CASH FLOW GENERATION AND ALTERNATIVES ANALYSIS THROUGH BIM AND SIMULATION

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To My Family,

To My Homeland, Palestine,

ABSTRACT

Cash flow analysis is a major aspect of managing a construction project to improve project success metrics and to prevent liquidity issues during construction phase. Conventional methods used to analyze cash flow simplify many process elements and perform analysis based on master-level schedule activities and their associated costs. Recent studies generate cash flow using building information models (BIM), construction schedule and financial parameters for more accurate project cash flow, but it is challenging to evaluate detailed project alternatives that improve project cash flow while satisfying project constraints and consider scenarios for project financials.

This thesis develops a structured approach to generate project cash flows through a BIM and resource-integrated 3D simulation platform called GSimX. It also provides a prototype for project cash flow generation through Excel in order to verify and compare it with the simulation platform. Since cash inflows and outflows from simulation are generated based on common cash flow parameters with contractual focus, cash flow alternatives can easily be obtained by modifying parameters such as payment terms, activity sequences, and resources. The thesis also describes ways to evaluate generated cash flow alternatives to enhance the financial decision-making process and to avoid financial hurdles during project execution.

ÖZETÇE

Nakit akış analizleri inşaat yönetimi, projenin etkili bir şekilde ilerleyebilmesi ve oluşabilecek sorunların önüne geçilebilmesi adına büyük önem taşır. Kullanılan geleneksel nakit akis analizi yöntemleri ağırlıklı olarak basit düzeylerde olup, analizler genelde master program seviyesinde sağlanmakta ve aktivite bazında gerçekleştirilmektedir. Daha önce yapılan çalışmalarda nakit akışları yapı bilgi modellemesi (BIM) kullanılarak oluşturulmakta ve bu anlamda iş programı, kaynaklar, finansal parametreler ve diger etkenlerde goz onunde bulundurulmaktadir. Fakat alternatif nakis akış yöntemlerini incelemek ve bunlar hakkında belirli sonuçlara varmak zorlu olmakla beraber, projenin verimliği üzerinde etkili olabilir ve finansal anlamda değişik senaryoların incelenip uygulanmasında yardımcı olabilir.

Bu tez proje nakit akışlarını BIM ve kaynak tabanlı bir simülasyon platformu olan GSimX üzerinde oluşturmak için yapısal bir yaklaşım geliştirmektedir. Bu amaçla gerekli inşaat nakit akışı parametreleri tanımlanmıştır. Excel üzerinde oluşturulan bir prototip nakit akışı ile yaklaşımı tanımlanmış ve elde edilen sonuçlar simülasyon sonuçları ile karşılaştırılabilir düzeye getirilmiştir. Bu tez ayrıca nakit akışının parametreler üzerinde simülasyon ortamında hesaplanması için gereksinimleri tanımlamıştır. Nakit akışları kontrat ağırlıklı yaygın parametreler üzerinden simülasyon sonrası hesaplandığından alternatif senaryolar ödeme şartları, aktivite sıralaması ve kaynaklar gibi farklı değişkenler kullanılarak kolayca oluşturulabilir. Ayrıca sunulan bu tezde oluşturulan alternatif karşılaştırılması için yöntemler tanımlanmakta, dolayısıyla projenin finansal karar verme sürecini geliştirilmekte ve imalat sırasında finansal problemlerin azaltılmasına katkıda bulunulmaktadır.

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ABBREVIATIONS

3D Model:	Three-Dimensional Model
4D Model:	Four-Dimensional Model
AEC:	Architecture Engineering Construction
BIM:	Building Information Modeling
BOQ:	Bill of Quantity
CI:	Cash Inflow
CO:	Cash Outflow
CPM:	Critical Path Method
FIDIC:	International Federation of Consulting Engineers
GRAAD:	General Resource/Activity Allocation Database
MD CAD:	Multiple Dimensional Computer Aided Design
MEP:	Mechanical, Electrical and Plumbing work disciplines
NPV:	Net Present Value
XML:	eXtensible Markup Language

CHAPTER I

INTRODUCTION

In the Architecture/Engineering/Construction (AEC) industry, there are many factors that shape project success or failure, and one of the most important ones is project financials. Construction companies always aim to deliver the project to the owner with expected quality, highest profit and within the shortest period. This prompts contractors to avoid any delays in schedule or payments, so the proper financial planning for any project helps avoid financial difficulties during the execution phase. Good planning of project financials increases the probability of achieving project goals within project planned budget and time frame. Any financial difficulties might lead to project delay, increase in interest or cost, statutory hurdles and project financial failure which may lead consequently to the failure of the business.

The reasons behind project financial failures have been studied by various authors (Kale and Arditi (1998), Koksal and Arditi (2004)). One finding is that the lack of cash flow management is a major reason in construction project failures, which would lead to project freeze, financial loss, creditors loss or bankruptcy (Mahamid 2012).

Construction projects have many ingoing and outgoing payments. The contractor receives payments from the owner and meanwhile pays his dues for staff, suppliers, and subcontractors. These incoming and outgoing payments are usually represented by project cash flow. Cash flow illustrates the dates and amounts of received and spent payments of the project. Cash flow might be generated and analyzed before or during the construction phase, and it is subject to change over time due to project conditions. In this thesis, we propose a methodology to generate multiple cash flow scenarios and evaluate forecast of cash flow before construction phase, implemented through a BIM and resource integrated simulation platform.

1.1. Importance of Cash Flow Analysis for Construction Projects

Cash flow analysis shows the profitability and monetary status of a project. It can be performed during pre-construction to show the contractor the capital and financial power needed to implement the project, or during construction process to update the preconstruction made financial analysis. It also shows potential financial risks that might affect the project progress by highlighting periods and activities that will challenge the contractor financially. It guides the contractor to decide whether they can handle the works and accept the bid according to the owner payment terms, since cash flow provides information about the financial trends and demands while executing the project.

Considering contractual payment terms and their role in cash flow analysis is requisite; those terms shape the amount of executed work payments and the delay period to proceed or receive the payment. Any change in those terms will lead to a variation in the cash flow analysis results. Defining the proper payment terms according to the contractor prospective financial abilities during the execution of the works may prevent the contractor from any shortfall in the ability to pay the tabulated dues. Moreover, it provides an insight to stipulate the most suitable payment terms in the contract and subcontracts according to the contractor financial power and ability.

When a contractor finds out that the preconstruction cost estimation and cash flow analysis results are over his financial abilities and budget, he will start looking for solutions that let him to overcome these difficulties. Otherwise, the contractor might not go for bidding for the project. On the other hand, changing some parameters that have effect on cash flow results such as work implementation strategies, going for subcontracting, acquiring labors, or negotiation with owner about payment terms or some contract clauses might make the contractor bid for the project with more confidence. Creating cash flow alternatives can be a solution to provide an affordable project financial plan. Contractor wishes to choose the most suitable cash flow alternative that will lead to the maximized profit.

Having an good cash flow will lead to assuring sufficient profit out of project execution. It will also provide some financial freedom during the execution phase. Contractors aim to enlarge the gap between the received and spent money, receive money in advance and spend it later on project dues. This open the doors to use some techniques to maximize profit such as accelerating some certain activities which will require to spend the activity cost in a shorter duration than the planned. So if the contractor is capable of paying more than planned at any point of the project timeline, this will provide the contractor the ability to manage money among multiple company projects and maximize overall profit, and provide potential rewards at the end of a project as a prize for his fast implementation.

