}$). In the payment period ($T_{s^*}^{pay}$) after the arrival date ($t_{l,2}^{arrival}$), the remaining payment ($RP_{l,2}$) should be provided to the supplier s^* . This process will continue until the end use date of MT_l (t_{l,R_l}^{end}).

3.3.4. Adjusted cash outflow

After the cash outflows for equipment, manpower, and material are adjusted by considering the characteristics of their patterns, the final cash outflow of the project is given by

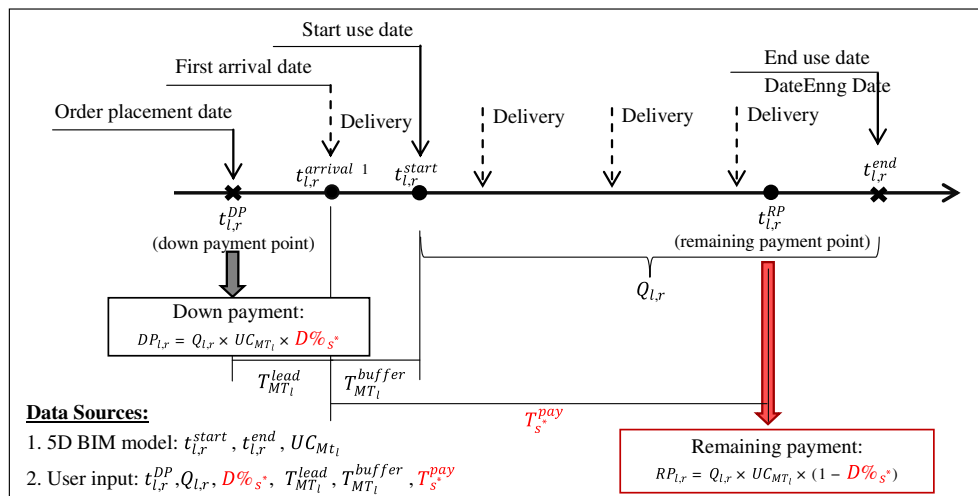


Fig. 7. Cash outflow pattern of the order r (O_r) of material l (MT_l).

Eq. (18) and the monthly cash outflow can be represented by Eq. (19):

$$CO = \sum_{m=1}^M (CO_{EQ}^m + CO_{MP}^m + CO_{MT}^m + CO_{ID}^m) \quad (18)$$

where CO is the total cash flow of the project; M is the number of months of the project; and CO_{EQ}^m , CO_{MP}^m , CO_{MT}^m , and CO_{ID}^m denote the cash outflow of manpower, material, equipment, and indirect cost for month m , respectively.

$$CO^m = \sum_{m=1}^m (CO_{EQ}^m + CO_{MP}^m + CO_{MT}^m + CO_{ID}^m), \quad m = 1, 2, \dots, M \quad (19)$$

where CO^m is the adjusted cash outflow during month m .

3.4. Project financing and decision making

3.4.1. Project financing

All projects require financing and no project progresses without adequate financial resources (Merna, 2008). At the beginning of each month, the contractor prepares funds for the whole month's expenditure on the project. There is also a contingency money buffer ($BF\%$). The money buffer may be consumed each month if there is any variation within the month. The same percentage of buffer will be maintained at the beginning of each month. By considering a money buffer, the cash outflow equation changes to Eq. (20):

$$CO_B^m = \sum_{m=1}^m CO^t \times (1 + BF\%), \quad m = 1, 2, \dots, M \quad (20)$$

As shown in Fig. 9, by considering the money buffer, the cash outflow curve moves from the solid line to the dotted line

labeled as 'Cash outflow + buffer.' Since the client pays the contractor after a payment period, the cash inflow of a project often lags behind the cash outflow. The difference between the cash inflow and outflow is called the overdraft. The contractor should finance the overdrafts in managing their project smoothly without liquidity problems. With a money buffer, the overdraft becomes larger. The overdraft could be reduced by two methods: unbalanced bid or mobilization payment by the client. The unbalanced bid means that the contractor inflates the unit prices of the early work items and deflates prices of later items. However, since the client is very sensitive toward the bidding unbalancing, some contracts allow the contractor to quote a "mobilization" bid item to obviate unbalanced bids. Consequently, the unit prices of work items should be deflated. The deflated unit price can be represented by Eq. (21).

$$UP_w^{DF} = UP_w \times (1 - DF\%_w), \quad w = 1, \dots, W \quad (21)$$

where UP_w^{DF} denotes the deflated unit price for work item w due to mobilization payment; UP_w represents the original unit price for work item w ; $DF\%_w$ is the unit price deflation rate for work item w ; and W is the number of work items. Consequently, the mobilization item moves the curve of the cash inflow to the left of the curve of cash outflow (Fig. 9(b)).

Without mobilization payment and (b) cash inflow pattern with mobilization payment).

Although the overdraft can be reduced, it cannot be avoided. How to finance the overdraft is one of the biggest problems that a contractor faces. There are various financial instruments to finance the overdraft costs. Issuing bonds or stocks to raise money for infrastructure projects is common practice (Merna, 2008). Using their own funds or financing from banks are also common ways to provide working capital during the construction phase. In this paper, it is assumed that borrowing money

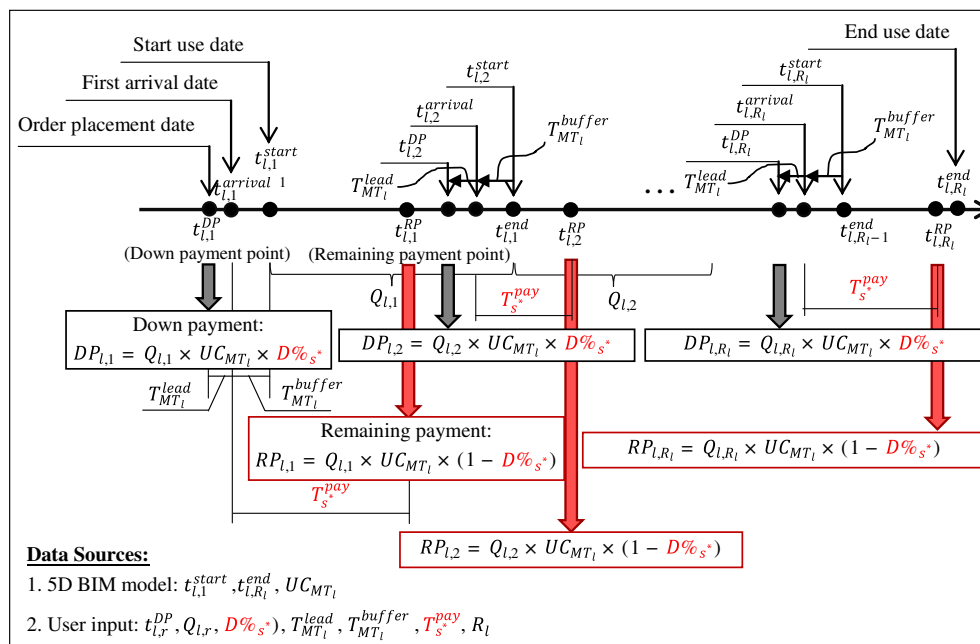


Fig. 8. Cash outflow pattern of material (MT_l).