On the other hand, the accompanied risks of poor financial plan, might lead to an acute financial loss while implementing the project. It will lead to less profit or make the contractor incapable in delivering his financial dues for staff, suppliers, and subcontractors. Some observed real practice cases led the contractor to more deleterious results, such as losing a source of fund from banks, termination from the project or even bankruptcy. This comes as a result of not having enough capital and liquidity while executing the project and it happens when the contractor dues are higher than his received money in a certain period due to the lack in financial management.

1.2. Challenges in cash flow forecasting and analysis in construction

Cash flow forecasting and analysis process requires studying the project design, bill of quantity (BOQ), contract, schedule, and resources and integrate them together to price each project activity along its duration. It also includes finding out how activities payments will be issued along the timeline of the project. Construction projects contain a wide range of planning, design, financial and contractual data that lead to shape the cash flow of the project; it is challenging to cover all of them while forecasting the cash flow and change them to generate cash flow alternatives.

When cash flow analysis is performed in the preconstruction phase, it may contain mistakes due to haste, not covering all of project financial aspects and/or poor budgeting and project management (Arditi, Koksal et al. 2000).

The ability to determine cash flow alternatives based on changing cash flow factors and planning information is a challenge; it requires integration of all project data and matching it with the financial plan. During construction phase, design, prices of materials or cost data are subject to change, so contractors need to update their financial plans as fast as possible. When this is made manually for large scale projects it becomes hard to avoid errors and mistakes, so technology has to accelerate this process while providing better accuracy of data output.

The other challenge in cash flow generation is the ability to update the massive project data and reflect it on the cash flow. Most construction projects do not adhere to the planned schedule and budget. According to (Zayed and Liu 2014), construction projects manifest a deviation from the original cost by 9.7 to 16.3 percent from the original planned cost, this requires updating the project cash flow data dynamically along with the planning and contractual updates.

Cash flow generation and forecasting in some existing research focus on limited factors, such as date and project type to generate cash flow (Kenley 2003). The literature of cash flow forecasting will be discussed in detail in Chapter 2. Most cash flow forecasting and analysis approaches lack to the ability of evaluating several alternatives of cash flow and updating dynamically before and during the construction phase.

1.3. Role of technology in construction cash flow generation

Construction is adopting technological solutions to improve the quality, efficiency, productivity and representation of the whole process and BIM has become a multifunctional and widely used solution for most of the aforementioned aspects (Arayici, Coates et al. 2011). The application of BIM has improved the coordination between drawings types and detecting the clashes, enhanced the collaboration, interoperability and communication among projects departments. It has also minimized risks of delays and cost overruns. BIM provides the ability to visualize the project process in multiple dimensions that is related to design, clash detection, coordination, scheduling, cost and energy consumption etc. aspects. Simulation is also has been engaged with BIM for analyzing BIM data and provide outputs as necessary.

Generating cash flow requires considering all major projects financial parameters that shape the monetary status of the contractor. Lu, Won et al. (2016) uses BIM to generate cash flow through a software application that considers design alternatives to produce cash flow alternatives, but in most cases, stakeholders do not seek for design change to improve the cash flow of the project.

During construction, project design, schedule, conditions and planning resources get updated and many variations on the financial plan take place (Ibbs, Kwak et al. 2003). In this case cash flow forecast update is crucial to make right financial decisions observing the project status.

GSimX is a BIM based resource integrated simulation platform that simulates construction on BIM using location-based scheduling principles supporting resource allocation to enhancing the planning process. Cash flow generation feature has been added based on this thesis research to provide the ability in defining cash flow parameters for the simulation model and generate cash flow alternatives based on the payment terms, planning resources and activities sequences.

Today's technological solutions to generate cash flow mainly rely on design and schedule data as do most recent BIM-based approaches. Improvements for these platforms have to engage other factors that affect cash flow like contract type, payment terms and planning resources. It is also not common to generate cash flow alternatives according to these factors, which limit better forecast for the financial plan.

1.4. Research aims and objectives

This thesis aims to introduce an approach for cash flow generation for construction projects by identifying and using primary parameters that affect cash flow forecasts. It also proposes a structured methodology of generating cash flow alternatives in the preconstruction phase through a BIM and resource integrated simulation platform (GSimX). In this regard, the following specific objectives are investigated:

1- Identifying the construction cash flow parameters that relates to BIM model, planning resources, contract conditions and payment terms.

2- Creating an Excel prototype for calculating construction cash flow and comparing it to the automatically generated one through BIM and GSimX simulation. Since GSimX is a resource integrated software that also includes the BIM model of the project, defining project cash flow parameters as a feature is crucial to generate the cash flow.

3- Defining requirements for implementing cash flow parameters in GSimX platform to consider them for cash flow generation after simulation.

4- Creating and evaluating cash flow forecast alternatives to come up with improved and less risky financial plan for a project.

This approach aims to provide cash flow generation ability through BIM and the simulation platform GSimX. It also offers generating cash flow alternatives in preconstruction phase and provide a way to keep it dynamic and easy to update during construction. This approach deals with the main cash flow affecting parameter that play a major role in shaping it. Those parameters are the main factors that quantify the interim payments whether outgoing or received ones, and assign financial attributes to project activities. The financial attributes reflect the contract conditions and payment terms, defining all possible parameters is out of our concern due to the wide range of cases, but engaging for each project individually is possible.

This study is creating the cash flow forecasts through BIM and GSimX while considering the payment parameters integrated with planning resources, also to present the benefits of generating the cash flow forecast alternatives through BIM and GSimX by changing the cash flow parameters and planning resources.

1.5. *Scope of work*

This approach can be applied for infrastructure, residential, commercial and special projects. In addition, lump sum and cost-plus contracts are compatible with this approach. By considering the commonly used unit price contract type, cash flow generation is easier to attain since it separates the cost and profit for each project item individually.

A structured framework to define and predict cash inflow and outflow is specified by considering the payment terms, planning resources, work sequence, activity relationships and BIM design. In this approach, the effects of design alternatives on cash flow is not considered. In addition, each project for a contractor is considered separately, without considering the overall progress and financial status of other held projects by contractor.

This thesis study applies the proposed methodology of cash flow forecast generation for a residential medium-scale in preconstruction phase as a test case. The test case has a design, CPM schedule, and 3D BIM model. The type of contract is assumed to be unit price contract and the payment terms are defined for all test case activities. More details will be described in the Test Case chapter.

1.6. *Research method*

Figure 1.1 shows the main steps that has been made to conduct cash flow generation as an objective of this research.

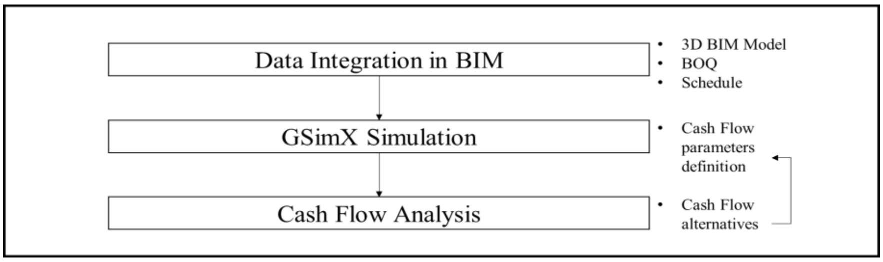

Figure 1.1 Cash flow generation steps

Figure 1.2 shows the steps of conducting this research. The research objectives have been determined by a literature survey of recent work related to technology and BIM role in construction management, and to highlight the challenges and missing aspects in generating cash flow forecasts. Literature review provided existing work regarding cash flow forecasting and recent approaches for generating cash flow forecasts through BIM and simulation. It also highlighted the gaps between design, planning, contractual matters and the miscoordination among them and their effect on cash flow. Interviews with experts were conducted to spot light on cash flow generation and analysis in practice, and to help determine factors and parameters that shape it. Experts also helped clarify the hurdles that companies face while preparing data for cash flow and to describe reasons behind the variance between project cash flow forecast before construction and the actual cash flow after project is complete.