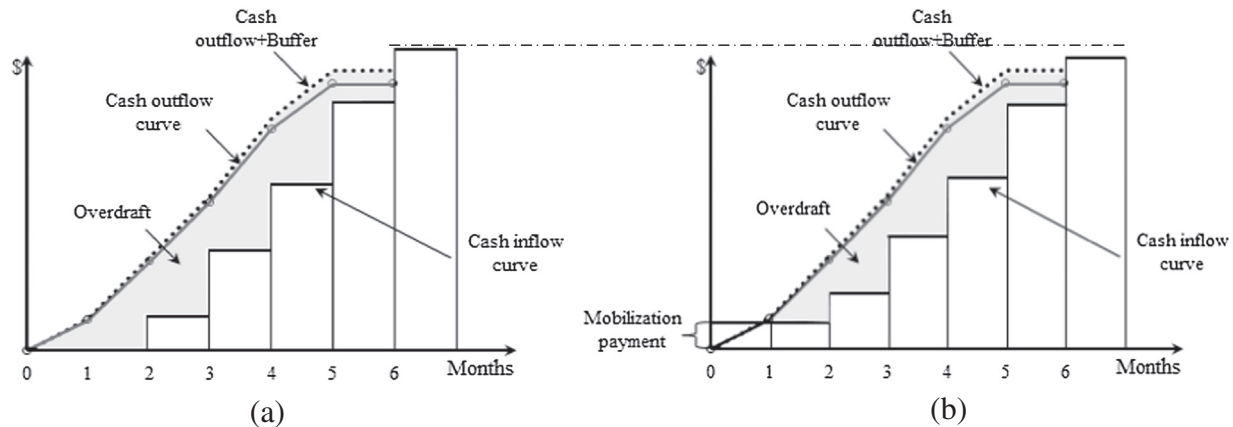


Fig. 9. Relationship among the overdraft cost and cash inflow and outflow curves ((a) cash inflow pattern.

from a bank is used, which leads to additional interest costs for a project. Note that even if contractors use their own funds, this has a cost, since otherwise the funds could be earning interest. Therefore, the actual profit is decreased as much as the additional interest cost and is represented by Eq. (22):

$$Profit_{actual} = CI - CO - I \quad (22)$$

where CI is the total cash inflow of the project; CO is the total cash outflow; and I represents the interest cost that the contractor should pay a bank to finance the overdrafts.

Generally, there are two types of loans: short-term and long-term loans. Since the contractor will get payments from the client gradually, it is usually wiser for him to apply for short-term loans. The loan period of a short-term loan is usually less than a year. The contractor should repay the interest regularly, on a monthly or quarterly basis, and the principal at the end of the loan term. The contractor should decide the appropriate loan term and repayment method based on the duration of the project, cash outflow, and cash inflow patterns. The interest and the principal (if any) should be repaid first through using periodic payment from the client to reduce the interest cost. The remaining overdraft cost should be covered by applying for a loan. If the payment of the client is more than the entire cash outflow, the surplus should be kept for next month's expenditure.

3.4.2. Decision making for conducting what-if scenarios

For a single project, many variables that fall into the four parts of the framework can change depending on contract conditions and situation of contractors or clients. Examples of influence factors in the four parts are as follows:

- (1) 5D preparation: design change; equipment or labor productivity change; different construction methods; resource unit cost change; etc.
- (2) Cash inflow: longer payment period; payment delay change; retainage percentage change; with or without mobilization payment; etc.
- (3) Cash outflow: lead time change; buffer time change; etc.

- (4) Project financing: financing instrument change; interest rate change; etc.

The contractor will face various alternatives that are generated by these influence factors in financing the overdraft. The framework proposed in this paper allows a contractor to compare the alternatives and choose the better one. The right plan should be more profitable than others. If the contractor wants to bid on multiple projects, he would be able to estimate the cash flow for each project and determine which project is the most profitable by using the proposed framework.

4. Illustrative example

4.1. Prototype system implementation

The proposed system consists of four main modules, (1) Cost Estimation, (2) Cash Flow Analysis, (3) Project financing, and (4) Output. The resource cost data and lists of work items are required in advance to make financial decisions using BIM. Inputting additional information is also required at each step. Firstly, Module 1 (Cost Estimation) requires the user to integrate the timeline file and QTO list in the system. If the user has other cost items to input, he should input in this module. Cash inflow patterns, including mobilization payment percentage, periodic payment requirements, retainage percentage, and retainage payment method, should be inputted in the Cash Inflow part of Module 2 (Cash Flow Analysis). Equipment, manpower, and material payment patterns should be inputted in the Cash Outflow part of Module 2. Project financing parameters, including money buffer and financial methods should be inputted in Module 3 (Project Financing). Module 4 (Output) allows the user to have an overview of the resources used in this project and various cash flow lines.

4.1.1. 5D preparation

The proposed framework was applied to estimate the cash flow of a four-story building built of reinforced concrete and wood (Fig. 10). The total floor area of the building is 35,452 ft² (3294 m²). The model was generated using