Cash flow generation methodology includes project data collection with schedule and cost information and implementation with the BIM model of the project. It also includes the definition for cash flow parameters and their link to project activities and elements. BIM design and planning resources data integration for the test case involves relating 3D BIM model elements to activities in the schedule in GSimX and assigning resource data, which will be described in Chapters 3 and 4. Cash flow parameters that shape the financial plan are defined and integrated with test case data. Cash flow parameters are used for manual calculation of cash flow and the automated one that results from GSimX simulation. Cash flow alternatives are generated by redefining parameters values in GSimX or by changing planning resources. Several values for payments terms were inserted to generate different cash flow alternatives. For the evaluation process on cash flow alternatives, this approach set out the main concerns that should be taken into consideration for choosing the best cash flow alternative and the measures to approve the financial plan.

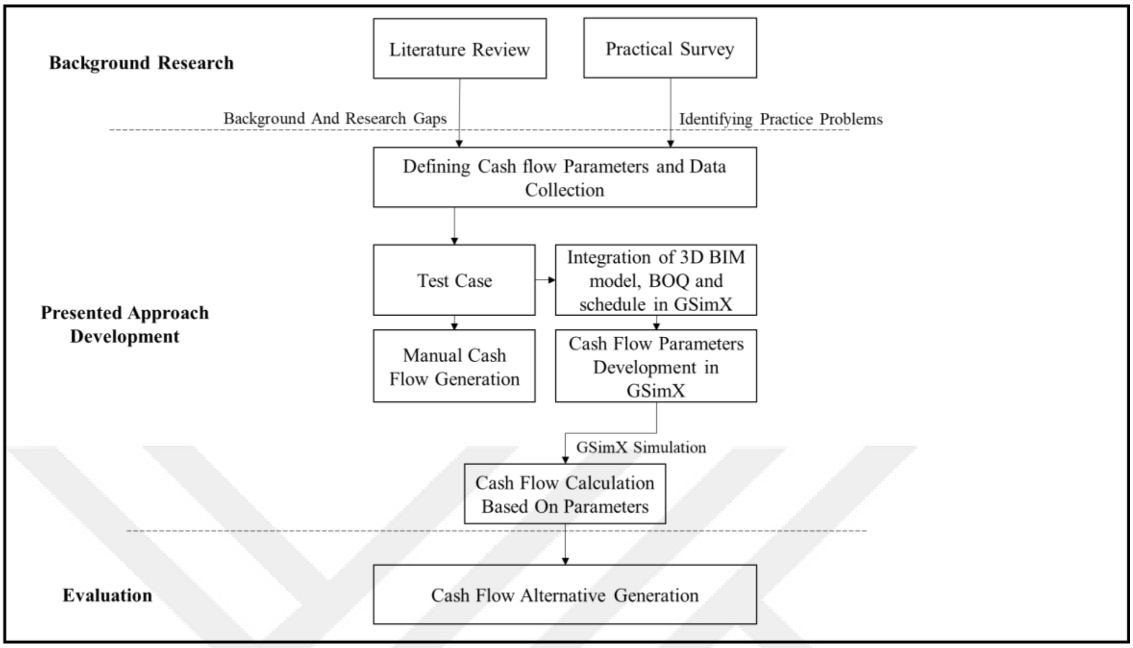

Figure 1.2 Research Steps for Cash Flow Generation Through BIM

1.7. Organization of the thesis

The remainder of this thesis is organized as follows: Chapter 2 discusses the background of this research, approaches to generate cash flow through BIM and simulation of project data, the benefits of generating cash flow forecasts and limitations of the existing work. It also covers cost estimation methods and project control approaches such as earned value analysis to show its relationships to cash flow forecasts. Moreover, it introduces location-based scheduling and GSimX as a resource-integrated simulation tool and its application with BIM to generate cash flow forecasts. Chapter 3 discusses the research methodology of integrating planning resources and cash flow parameters through BIM to generate cash flow. Chapter 4 presents a test case for the study, with manual calculation of its cash flow and automated cash flow analysis, verifying the generated data through manual and automated processes. Finally, In Chapter 5 results and findings are presented with the contributions of this thesis on cash flow generation and future research.

CHAPTER II

BACKGROUND

This thesis particularly focuses on improving the cash flow generation process within an automated construction environment using Building Information Modeling (BIM) and simulation technologies. As a result, it aims to help analyze cash flows reliably and easily. In this research, techniques to implement cash flow analysis process on a BIM and simulation integrated platform are developed. This helps provide cash flow alternatives and provide a dynamic method to generate alternative cash flow forecasts in preconstruction phase and update cash flow analysis easily during the construction process.

This chapter provides a background discussion for the existing techniques and approaches related to this thesis. It discusses traditional construction cash flow in practice; BIM and simulation role in construction management and cash flow analysis and its forecasting within BIM and simulation tools.

2.1. Traditional Construction Cash Flow Forecasting

During project bidding phase, contractors aim to estimate project costs they are bidding for to evaluate the total cost of the project and to get information on the ongoing and received payments due dates and amounts that will take place during execution of the project. Quantity take--off describes the total cost for each BOQ item and it may include loaded costs like labor and equipment. Every BOQ item has to be included in the project cash flow, for this purpose, project schedule activities cost considers all BOQ items and their cost, so the total cost of project activities has to match the total cost of project BQQ items. Once activity costs are defined along with their duration, cash flow for the project can be obtained by determining the periodic costs of the project.

Project cash flow is the difference between the project’s monetary income and disbursements of dues and liabilities. It is separately defined by its two main types: cash inflow and cash outflow. *Cash inflow* in construction is the incoming money from owner to the contractor according to the contractor progress in project works in a certain time period, typically on monthly basis. The works payment amount is estimated based on the percentage of total project completion or actual field measurements of quantities placed on site. *Cash outflow* is the amount of money that is paid from the contractor to his suppliers, subcontractors, crews etc. (Peurifoy 1975).

Cash flow graphical representation consists of detailed display for cash inflow and outflow information. It shows whether surplus funds will be available during construction, or whether negative cash position will occur. It considers several parameters that shape the project cash flow.