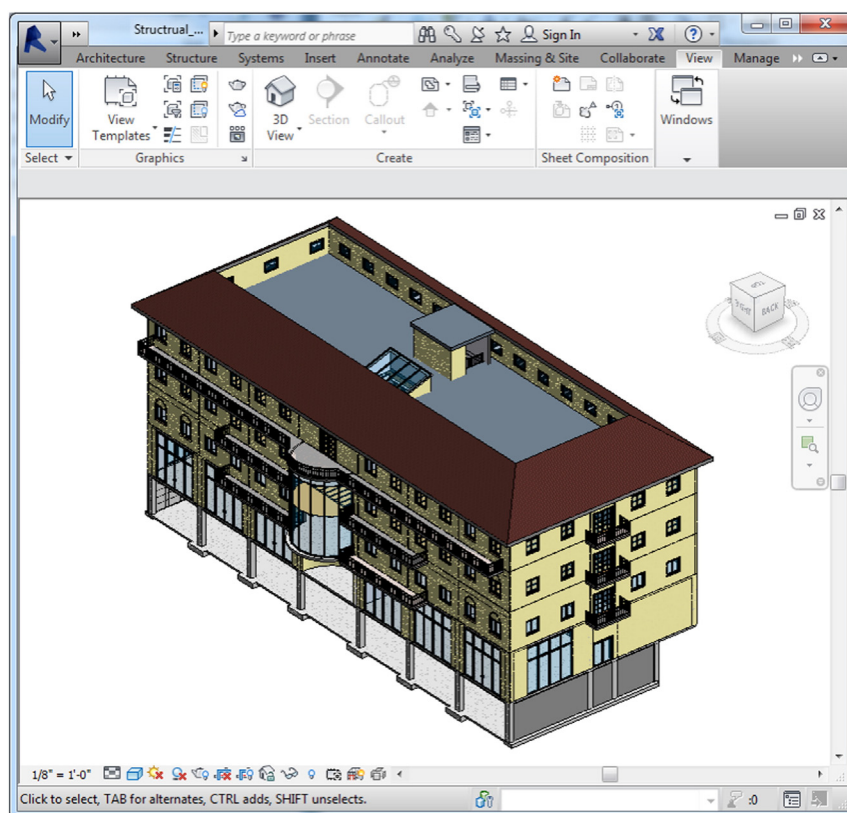


Fig. 10. The case model.

Autodesk Revit 2014 and exported to the developed financial decision making support system. The system was a non-commercial prototype system based on the integration of Autodesk Navisworks 2014 and Microsoft Excel Visual Basic for Application (VBA). Autodesk Navisworks 2014 was used for quantification and simulation, while Excel VBA was utilized for the automated financial analysis. An add-in application was developed in Autodesk Navisworks 2014 to activate the Excel VBA interface.

Autodesk Navisworks 2014 reported that the model contained 1,579 building elements and 16 labor teams, 29 material types, and 3 equipment facilities were required for construction (Table 1) in generating the QTO list.

By linking the QTO list to the schedule database, the tasks and time frame of this project were set up. 36 tasks were

defined and the total duration was 351 days, from 3 January to 19 December in 2011 (240 working days, see Fig. 11). By linking the schedule-loaded QTO list to the cost database, the cost distribution on the project schedule was generated and total project cost was USD 3,125,661, with USD 3,006,264 (96%) as direct cost and USD 119,397 (4%) as indirect cost (see Table 2). Equipment cost contributes the least portion (8%) of total project cost, because the project is a four-story building and doesn't require much equipment. On the other hand, a large number of workers were required to complete most of tasks. Consequently, manpower cost (39%) is similar to material cost (50%) in this project. In addition, there were three types of indirect cost, which includes supervision, cleanup, and bonds/insurance fee, adding up to the total indirect cost.

Table 1

Lists of equipment, manpower, and material resources in the illustrative example.

Equipment (3)

- | | | |
|-------------------|----------------|-------------------------------|
| 1. Material Hoist | 2. Tower Crane | 3. Concrete Pumping Equipment |
|-------------------|----------------|-------------------------------|

Manpower (16)

- | | | | |
|------------------------------|------------------------------------|--|--------------------------------------|
| 1. Formwork Carpenter | 5. Concrete Pourer | 9. Wood Roof Floor Carpenter | 13. Wood Joist Carpenter |
| 2. Wood Joist Carpenter | 6. Wood Column Carpenter | 10. Glulam Beam Carpenter | 14. Plywood Floor Carpenter |
| 3. Rodman | 7. Wood Roof Framing Carpenter | 11. Exterior Door Installation Labor | 15. Interior Door Installation Labor |
| 4. Window Installation Labor | 8. Curtain Wall Installation Labor | 12. Toilet Partition Wall Installation Labor | 16. Handrail Labor |

Material (29)

- | | | | |
|---------------------------------|-------------------------------|------------------------|-----------------------------|
| 1–2. Concrete (2 types) | 12. Formwork | 18–19. Rebar (2 types) | 23–24. Wood Studs (2 types) |
| 3–4. T/JL Wood Joists (2 types) | 13–15. Wood Framing (3 types) | 20–21. Floor (2 types) | 25–28. Doors (4 types) |
| 5–11. Windows (7 types) | 16–17. Walls (2 types) | 22. Handrail | 29. Scaffolding |

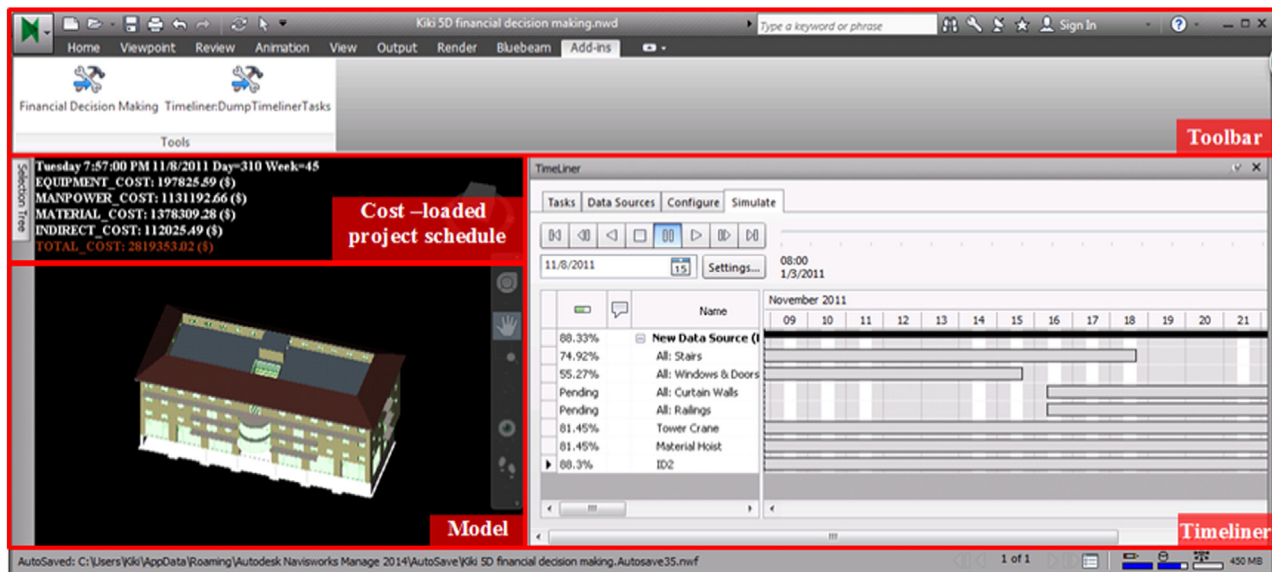


Fig. 11. The interface 5D simulation by using Autodesk Navisworks 2014, which contains four modules - (1) Toolbar on the top; (2) Cost loaded project schedule information on the upper left side of the simulation interface; (3) Project model on the lower side of the simulation interface; and (4) Timeliner on the lower right side.