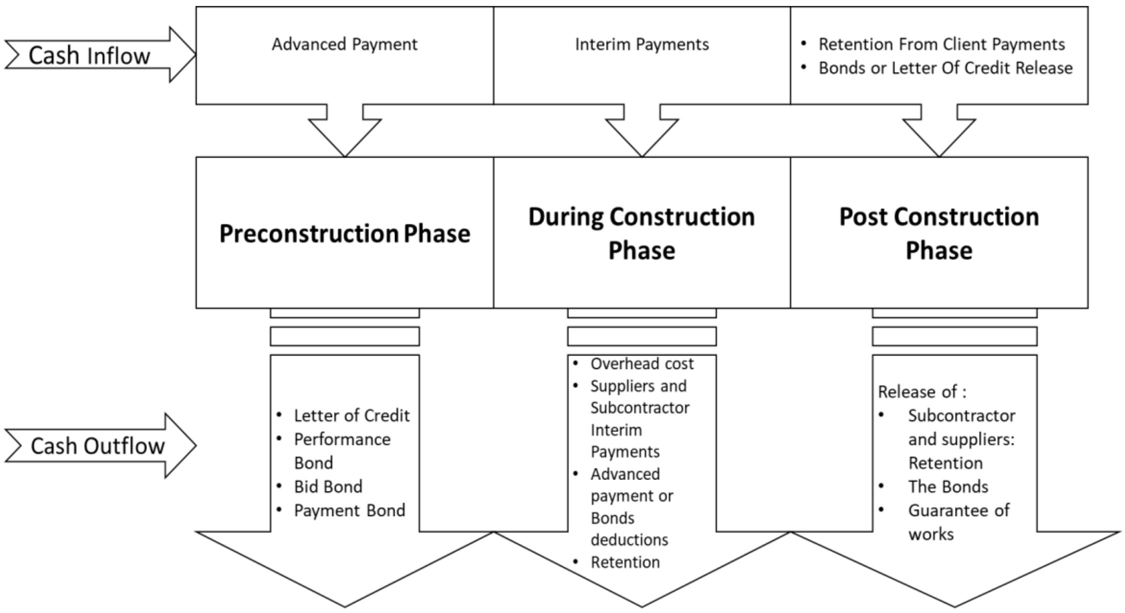

Figure 2.1 Typical parameters for cash flow generation process for contractors

Parameter of cash flow generation process are shown in Figure 2.1. Typical cash flow parameters in construction industry include:

- *Retention:* the percentage (usually between 5% to 10%) of the monthly interim payments amount retained by the owner of the project before issuing the monthly payments to the contractor, the purpose of it is to ensure that the contractor will deliver the project as agreed in the contract.
- *Performance bond:* is to ensure that the contractor has a responsible financial party that can stand behind him if he does not perform the project requirements properly. It may be provided to the owner as a letter of credit from the contractor bank or it may be deducted as a percentage (between 10% to 100%) from each monthly payment certificate and released after the contractor fully accomplish the project.
- *Bid bond*: is required by the owner from every contractor to accept their bids, used to assure that a successful bidder (contractor) will sign a binding agreement with the owner and will provide the other required bonds.
- *Payment bond:* protects the subcontractors, material suppliers and labors if the construction firm/general contractor fails to make payments to them required bonds. It should be sufficient to cover all costs of labor and materials. (Hinze 1993)
- *Interim payment:* The frequent monthly payments issued from client to contractor or from contractor to his subcontractors, it starts after the advanced payment until the final payment, the period between each payment is upon the agreement between its parties, typically on monthly basis or upon progress percentage.
- *Advanced payment* is the money amount given to the contractor from owner in some projects to help in mobilization and start-up costs of the project. It has

various ranges of total contract amount, typically between 10% to 20. Owner typically restores advanced payment by deducting it as a percentage from each contractor's monthly interim payments certificates (Hinze 1993).

Project cash flow is prepared in practice by studying the project contract conditions, BOQ and schedule to describe the cash flow of project financials, activity costs and the remaining payments after the execution of the project. Generally it aims to create the function of cost projection along project timeline and to specify the sequence of payments and their amounts (Navon 1996). Traditional methods for cash flow generation in practice are time consuming, subjected to cumulative human errors, it is also not flexible for update upon project changes and cash flow alternatives are not considered (Khosrowshahi 1991). Figure 2.2 (Al-Joburi, Al-Aomar et al. 2012) shows a typical cash flow representation for a periodic income and the cumulative cash inflow and outflow curve. Payment dates are presented on the horizontal axis versus the money amount on the vertical axis, periodic payments are shown in the bars with their date and amount, and the cumulative curve calculated by summing up each consecutive payment up to that date.

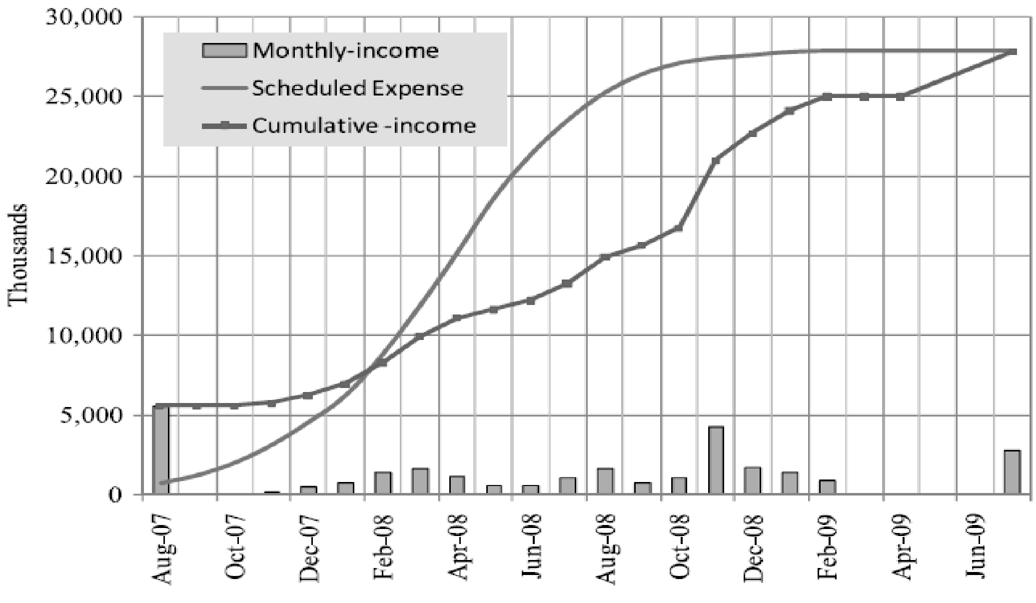

Figure 2.2 Periodic and cumulative cash flow example (Al-Joburi, Al-Aomar et al. 2012)

Contractors who deal with multiple projects simultaneously seek to keep observing the overall financial status of the company; a profitable project for the contractor does not necessarily indicate success especially in case of problematic projects. If contractor is losing money in a certain project or does not progress, this will affect the other held projects of the contractor and might lead to large financial loss along time. Balance sheet analysis was proposed by Cleaver (1971) to deal with cash flow analysis for a contractor running multiple projects. It aims to determine the contractor capital net balance of all projects, so contractor may provide a certain project due form this total capital that he received from all projects, this is used in the practice, but it might lead to a financial crisis if liquidity deficit took a place. In this proposed approach, balance sheets are not considered and each project is considered separately.

Traditional approaches do not include contract type and effect of site conditions on cash flow analysis and do not easily provide the ability to generate cash flow alternatives. They are also considered slow to be applicable with the dynamic nature of construction projects that require a quick update of cash flow data.

2.2. Cash Flow Forecasting Models

2.2.1. Ashley and Teicholz

Ashley and Teicholz (1977) proposed a model by a linear unbalancing rule used to predict the cost curve of the project. Project was divided into cost categories as percentages of the total cost of the activity. This model also considers the time lag of payments by a formula that add time range for each due date of payments and provided payments curve which was extracted from the cash inflow curve. It relied on the income amount of money to issue to outgoing payments considering a specified percentage of retention and time lag. This model proposed equations to calculate the cash inflow curve with subtracted retainage with allowance for time lag. This model came up with limited cash flow forecasts, but it was not detailed enough to cover the major project entities and resources costs.

2.2.2. Kaka and Price Model

Kaka (1991) developed a model to forecast net cash flow by improving on (Kenley and Wilson 1989) in examining net cash flow for projects. This model was used to predict each project cash flow individually based on each project BOQ and schedule activities costs. This model used weighted mean delays for cash flow payment categories and suggested front-end loading strategy for activities, so the contractor may receive activities of largest payments by the earliest. It also considered inflation rates risk and other random factors that might increase the total cost of the project unexpectedly. It also considered the material purchasing periods and preconstruction phase. Furthermore, retention payments were listed in their model by adopting Ashley and Teicholz (1977) model retention formulas.

Kaka's improved model Kaka (1996) added more categories for costs and payments, while including risk analysis by applying stochastic approaches for two top-bottom values for each payment and its retention. This model provided three cash outflow curves of maximum, average and minimum amounts of monthly payments. Although providing different categories of cash flow and associated risks, this model showed only range of possibilities that will help the contractor to see the minimum, average and maximum values of cash flow curves.

2.2.3. Navon Model

Navon (1995) provided a computer application that generates cash flow forecasts by creating integration algorithms for the cost items and their relevant schedule activities.

These algorithms automatically integrate the BOQ items and schedule in a database in order to generate cash flow as in Ashley and Teicholz (1977) model. Navon model created cost items that subcategorize each activity into all distinct cost entities according to the activity physical elements. This model also considered the time lag and payment terms for cash inflow and outflow, it is also defined the policies of purchasing materials, payment terms and monthly number of crews to be considered in the cash flow forecast.

In Navon Model, the relationships between activities, item costs and resources were classified into four categories according to their dependency on each other in order to grouping connected activities by dependency and limit the effect of change in dependent activities. The categories were classified to create the resource cost projection on activities by due date in order to integrate the BOQ and activities schedule data according to their cost divisions and periods, to form general resource/activity allocation database (GRAAD).

Navon model also considered many factors as time lags, project calendar, material supply, subcontractors cost and overhead costs to specify each factor financial schedule and impact on the project cash flow forecast. This model does not define the factors for cash outflow forecasts. It relies on Ashley and Teicholz (1977) model and provides an algorithm for calculation. Nowadays, BIM helps solve the cost and schedule integration problem through attaching project schedule, resources and cost data.

2.2.4. Khosrowshahi Model

Khosrowshahi (1991) proposed a cash flow model for cost estimators that mainly focus on the periodic changes in the project cash flow curve. It studies the project cash flow curve to spot the critical and inflection points and separate them in a periodic cash flow graph in order to control them to avoid any financial troughs or spikes during project. It also relies on several assumptions like considering the periodic cash flow values curve are independent from each other, initial and final values are zero which means that advanced payments are ignored in this cash flow model. This mathematical model does not consider main factors that shape the cash flow curve like the project design, payment terms, BOQ and activities or resources cost.

Khosrowshahi (2000) discussed the effect of negotiation with owner, suppliers and subcontractors to manipulate the cash flow forecasts. The research conducted a graphical analysis for cash flow alternatives generated by considering different values for project starting date, payment delays, first payment interval, front-ending loading for activities and interest rate. One hundred cash flow scenarios were provided and each alternative was evaluated based on overall profit margin. This research highlights the importance of considering the cash flow forming factors and mathematical models to optimize them, but it generates cash flow alternatives for simplistic scenarios. Currently sophisticated tools are available such as Building Information Management (BIM) for more realistic cash flow generation for complex projects.

2.2.5. Other Cash Flow Forecasting Models

There are other research on construction cash flow forecasting and analysis using various computational approaches. Boussabaine and Elhag (1999) used fuzzy techniques to generate the cash flow analysis for 30 projects and discussed the variations between the original cash flow curves of these projects and the fuzzy technique results. Boussabaine and Kaka (1998) proposed using neural networks for cash flow forecasting to reduce the limitations and inaccuracy of mathematical linear models by forecasting cash flow of specified periods for 40 projects. Although the results showed slight difference between the original and forecasted cash flows, it did not cover the whole project period at once and it relied on collected data of the completed projects to create probable cash flow forecasts regardless of planning parameters and financial factors. Kim and Park (2012) proposed an algorithm to forecast cash flow considering time lag for payments for materials, labor, subcontracting and expenses costs. Earned value including time lag and resources over time were considered as variables for factors that have major effect on the cash inflow and outflow forecasts.

Several mathematical models were created to define and analyze construction cash flows. Mathematical models and manual processes helped researchers represent the cash flow generation by formulas that combine cost and schedule data (Reinschmidt and Frank 1976, Sears 1981). Park, Han et al. (2005) categorized the cost entities and proposed a model to generate cash flow forecasts according to the weight of each cost category relying on the project planned cost and earned value analysis reports during the construction phase. These mathematical models may be time draining to analyze all project data specially for the large-scale projects that are full of details. In addition, they ignored many factors that play major role in cash flow analysis like time lag or payment terms (Kim and Grobler 2013).

Hegazy and Ersahin (2001) proposed a spreadsheet-based model that combine the critical path network with time-cost tradeoff analysis, resources management and cash flow. The purpose of this model was to reduce the overall cost of the project. The model considered delays in activities and payments and described the type of dependency between activities and their resource costs. Moreover, it combined some parameters of cash flow like the mobilization payment, payment delay, retainage and manually calculated daily expenditures. This approach applies trials on the inserted project data that aims to optimize the schedule and reduce the total cost of the project. But the resulting cash flow was time draining to be generated due to data collection and entry and it lacked of informative and dynamic graphical representation for the results, it also did not provide analysis for the cash flow during the of project period. Hwee and Tiong (2002) presented a computer model to forecast cash flow considering duration, materials cost variations, cost estimation errors and variation in design or project as risk factors. It also assumed that the contract type is lump sum. It also considers payment delays and retention. Lee, Lim et al. (2011) proposed an approach to improve the reliability of cash flow forecasts by proposing a stochastic computer tool that determine the best fit probability distribution functions for CPM. Primavera Project Planner (P3) software schedules and generates project cash flow upon the project constraints of resources, schedule, contract conditions and payment terms. However, this approach is limited to existing schedules; it is not connected to BIM and does not support easy generation of cash flow alternatives based on parameters.

2.3. Cash Flow Forecasting and BIM

As technology adoption increases in engineering projects, researchers and construction companies find BIM as a useful tool to create digital models for the project data and elements. BIM has become an indispensable tool for engineering projects management (Azhar 2008). Its adoption and implementation has a wide expansion worldwide and its adoption took place and helped designers, consultants and contractors to avoid many problems related to design coordination, planning and project management (Smith 2014). BIM become a platform to visualize most of project aspects like, 3D model, cost estimations, scheduling, energy analysis and maintenance plans. (Lin 2013).

Research on project cash flow since early 1970’s provides approaches to predict cash flow in early bidding or preconstruction phase and to develop approaches that help in generating accurate and cash flow (Kim and Grobler 2013). Each research considers certain aspects in cash flow analysis according to its practice era and available tools.

Since 1980s, research was conducted to link schedule and cost data with three-dimensional computer-aided design (3D CAD) models (O'Brien 2000). It was demonstrated that sequence of activities and coordination improved during coordination process (Reinschmidt, Griffis et al. 1991). The development of 3D CAD models led the researchers to seek for further aspects to be analyzed along with the 3D models of the project (Thabet 1992, Akinci and Fischer 1998, Riley 2005). 4D models that combine the 3D CAD models with schedule data were proposed by many researchers, it represented the construction progress with automated and dynamic perspective relying on the computer tools.

Researchers used BIM in the various aspects of construction process. Wong, Li et al. (2014) proposed a 5D BIM tool that enhance the safety procedures and strategies at construction sites calculate carbon emission and detect through simulation the black spots at sites during planning stage. Kim, Orr et al. (2014) provided a highway alignment and design review tool that reduce the time and efforts to provide the cost and duration analysis for design alternatives.