Table 2
Cost information of the illustrative example (USD).

Direct cost				Indirect cost	Total cost
Equipment	Manpower	Material	Sub-total		
239,647.43	1,208,171.77	1,558,445.52	3,006,264.72	119,396.76	3,125,661.47

4.1.2. Cash inflow analysis

Based on the contract, the contractor quoted a unit price for each work item (Fig. 12). In addition, the contractor was reimbursed on a periodic basis for the item quantities finished with some retainage. It is assumed that the retainage percentage ($R\%$) is a constant and does not change with project progress in this example. As shown in Fig. 13, the client provided the contractor progress payments for completed work with one month delay and retained a fixed percentage of money ($R\%$ =

10%). All the retainage amounts were paid back to the contractor in the final payment. We assume that client did not provide mobilization payment to the contractor in this illustrative example.

4.1.3. Cash outflow analysis

To accurately calculate the cash outflow amount and timing, the contractor should input the cash outflow patterns of equipment, manpower, and material resources. Three

Unit Price Overview				
Work Item name	Quantity	Unit Price	Unit	Total Price
All: Curtain Walls	3153.12	62.99	sf	198617.95
All: Interior Walls-Interior 4 7/8" Partition	560.67	140.63	lf	78849.54
All: Interior Walls-Toilet Partition Wall 1"	388.79	10.14	sf	3941.99
All: Railings	715.18	17.96	lf	12845.37
All: Stairs	217.78	441.85	cy	96225.85
Double Glass Door 1	5.00	736.66	ea	3683.29
Double Glass Door 2	7.00	736.66	ea	5156.61
Double Window with Archtop and Trim	12.00	281.27	ea	3375.23
Double Window with Trim	84.00	254.48	ea	21376.48
Fixed Window	4.00	187.51	ea	750.05
Single Flush 22"x60"	4.00	214.30	ea	857.20
Single Flush 32"x60"	8.00	221.00	ea	1767.98
Single Flush Door	40.00	227.69	ea	9107.77
Store Front Double Door	8.00	736.66	ea	5893.26
Window Awning with Trim	30.00	227.69	ea	6830.83
Window Transom with Trim	16.00	200.91	ea	3214.51
Level 1: Beams (Concrete)-12x12	4.00	753.60	cy	3015.74
Level 1: Beams (Concrete)-12x18	15.22	760.29	cy	11574.29
Level 1: Columns (Concrete)-10x10	3.98	832.04	cy	3312.75
Return				Total Price: \$3,531,997.46

Fig. 12. A portion of work item list and quoted unit price.

Cash Inflow

Mobilization Payment (CI_Mb)

Mobilization Payment Percentage (MB%): 0

Periodic Payments (CI_m)

Unit Price Deflation Rate (DF%): 0 Retainage Percentage (R%): 10

Payment Lag (T_lag)

Payment Period: at the end of each month, with 1 Month Delay

Retainage Payment (R)

Retainage Payment Method: in the last payment

Cash Inflow Overview Return

Fig. 13. Cash inflow pattern of baseline—Plan A.

equipment facilities, which were concrete pumping equipment, a tower crane, and a material hoist, were used in this project (see Fig. 14). The fees for the three equipment facilities were immediately paid to the suppliers at the end of their service. As shown in Fig. 15, 16 types of professional teams served in the project. They were paid monthly based on their work quantities. The material cash outflow pattern needs three types of information: supplier, material, and order information. Supplier information contains supplier names, down payment percentage, and payment period information. Material names,

lead time, and buffer data are material-related information. Order information contains order IDs, material names, order quantities, and order placement date. There were 12 suppliers providing 29 material types. Fig. 16 presents a portion of suppliers and information on the 29 materials. These 29 materials were divided into 68 orders delivered to the construction site. For example, different uses of 2×6 Wood Studs 16" OC were divided into 4 orders from Order 2 (O_2) to Order 5 (O_5). Fig. 17 shows a portion of material order information.

Equipment Name	Start Service Date	End Service Date	Unit Cost (\$)	Quantity	Unit	Total Cost (\$)	Supplier Name	Payment Period	Payment Date
Concrete Pumping Eq	01/03/2011 8:00	11/18/2011 17:00	24.00	885.31	cy	21,247.43	Concrete Pumping Eq Supplier	At the end of service	11/18/2011 17:00
Material Hoist	05/13/2011 8:00	12/19/2011 17:00	3,600.00	7.00	Month	25,200.00	Material Hoist Supplier	At the end of service	12/19/2011 17:00
Tower Crane	05/13/2011 8:00	12/19/2011 17:00	27,600.00	7.00	Month	193,200.00	Tower Crane Supplier	At the end of service	12/19/2011 17:00
Total Equipment Cost:						\$239,647.43			

Fig. 14. Full list of equipment cash outflow payment pattern.

Manpower Name	Start Service Date	End Service Date	Unit Cost (\$)	Quantity	Unit	Total Cost (\$)	Payment Period
Concrete Pourer	1/3/2011 8:00	11/18/2011 17:00	24	885.31	cy	21,247.43	At the end of each month
Curtain Wall Installation Labor	11/16/2011 8:00	11/28/2011 17:00	8.36	3,153.12	sf	26,360.07	At the end of each month
Exterior Door Installation Labor	10/31/2011 8:00	11/15/2011 17:00	350	20.00	ea	7,000.00	At the end of each month
Formwork Carpenter	1/3/2011 8:00	11/18/2011 17:00	5	885.31	cy	4,426.55	At the end of each month
Glulam Beam Carpenter	6/14/2011 8:00	9/15/2011 17:00	50	1,740.50	lf	87,025.00	At the end of each month
Handrail Labor	11/16/2011 8:00	11/28/2011 17:00	9.26	715.18	lf	6,622.55	At the end of each month
Interior Door Installation Labor	10/31/2011 8:00	11/15/2011 17:00	80	52.00	ea	4,160.00	At the end of each month
Plywood Floor Carpenter	7/6/2011 8:00	8/24/2011 17:00	5.35	18,821.62	sf	100,695.69	At the end of each month
Rodman	1/3/2011 8:00	11/18/2011 17:00	34	885.31	cy	30,100.52	At the end of each month
Toilet Partition Wall Installation L	11/29/2011 8:00	12/19/2011 17:00	2.57	388.79	sf	999.19	At the end of each month
Window Installation Labor	10/31/2011 8:00	11/15/2011 17:00	100	146.00	ea	14,600.00	At the end of each month
Wood Column Carpenter	5/31/2011 8:00	9/6/2011 17:00	50	1,152.00	lf	57,600.00	At the end of each month
Wood Joist Carpenter	6/14/2011 8:00	9/28/2011 17:00	50	12,969.17	lf	648,458.59	At the end of each month
Wood Roof Floor Carpenter	9/29/2011 8:00	10/7/2011 17:00	4	4,515.86	sf	18,063.42	At the end of each month
Wood Roof Framing Carpenter	10/10/2011 8:00	10/28/2011 17:00	7.5	10,024.82	sf	75,186.14	At the end of each month
Wood Wall Carpenter	5/31/2011 8:00	12/19/2011 17:00	50	2,112.53	lf	105,626.60	At the end of each month
Total Manpower Cost:						\$1,208,171.77	

Fig. 15. Full list of manpower cash outflow payment pattern.