Project cost, material, resource and schedule data can be attached and integrated with the BIM model to provide the ability to perform planning and cost estimation analysis beside clash detection. Feng, Chen et al. (2010) automated scheduling process by suggesting multiple dimension CAD (MD CAD) model using CAD model, object sequencing matrix and genetic algorithm to integrate time and cost data. However, integration of time and cost data is not sufficient for the decision-making process; stakeholders seek to be aware of several financial scenarios and quickly update the financial plan according to the budget and project updates (Stanley and Thurnell 2014).

There are several research that propose cash flow analysis through BIM (Lu, Won et al. 2016). Kim and Grobler (2013) proposed a prototype tool that analyze cash flow through BIM by the extraction from BIM models the schedule, BOQ and cost data. This work reduced the required time for analyzing cash flow significantly but did not consider the different type of payments, financial risks, project continuous update for schedule and cost data, the inflow and outflow pattern of cash. In addition, simulation and BIM-based decision making was not included.

Lu, Won et al. (2016) proposed an approach to generate cash flow through BIM by using five-dimensional building information modeling (5D BIM). A 5D BIM framework using Revit, Navisworks and Excel Macros were provided to perform cash flow analysis and cash flow forecast through an external Revit plug in. This 5D BIM framework based on creating the BIM model from AutoCAD 2D drawings and bill of quantity (BOQ) to visualize the projects and extract quantity takeoff (QTO) respectively. From QTO, equipment, material and manpower quantities were determined. Then schedule database was established considering the productivity rates of each equipment and manpower. This database was integrated with the BIM model and the QTO database so that the amount of executed quantities over time were determined and each BOQ item was attached to its corresponding activity in the schedule, and consequently all construction tasks and project timeline were determined. After that cost - including direct and indirect cost - database was added and integrated with project BOQ, QTO and schedule in Revit and Navisworks.

To generate cash flow, other parameters that effect on the financial status of the any project were included such as contract type, payment period, payment delay, profit percentage, retainage percentage and mobilization payment. By considering these parameters researchers outlined the structure that form the Cash Inflow (CI) pattern. After this they could perform the CI calculation and find the amount and date of the periodical payments, profit, retention amount, mobilization payments and consequently the CI curve was obtained. Cash Outflow (CO) pattern was structured by analyzing equipment, manpower and material payment patterns. The integration between CI and CO data provided the ability to obtain the excess/deficit money amount, overdraft and interest costs. By illustrating the financial scenario of the project stakeholders can make more objective decisions. The approach also proposed the ability to generate different cash flow alternatives based on changing the design and determine the least cost alternative. However, other parameters like planning resources, payment terms, work sequencing were not included in generating and comparing cash flow alternatives. Current BIM platforms and software can help perform cost estimation and scheduling, but they do not use planning resources, cash flow parameters, work sequences or simulation to generate cash flow.

2.4. Simulation and GSimX

Most of the current solutions for BIM-based platforms are concerned in design coordination, quantity takeoff, attaching the project schedule to the 3D BIM model for animation purposes (Hasan 2018). Moreover, the full implementation for further financial analysis features is still limited and lack for more comprehensive and practical solutions that provide the ability to generate cash flow analysis through BIM and simulation platforms.

GSimX is a prototype of resource-integrated BIM-based simulation platform that has been used to implement the research approach in this thesis. It attaches the entire BIM model with its relevant schedule activities to build simulation model of the construction process, it also applies location-based scheduling to enhance the original project schedule considering available crew, equipment, and site space availability.

2.4.1. GSimX Definition

GSimX **(G**eometry-based **Sim**ulator **X**) is a prototype of resource-integrated simulation platform that interactively define the project subsystems, resources and integrate project 3D BIM model with CPM schedule (Baltasi and Akbas 2017, Akbas 2003) . GSimX user has to assign project resources to their relevant activity in the CPM schedule, which become agents during simulation. BIM model elements will pass through discrete-event simulation as work locations, combining the BIM model with resources and processing them according to the schedule will be take place in the simulation as queueing networks that order them in the analysis and visualization process according to their sequence and date in the schedule. Simulation is complete after all BIM elements and their resources are completed in their location flow (Hasan 2018).

Cash flow analysis through GSimX requires defining cash flow parameters for the simulation GSimX model. It relies on engaging the main parameters that shape the cash flow in the simulation process. Cash flow analysis is a further improvement to GSimX. This thesis work will describe cash flow parameters and generation through GSimX in more details in the Methodology Chapter.

2.4.2. GSimX Approach

GSimX simulation model is created by importing the 3D BIM and project CPM schedule to GSimX, certain steps need to be followed (Akbas 2016, Hasan 2018):

(1) Define location flows: once schedule is imported with the 3D BIM model to GSimX, activities will be automatically linked to their related BIM model

elements to form the simulation model. Consequently, work locations will be identified in addition to crews for activities,

(2) Resource identification that includes the required crews, equipment and materials for activities, crews will be allocated while defining the needed number of workers per each crew. Similarly, equipment and materials amount are determined and defined according to their capacity and cost,

(3) Attaching resources to activities: for each activity, necessary crews, equipment and materials is defined. This can be imported from scheduling software. In addition, the direction and order for executing the activity can also be defined and one or more crews can be assigned to each activity. Productivity rate function, resources and capacity of the activity for the number of crews are also defined,

(4) Running the simulation: All work location (customers) in the queueing network will pass and take place in the simulation according to their sequence. Each crew occupies a work location until finishing it; all crews have to be available and not busy to enter the queueing network for the next task. Serving time is the multiplication of productivity rate function with the assigned quantity of work for the task. GSimX has workspace to visualize the 3D BIM model and simulation process that starts by the first activity and its defined crews (servers),

(5) Results analysis: each simulation run creates data output that contains the updated duration of project considering the assigned crews, equipment and materials for activities. It also provides information about the utilization factors and total cost for each crew and resource tabulated in the simulation results.

2.4.3. Cash Flow Analysis by GSimX

GSimX simulation model contains schedule and cost data integrated with BIM model. If cash flow parameters are defined and after each simulation a new cash flow is generated, results can be generated and studied easily for many alternatives. Cash flow analysis by alternative evaluation can be performed by modifying cash flow parameters and running the simulation again to show their change effect on the cash flow cumulative graph and total cost of the project.

In conclusion, GSimX approach improves the cash flow analysis process and financial decision making for AEC projects and set clearer financial scenarios for the contractor to follow. It also enhances the management of planning resources and activities sequencing. Moreover, it allows the ability to combine planning resources and sequences easily with the cash flow parameters in BIM model and monitor the effect of their change on the entire project.

2.5. Literature Review Conclusion

Classical cash flow forecasting for AEC projects is limited especially with the current advanced technologies that have been adopted and implemented in the construction industry. In addition, for fast track and mega projects traditional methods require massive efforts to be applied and they may deliver an unclear vision for the prospective financial status of the project due to the shortage in considering several factors that impact cash flow forecasts.

The earlier cash flow forecasting models Ashley and Teicholz (1977), Khosrowshahi (1991), Kaka (1996), Navon (1996) proposed mathematical solutions for cash flow forecasting. The difficulty in implementation especially for large scale projects may lead to lack of accuracy, human errors, difficulties in validation of results to be applied in the AEC industry, made those models hard to take place in forecasting the cash flow for construction projects.