Material Name	Start Use Date	End Use Date	Unit Cost	Quantity	Unit	Total Cost	Supplier Name	Down Payment %	Payment Period	Lead Time	Buffer Time
2x4 Wood Studs 16" OC	11/29/2011 8:00	12/19/2011 17:00	55.00	560.67	lf	30,836.80	Wood Wall Supplier	20%	10	7	0
2x6 Wood Studs 16" OC	5/31/2011 8:00	10/28/2011 17:00	62.00	1,551.86	lf	96,215.50	Wood Wall Supplier	20%	10	7	0
Awning with Trim 24"x48"	10/31/2011 8:00	11/15/2011 17:00	70.00	30.00	ea	2,100.00	Doors and Windows Supplier	50%	12	7	0
Concrete 3000 psi	1/3/2011 8:00	11/18/2011 17:00	95.00	455.04	cy	43,228.41	Concrete Supplier	10%	20	5	0
Concrete 3500 psi	2/1/2011 8:00	5/30/2011 17:00	100.00	430.27	cy	43,027.36	Concrete Supplier	10%	20	5	0
Curtain Walls Panel and Mullion	11/16/2011 8:00	11/28/2011 17:00	38.67	3,153.12	sf	121,931.09	Curtain Wall Supplier	30%	10	7	0
Double Glass Door 1 72"x84"	10/31/2011 8:00	11/15/2011 17:00	200.00	5.00	ea	1,000.00	Doors and Windows Supplier	50%	12	10	0
Double Glass Door 2 72"x84"	10/31/2011 8:00	11/15/2011 17:00	200.00	7.00	ea	1,400.00	Doors and Windows Supplier	50%	12	10	0
Double Window with Archtop and Trim	10/31/2011 8:00	11/15/2011 17:00	110.00	12.00	ea	1,320.00	Doors and Windows Supplier	50%	12	10	0
Double Window with Trim 48"x48"	10/31/2011 8:00	11/15/2011 17:00	90.00	84.00	ea	7,560.00	Doors and Windows Supplier	50%	12	7	0
Total Material Cost: \$1,558,445.52							Add Order Information Return				

Fig. 16. A portion of material suppliers and ordering information.

Material Name	Start Using Date	End Using Date	Quantity	Unit	Unit Cost (\$)	Total Cost (\$)	Order ID
2x4 Wood Studs 16" OC	11/29/2011 8:00	12/19/2011 17:00	560.67	lf	55.00	30,836.80	1
2x6 Wood Studs 16" OC	05/31/2011 8:00	06/21/2011 17:00	305.92	lf	62.00	18,967.02	2
2x6 Wood Studs 16" OC	07/14/2011 8:00	08/03/2011 17:00	393.04	lf	62.00	24,368.58	3
2x6 Wood Studs 16" OC	08/25/2011 8:00	09/15/2011 17:00	393.13	lf	62.00	24,373.75	4
2x6 Wood Studs 16" OC	10/10/2011 8:00	10/28/2011 17:00	459.78	lf	62.00	28,506.15	5
Awning with Trim 24"x48"	10/31/2011 8:00	11/15/2011 17:00	30.00	ea	70.00	2,100.00	6
Concrete 3000 psi	01/03/2011 8:00	01/31/2011 17:00	41.93	cy	95.00	3,983.55	7
Concrete 3000 psi	02/01/2011 8:00	02/15/2011 17:00	3.15	cy	95.00	299.07	8
Concrete 3000 psi	02/01/2011 8:00	02/15/2011 17:00	26.15	cy	95.00	2,483.78	8
Concrete 3000 psi	02/01/2011 8:00	02/23/2011 17:00	73.85	cy	95.00	7,015.53	9
Concrete 3000 psi	02/24/2011 8:00	03/16/2011 17:00	4.00	cy	95.00	380.17	10
Concrete 3000 psi	04/04/2011 8:00	04/15/2011 17:00	3.98	cy	95.00	378.24	10
Concrete 3000 psi	04/04/2011 8:00	04/15/2011 17:00	26.00	cy	95.00	2,470.00	10
Concrete 3000 psi	04/18/2011 8:00	05/12/2011 17:00	4.00	cy	95.00	380.17	11
Concrete 3000 psi	05/13/2011 8:00	05/30/2011 17:00	7.13	cy	95.00	677.77	11
Concrete 3000 psi	05/31/2011 8:00	06/13/2011 17:00	10.37	cy	95.00	984.80	12
Concrete 3000 psi	07/06/2011 8:00	07/13/2011 17:00	7.98	cy	95.00	758.41	12
Concrete 3000 psi	07/14/2011 8:00	07/26/2011 17:00	10.37	cy	95.00	984.80	12
Total Cost: \$1,558,445.52						Return	

Fig. 17. A portion of material order information.

After the cash outflow patterns of the three resources were adjusted, the finalized cash outflow was analyzed. As shown in Fig. 18, the adjusted cumulative cash outflow (ACCO) occurred earlier than the project start since down payments on

some materials were paid in advance before the project started. This is also the reason that the Navisworks cumulative cash outflow (NCCO) lags behind ACCO at the beginning phase. However, ACCO mostly lags behind NCCO since most costs

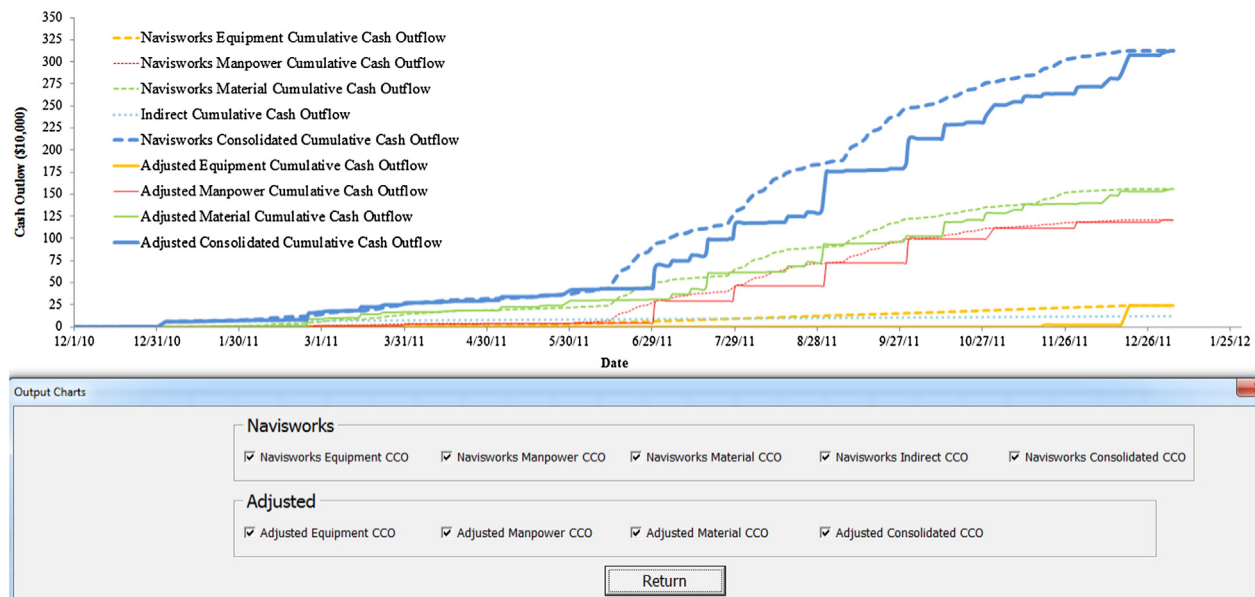


Fig. 18. A comparison between the Navisworks and the adjusted cumulative cash outflows.

Fig. 19. Project financing input of baseline—Plan A.

were paid to the suppliers after a payment period passed from completion of the service.

4.1.4. Project financing

After inputting the mobilization payment percentage, unit price deflation rate, retainage percentage, money buffer, interest rate, and loan information on the system, the contractor can quickly calculate the actual profit of the baseline plan in the illustrative example (Fig. 19). We assumed that the contractor set a 5% money buffer at the beginning of each month and decided to apply for a three-month short-term loan at an interest rate of 5.6% per year to finance overdraft cost. The contractor had to repay the interest on a monthly basis and repay the principal at the end of the loan term. The estimated total actual profit of this plan using the framework proposed in this paper is USD 378,245.

4.2. What-if scenarios

What-if scenarios were generated by changing the design and cash inflow payment scheme of the baseline plan (Plan A) to check the applicability of the proposed framework for various alternatives. Since cash flows of a project can vary depending on the design and cash inflow payment scheme, we compared differences of various cash flows generated due to different design and cash inflow payment scheme by using the proposed framework. One of the window types in the BIM model that was used to analyze the cash flow of the baseline plan was changed to measure differences of cash flow which were caused by the design change. The original and revised BIM models were used to analyze cash flows of Plans A and B, respectively. The cash flow of the illustrative example with a different cash inflow payment pattern, which was called Plan C, was also measured using the framework.

Table 3
Quantity, schedule, and cost information of Plan A and Plan B.

Plan A													
Title	Quantity	Unit	Labor productivity (quantity/day)	Working days	Schedule info. (year: 2011)			Cost info. (USD \$)		Manpower payment point	Material payment		
					Start date	End date	Month	Unit cost	Cost		Order ID	DPP	RPP
...													
All: windows & doors			/	12	10-31	11-15	11,12		7560				11, 12, 13
Mt: Double Window with Trim 48"×48"	84	ea						90	7560		O ₂₂	10-19	12-01
...													
Level 2: Exterior walls (wood)			26	15	07-14	08-03	8,9		44,021				8,9
Mt: 2 × 6 Wood Studs 16" OC	393	If						62	24,369		O ₃	07-05	08-17
Mp: Wood Wall Carpenter	393	If						50	19,652	07-29, 08-31			
Level 3: Exterior walls (wood)			26	15	08-25	09-15	9,10		44,030				9, 10
Mt: 2 × 6 Wood Studs 16" OC	393	If						62	24,374		O ₄	08-16	09-29
Mp: Wood Wall Carpenter	393	If						50	19,656	08-31, 09-30			
Level 4: Exterior walls (wood)			26	15	10-10	10-28	11		51,495				10, 11, 12
Mt: 2 × 6 Wood Studs 16" OC	460	If						62	28,506		O ₅	09-28	11-11
Mp: Wood Wall Carpenter	460	If						50	22,989	10-31			
Scaffolding	7	nth	/	/	03-17	10-28	4-11	21,546	150,822		/	02-24	10-28
...													
Total duration					01-03	12-19							
Total cost									3,125,661				
Plan B													
Title	Quantity	Unit	Labor productivity (quantity/day)	Working days	Schedule info. (year: 2011)			Cost info. (USD \$)		Manpower payment point	Material payment		
					Start date	End date	Month	Unit cost	Cost		Order ID	DPP	RPP
...													
All: windows & doors			/	12	10-31	11-15	11,12		2520				11, 12, 13
Mt: Fixed Window 24"×48"	84	ea						30	2520		O ₂₂	10-19	12-01
...													
Level 2: Exterior walls (wood)			26	16	07-14	08-04	8,9		46,415				8,9
Mt: 2 × 6 Wood Studs 16" OC	414	If						62	25,694		O ₃	07-05	08-18
Mp: Wood Wall Carpenter	414	If						50	20,721	07-29, 08-31			
Level 3: Exterior walls (wood)			26	16	08-25	09-16	9,10		46,425				9, 10
Mt: 2 × 6 Wood Studs 16" OC	415	If						62	25,699		O ₄	08-16	09-30
Mp: Wood Wall Carpenter	415	If						50	20,725	08-31, 09-30			
Level 4: Exterior walls (wood)			26	16	10-10	10-31	11		53,890				10, 11, 12
Mt: 2 × 6 Wood Studs 16" OC	481	If						62	29,832		O ₅	09-28	11-14
Mp: Wood Wall Carpenter	481	If						50	24,058	10-31			
Scaffolding	7	nth	/	/	03-17	10-31	4-11	21,546	150,822		/	02-24	10-31
...													
Total duration					01-03	12-19							
Total cost									3,127,806				2145

Note: DPP: Down Payment Point ; RPP: Remaining Payment Point.