BIM technology implementation in construction projects is trendy and effective nowadays; BIM provided the ability to integrate most of the important project data and provided the ability to reflect any change in drawings, BOQ, schedule, resources and contract conditions on all BIM model entities. This is a valuable advantage that saves lots of efforts and maintain accuracy, however analysis for construction stages with BIM is still limited. There are proposed approaches using simulation with BIM with limited cash flow forecasts. GSimX is a potential such approach that simulate construction processes integrated with resources on BIM. Extending it with cash flow generation will improve cash flow generation process, maintain accuracy, and provide more reliable information presentation. It will also enhance the planning and financial decision making given the wider range of considered parameters in the cash flow analysis. Moreover, the ability to generate cash flow alternative within minutes for the entire projects is a promising advantage, specially that this is made in the simulation-BIM based platform.

This approach uses GSimX to generate cash flow forecasts in the preconstruction phase, with parameters common in project delivery systems like contract and subcontract payment terms. It also aims to generate cash flow alternatives based on changing those parameters. It is time draining to generate manually cash flow alternatives at the start of each project, and it might include many errors and unforeseeable factors that had to be included. Therefore, computerizing the generation of cash flow analysis is highly recommended and vital. The next chapter describes the methodology to achieve this.

CHAPTER III

METHODOLOGY

The main goal of this thesis work is to enable BIM and resource integrated simulation platform for cash flow analysis. Users should be able to generate cash flows and easily provide alternatives for cash flow either in the preconstruction phase or during construction given the contract type, site progress, project schedule, BOQ and contract conditions and updates. This proposed methodology is obtained by preparing the project schedule, BOQ data and cash flow parameters and integrate them with the 3D BIM model in GSimX to generate cash flow alternatives through simulation.

This chapter discusses methods to provide an approach for cash flow generation using Excel and through BIM and simulation, also to identify the needed information to generate cash flow through BIM for different types and sizes of projects. Moreover, this approach discusses the project financial, contractual and planning information preparation and management in preconstruction phase and during construction. Lastly the proposed methodology discusses GSimX involvement process for cash flow analysis generation by defining the simulation requirements, relations between them and cash flow parameters definition within GSimX.

3.1. Cash Flow Parameters

For automated generation of cash flow using BIM, the factors that have an impact on the cash flow results are considered as parameters. Those cash flow parameters are related to contract type that specify the payment terms, planning resources and work sequences.

Cash flow parameters are divided into cash inflow and cash outflow parameters. Cash inflow parameters specify an aspect of the financial relation between owner and contractor, as it defines the terms of how the payments will be processed to the contractor. Cash outflow specifies the financial relation between the contractor and suppliers, labors, and subcontractors.

This thesis defines a common set of parameters for cash inflow and outflow suitable for comparison between the generated cash flow alternatives from simulation. For cash inflow, defined main cash flow parameters are the contract type, payment due date or period, percentages for profit, retention, advanced payment and performance bonds and bank guarantees (Table 3.1). For cash outflow (Table 3.2), focused parameters are for activities carried out by subcontracting or suppliers. Cash inflow and outflow parameters define the financial relationship between stakeholders. Each project has its own parameters values for cash inflow and outflow, these distinctive values form the cash inflow and outflow patter of the project. Cash inflow and outflow patterns are similar to each other in term of when, how and how much payments will be processed between owner and contractor or between contractor and suppliers, subcontractors and labors, etc. Those parameters can be applied for any project with variable circumstances since only their values vary from project to another.

The selected parameters in Table 3.1 are defined in Chapter 2. Not all possible cash flow parameters in construction projects have been included in this research. The main common and important ones have been selected.

Contract type influences the overall process of cash flow; some contract types like lump sum specifies the total price of the project and the contractor has to deliver the project within the cost so it is not flexible for any contractual changes between the contractor and the client unless the client asks for a change order so it contain higher risk on the contractor specially while pricing the project items. Unit price and cost-plus fee contracts has lower risk and more flexible for changes in quantities or design. *Advanced payment* is an initial payment to the contractor, and it helps mobilization and start of the project to go smoothly. *Retention* deduction can be found in most of the payments and contractor must take it into consideration while calculating the cash flow of the project since it might reach up to 20% of the total cost of project. Bonds may vary from a project to another upon the agreement between stakeholders, it all calculated and engaged in the cash flow calculation by their percentages that also varies and may reach to 50% in some case or even more, so considering them will help the contractor to calculate a more realistic and accurate cash flow.

These parameters have been selected as common and primary factors that significantly shape the cash flow. FIDIC compliant contracts discuss these parameters and they can be observed in any engineering contract in the real practice together with other parameters that refers to the project nature and type.

These parameters are applied to activities for cash flow generation in Excel and simulation prototypes, specifying how stakeholders process payments or financial liabilities. For some activities, such as the concrete placement, payments are due 28 days after completion, and for others, such as MEP work, payments are partial on delivery and the rest is after installation. In each case a specified value for the payment terms to be made to each activity to predict its periodic financial dues in the cash flow.

Cash inflow and outflow parameters as shown in Table 3.1 and Table 3.2 have been either defined at the project level, or assigned to individual schedule activities, crew types, or responsibility. Payments that a contractor has to make for suppliers, labors, subcontractors etc. are cash outflows. It is more complicated to predict the outflow pattern rather than the inflow, due to the variety and wider range of payments and type of activities for subcontractors or suppliers which the contractor has to fulfill their payment dues. It is also important to the pattern of how payments and invoices will be scheduled, since each contract has its own payment terms (Khalaf and Akbas 2019).

Table 3.3.1: Defined cash inflow parameters

Cash Inflow Parameter	Description	Examples
Contract type	The type of the contract that shape the relation between the project parties.	Lump sum, unit price, cost plus.
Advanced payment, A_K	Payment to contractor from owner at the start of the project, to meet a significant start for the project. Also known as the mobilization payment.	Owner pays to contractor 10% of the contract amount after the notice to proceed.
Retention, RG_K	Percent of contract value retained until work is done and tests comply with specifications.	5% retention deduction from each month invoice total.
Performance bond, G_K	It is a guarantee for the owner that the contractor will perform the works as per the contract.	A letter of credit with specific amount from bank.

Table 3.3.2: Defined cash outflow parameters

Cash outflow parameter	Description	Examples
Material payment	Material payment terms depending on the mutual agreement between the contractor and subcontractors/suppliers.	Payment delay, monthly payment or payment of each delivery.
Leased equipment Payment	Payments have different terms, depends on the mutual agreement between the contractor and subcontractors/suppliers.	Payments terms between leasing contract parties like payment delays.
Subcontractors & labor Payments	Payments have different terms, depends on the mutual agreement between the contractor and subcontractors/suppliers.	Payment delay or monthly payment.

3.2. Excel Prototype for Cash Flow

Although this thesis focuses on generating cash flows automatically through BIM and simulation, a manual calculation methodology for the cash flow analysis is provided to evaluate the general approach and verify the accuracy of the automated approach. Manual calculation for cash flow analysis needs to combine project schedule with BOQ data considering the project contract payment terms. Figure 3.1 shows the process of manually calculating project cash flow. All schedule activities with their sequence and assigned durations are combined with their relevant BOQ items and tabulated in Microsoft Excel. Each activity total cost is defined along with its duration and start and finish dates. This is followed by the step of defining the payment terms for project works. By assigning the payment terms for activities, the project payment will be tabulated, date and amount of each activity payment will be defined. As a result, the graph of cumulative cash flow can be plotted by inserting the timeline of payment amounts and their dates.