Results of Cash Flow Analysis

Plan A		Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 13	Mc	Total
Total Cash Inflow (CI)	CI from the client	66,503	124,103	60,336	62,083	582,886	371,199	568,983	642,406	299,529	287,674	3	3,531,997
	Previous Surplus	0	0	0	0	0	0	0	0	292,130	0		
Total Cash Outflow (CO)	Adjusted CO	25,949	122,954	268,132	484,023	584,077	372,047	382,090	197,211	391,450	25,641		3,125,661
	Buffer	1,297	6,148	13,407	24,201	29,204	18,602	19,105	9,861	19,572	1,282		156,283
	Interest Pay Back	984	806	833	1,869	3,960	4,120	4,230	3,467	2,815	1,985		28,091
	Principal Pay Back	74,770	99,578	36,611	36,499	105,383	258,647	484,509	139,738	282,218	320,951		2,006,487
	Subtotal	103,001	229,486	318,983	546,592	722,624	653,416	889,934	350,277	696,054	349,860		5,316,522
Project Financing	Bank Borrow	36,499	105,383	258,647	484,509	139,738	282,218	320,951	0	104,396	62,185		2,006,487
	Surplus	0	0	0	0	0	0	0	292,130	0	0	3	/
Actual Profit:(CI from the client-Adjusted CO-Interest)													378,245

Plan B		Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Month 13	Mc	Total
Total Cash Inflow (CI)	CI from the client	66,503	124,030	60,217	61,951	582,748	370,649	571,541	644,909	302,447	282,916	3	3,534,421
	Previous Surplus	0	0	0	0	0	0	0	0	290,670	0		
Total Cash Outflow (CO)	Adjusted CO	25,949	122,954	268,132	484,107	586,577	374,517	380,640	198,272	388,930	25,641		3,127,806
	Buffer	1,297	6,148	13,407	24,205	29,329	18,726	19,032	9,914	19,446	1,282		156,390
	Interest Pay Back	984	806	833	1,870	3,962	4,135	4,260	3,478	2,812	1,963		28,130
	Principal Pay Back	74,770	99,578	36,611	36,499	105,455	258,766	484,731	142,576	285,495	317,121		2,009,260
	Subtotal	103,001	229,486	318,983	546,681	725,323	656,144	888,662	354,239	696,683	346,008		5,321,586
Project Financing	Bank Borrow	36,499	105,455	258,766	484,731	142,576	285,495	317,121	0	103,566	63,092		2,009,260
	Surplus	0	0	0	0	0	0	0	290,670	0	0	3	/
Actual Profit:(CI from the client-Adjusted CO-Interest)													378,485

Actual Profit_A < Actual Profit_B
Choose: Plan B

Fig. 20. A portion of cash flow analyses of Plan A and Plan B with different design alternatives.

4.2.1. Scenario 1: Design change

84 Double Window With Trim 48" × 48" located on exterior walls of Levels 2 to 4 were replaced with 84 Fixed Window 24" × 48" to compare cash flows of two design alternatives. The contractor can change the design in Revit and then use the proposed framework to analyze the cash flows and decide which design option is more profitable. Table 3 shows the quantity, schedule, and cost information of plan A and Plan B. Unit prices of the original and replaced windows are USD 254 and 174, respectively. The quantities of the exterior wall material increased due to the reduced size of the windows. Quantity changes lead to the schedule change of the related tasks, assuming that the window installation team needs the same time to install these two types of windows. As the results, the duration of Level 2, 3 and 4 exterior walls (Wood) was changed from 15 days to 16 days, respectively. Scaffolding is removed after completion of all the exterior walls, therefore, the End Use Date of Scaffolding changed to 10-31-2011 in order to ensure Level 4 Exterior Walls were finished. However, the changed tasks were not in the critical path so that the total duration of the project remained the same. Since the tasks started from Month 4 to Month 12, the cost distribution for these months is also changed.

The cost of the All: Windows & Doors task was reduced by USD 5,040 due to the reduced quantities of windows. As a result, the costs (including manpower and material cost) of Level 2, 3 and 4 exterior walls (Wood) increased around USD 2395, respectively, assuming that the scaffolding supplier did not require additional cost for the 1-working-day extension use of scaffolding. Therefore, the cost of Scaffolding still remained the same as in Plan A. Although the duration of Level 2, 3 and 4 exterior walls (Wood) were extended one day, they had no influence on the project schedule since they were not in the

critical path. On the other hand, the indirect cost (including supervision fee and clean up fee) and equipment cost were not changed. As a result, the total cost was increased by USD 2145 because of the design change. Although the cash inflow pattern was the same as plan A, the cost distribution for Month 4 to Month 12 was different. The client provided periodic payments to contractor at the end of each month, with one month delay. Therefore, for example, the cash inflow of Month 4 occurred at the end of Month 5. As shown in Fig. 20, starting from Month 5, the cash inflow from the owner of Plan B was different from that of Plan A. The same material payment pattern needs to be inputted to the system to calculate the actual cash outflow of the contractor. Table 3 also shows the changed material payment information due to the design change. For example, the down payment and remaining payment of the 2 × 6 Wood Studs 16" OC material used in Level 2 Exterior Walls (Wood) occurred in Months 8 and 9, respectively. Therefore, at the end of Month 7 and Month 8 (the beginning of Months 8 and 9), the contractor should prepare money to cover coming month's expenditure (cash outflow) as well as a money buffer to avoid risk. Consequently, the adjusted CO and buffer for Month 7 of Plan B were different from those of Plan A (Fig. 20). Subsequently, the results of Month 8 to Month 12 for Plan B were also changed. After inputting the same project financing parameters, the cash

Table 4
Cash inflow payment schemes of Plan A and Plan C.

	Mobilization payment % (MB%)	Unit price Deflation rate % (DF%)	Retainage % (R%)
Plan A	0%	0%	10%
Plan C	12.7%	12.9%	10%

flows of the two plans were analyzed and compared using the proposed framework in Fig. 20. Since the actual profit of Plan B is larger than that of Plan A, Plan B is the better choice.

4.2.2. Scenario 2: cash inflow payment scheme change

Apart from the cash inflow payment scheme described in Plan A, the client provided another alternative (Plan C) for the contractor to consider (Table 4). The material, equipment, manpower, and indirect cost for Plan C were the same as those of Plan A, because we assumed that the design and retainage percentage of Plan C are the same as those of Plan A. The difference between Plans A and C is that the client provides a portion of money as mobilization payment to the contractor to help initialize the project. The contractor deflated the unit prices of the work items to receive mobilization payment from the client. Consequently, the unit price deflation rate ($DF = 12.9\%$) is larger than mobilization payment percentage ($MB\% = 12.7\%$). Consequently, the interest cost and revenue patterns of the project could be changed through adjusting the cash inflow payment scheme.

Although the contract price for Plan A is higher than that for Plan C, the contractor would pay a higher financing cost if the client does not provide mobilization payment to the contractor at the beginning of the project. Therefore, the contractor should choose the option with higher actual profit. After inputting the two cash inflow schemes into the proposed system and keeping the other values the same as Plan A, cash flows of these two plans were analyzed and are shown partially in Fig. 21. Although the contractor received more payments from the client for Plan A than those for Plan C, the actual profit of Plan C was larger than that of Plan A. Therefore, the contractor rejected Plan A and chose Plan C finally.

5. Summary and future work

Analyzing cash flows of a project accurately and choosing a better financing plan are important issues for contractors. The traditional methods of cash flow analysis required manual integration of schedule and cost information. This process is time-consuming. A system based on 3D modeling technology linked to schedule and cost information, which is called 5D BIM, can automate and simplify this process. However, previous studies on analyzing the cash flow based on 5D BIM were at a very early stage because they did not consider actual cash outflow patterns based on contracts and provide decision making for project financing. This paper, therefore, describes a 5D BIM framework to help contractors analyze cash flows of a single project and make financial decisions properly.

Compared to the traditional methods of cash flow analysis, the whole process proposed in this paper is simplified and automated by using the framework based on 5D BIM. Existing BIM software, such as Autodesk Navisworks, Vico Office, CostX, etc. can also integrate BOQ with schedule and cost data without manual processing. However, they cannot accurately analyze the cash flow of an AEC project because they assume that cash outflows are made continuously according to the completion status of individual tasks. In reality, some payments need to be settled at the time of ordering while other payments are realized a period after the associated tasks are completed. Moreover, they could not support BIM-based financial decision making for project financing. Therefore, the paper proposes a framework to provide more accurate solutions by calculating the cash inflow based on the contract with clients, the actual cash outflow by considering down payment, payment period, and lead time. To develop this framework, domain knowledge on payment patterns of material, equipment, and manpower are needed. Different requirements and

Results of Cash Flow Analysis													
Plan A													
		Month 0	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Mc	Total
Total Cash Inflow	CI from the client	0	0	0	75,908	66,503	124,103	60,336	62,083	582,886	371,199	5	3,531,997
	Previous Surplus	0	0	0	0	0	0	0	0	0	0	0	
Total Cash Outflow	Adjusted CO	954	71,205	94,499	105,428	25,949	122,954	268,132	484,023	584,077	372,047	3	3,125,661
	Buffer	48	3,560	4,725	5,271	1,297	6,148	13,407	24,201	29,204	18,602		156,283
	Interest Pay Back	0	5	354	818	984	806	833	1,869	3,960	4,120		28,091
	Principal Pay Back	0	0	0	1,002	74,770	99,578	36,611	36,499	105,383	258,647	4	2,006,487
	Subtotal	1,002	74,770	99,578	112,519	103,001	229,486	318,983	546,592	722,624	653,416	8	5,316,522
Project Financing	Bank Borrow	1,002	74,770	99,578	36,611	36,499	105,383	258,647	484,509	139,738	282,218	3	2,006,487
	Surplus	0	0	0	0	0	0	0	0	0	0		/
Actual Profit:(CI from the client-Adjusted CO-Interest)													378,245
Plan C													
		Month 0	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Mc	Total
Total Cash Inflow	CI from the client	0	396,959	0	66,401	58,174	108,560	52,779	54,307	509,884	324,709	4	3,525,746
	Previous Surplus	0	0	322,189	222,960	177,655	208,582	188,040	0	0	0		
Total Cash Outflow	Adjusted CO	954	71,205	94,499	105,428	25,949	122,954	268,132	484,023	584,077	372,047	3	3,125,661
	Buffer	48	3,560	4,725	5,271	1,297	6,148	13,407	24,201	29,204	18,602		156,283
	Interest Pay Back	0	5	5	5	0	0	0	190	2,309	2,802		17,131
	Principal Pay Back	0	0	0	1,002	0	0	0	0	0	40,719	4	1,223,609
	Subtotal	1,002	74,770	99,229	111,705	27,246	129,102	281,539	508,414	615,590	434,171	8	4,522,684
Project Financing	Bank Borrow	1,002	74,770	99,229	111,705	27,246	129,102	281,539	508,414	615,590	434,171	8	4,522,684
	Surplus	0	322,189	222,960	177,655	208,582	188,040	0	0	0	0		/
Actual Profit:(CI from the client-Adjusted CO-Interest)													382,954
Actual Profit_A < Actual Profit_C													
Choose: Plan C													
													Return

Fig. 21. Results of cash flow analyses of two financing plans with different cash inflow payment schemes.

scenarios are also considered based on the characteristics of a project and the project participants.

Based on actual overdraft cost and project financing methods, the framework allows contractors to plan appropriate project financing. Furthermore, the framework can help the contractor review different alternatives and choose a better plan. The illustrative examples using the framework are provided to demonstrate how the contractor can conduct financial decision making by considering two what-if scenarios, a design change and a cash inflow payment scheme change. With the framework, contractors who are considering bidding on multiple projects at the same period would be able to quickly compare cash flows and project financing scenarios for each option and determine which project is the most profitable. Other disciplines, like the client, can also utilize the framework after modifying the system developed in this paper.

Although the framework provides more accurate and automated cash flow analyses of a single project through integrating the QTO lists and schedule using 5D BIM and considering cash out flow patterns based on the contracts, it still has some limitations. First, the framework did not consider stochastic aspects to analyze the cash flows of construction projects. As the project proceeds, many uncertainties will be encountered. Whenever there is a change, the contractor can update the information in the framework and run the framework again to calculate the new cash flow analysis. Since cash flow analyses considering stochastic aspects can compute the variability of cash flows and predict the project financial risks, various stochastic problems, like variations in task duration and material delay, can be considered to provide more realistic project financing decision support in the future. In addition, the framework does not consider subcontractors in analyzing cash flows of a project. The subcontractor cost accounts for a large portion of the general contractor's cost. However, the material payment pattern is almost the same as that of the subcontractor. For example, the down payment is just like retention of the subcontractor. Therefore, a general contractor can also utilize the framework to analyze cash flow and conduct project financing by changing a specific material supplier to a subcontractor. The paper focuses on one contract type, a unit price contract in the case study. Other types of contracts can be incorporated by changing the cash inflow payment patterns in the framework. In addition, this paper assumes that borrowing money from the bank is the sole financing method and there is no cash flow between the different projects of a contractor. However, since a general contractor usually builds multiple projects with different characteristics simultaneously, application of various financing methods and cash flows among different projects are natural to reduce financial risks. Therefore, various financing methods, including issuing bonds or using their own capital, and influences between multiple projects will be considered in future work.

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