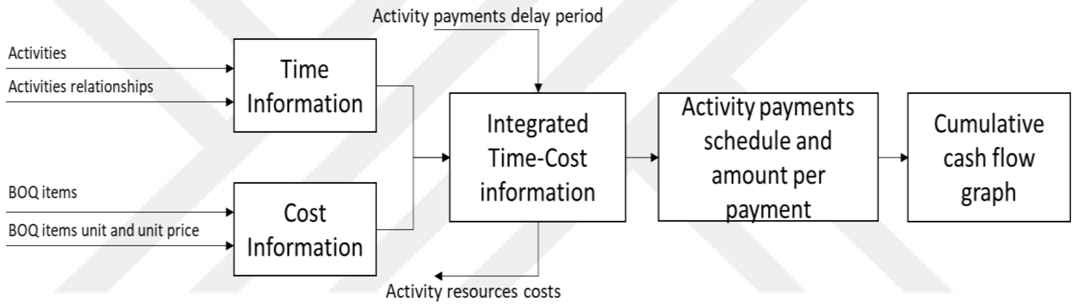

Figure 3.1 Cash flow generation process for the Excel prototype

For cash flow manual calculation, the following equations; Eq. (1) to Eq. (6) were applied to determine the cash flow through Microsoft Excel, these equations calculate the cash inflow which coming from owner to contractor commonly on monthly basis.

$$CI_m = \sum_1^K net\ P_K \quad (1)$$

$$net\ P_K = \sum_1^K (P_K - RG_K - A_K - G_K) \times Q_{K,m} \quad (2)$$

$$RG_K = \{(1 + R\%_K) \times P_K\} + \{(1 + G\%_K) \times P_K\} \times Q_{K,m} \quad (3)$$

$$A_K = (1 + A\%_K) \times P_K \times Q_{K,m} \quad (4)$$

$$P_K = C_K \times M\% \times Q_{K,m} \quad (5)$$

$$T_{K,delay} = K_{finish\ date/delivery} + t_{delay} \quad (6)$$

$K = 1, 2, \ldots K$ and $m = 1, 2, \ldots l$

Where CI_m is the total monthly cash inflow for activity K in month m, l is the last activity in the schedule; K is the activity or work item number; P_K is the price of the activity or item number; $Q_{K,m}$ is the quantity executed for activity K in the month m. The $net\ P_K$ is the price that include all payment deductions, performance bond is defined as G_K. RG_K in Eq.3 is the amount of retention deduction from each monthly payment, $R\%_K$ is the retention percentage amount for activity K, $G\%_K$ is the performance bond percentage deduction for activity K. A_K in Eq. 4 is the amount of advanced payment deduction from each monthly payment, $A\%_K$ is the percentage of advanced payment deduction. P_K in Eq. 5 is the price of activity K, C_K is the cost of activity K, M% is the profit percentage in activity K. The delay time $T_{K,delay}$ in Eq. (6) is the delay time of activity K payment that is defined by the delay period t_{delay} after activity K finish date or delivery.

Payment due date also can be delayed after the finish date of the activity by a delay period according to the agreements between the parties. Contract type can also affect the calculation of payments due to the difference in type of payment terms.

These formulas are first used in the manual calculations in Microsoft Excel and afterwards have been implemented within the simulation platform.

3.3. Data Preparation for Simulation on BIM

This section describes the process of creating the simulation model and integrating its data. This process aims to prepare the BOQ and schedule information for integration and attach it to BIM elements for simulation. Figure 3.2 summarizes the various steps to integrate the project data and showing the output of the process. This process includes data collection for project contract BOQ, cost information, schedule and the creation of

BIM 3D model. BOQ data regarding the activities, cost information should be transferred and defined in Microsoft Project or Primavera, to be combined with the project schedule.

The combined schedule file should be exported to GSimX in xml file format. User must define the dates, duration and assigned number of crews for each activity in the schedule. In addition, resource sheet has to define the rate for each resource and resources have to be classified as one of labor, materials or equipment. Revit 3D BIM model also should be exported to GSimX, all clash detections and coordination for drawings must be made to be ready for simulation as a last stage, Project data should be attached to its relevant 3D BIM elements in GSimX to create the cost distribution on scheduled, so each BIM model element will be linked to its related cost and schedule information, also resources quantities at the different times can be obtained too. This data is for GSimX simulation use, it will embedded in the background analysis of cash flow. The data integration process is a prerequisite for any simulation run GSimX. It is possible also in GSimX to define the number of maximum crews and equipment number as resources for activities.

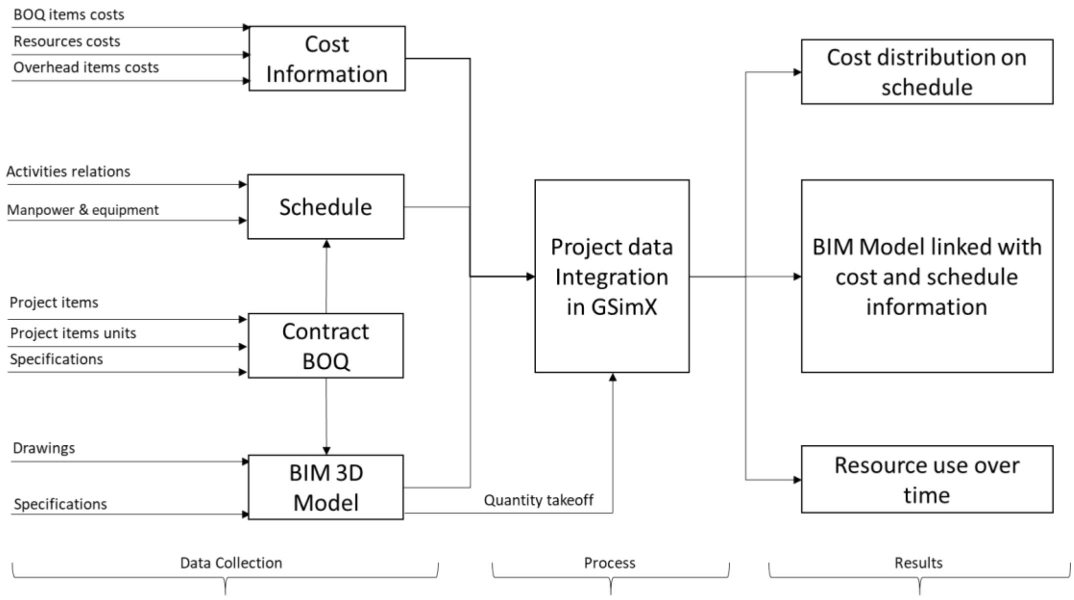

Figure 3.2 Cash flow data integration process

3.4. Automated Cash Flow Generation

Cash flow generation is implemented through the resource integrated platform GSimX, cash flow parameters have been added. Calculation of the BIM-based simulation model is made to dynamically calculate cash flows based on construction simulation. We compared the results of manual and software calculations and demonstrated that cash inflow and outflow can be calculated in the simulation platform for multiple cash flow analysis alternatives.

3.4.1. Simulation for Cash Flow Generation in GSimX

After integrating project schedule, cost and BOQ data with the 3D BIM model in GSimX, defining cash flow parameters take place. Figure 3.3 shows the process of conducting cash flow generation through simulation. In GSimX, simulation model is built by defining location flows and assigning necessary resources and their parameters. Location flows are project activities assigned to BIM scopes of work with the right sequence. Then cash flow parameters for activities are defined within GSimX, and the model is simulated as the first simulation run. Cash flow results are calculated based on the parameters that creates the cash flow analysis. Each simulation run will generate a tabulated cost information data, and cash flow analysis represented by cash inflow and outflow graphs with cumulative cost of the project at its different times (Khalaf and Akbas 2019).

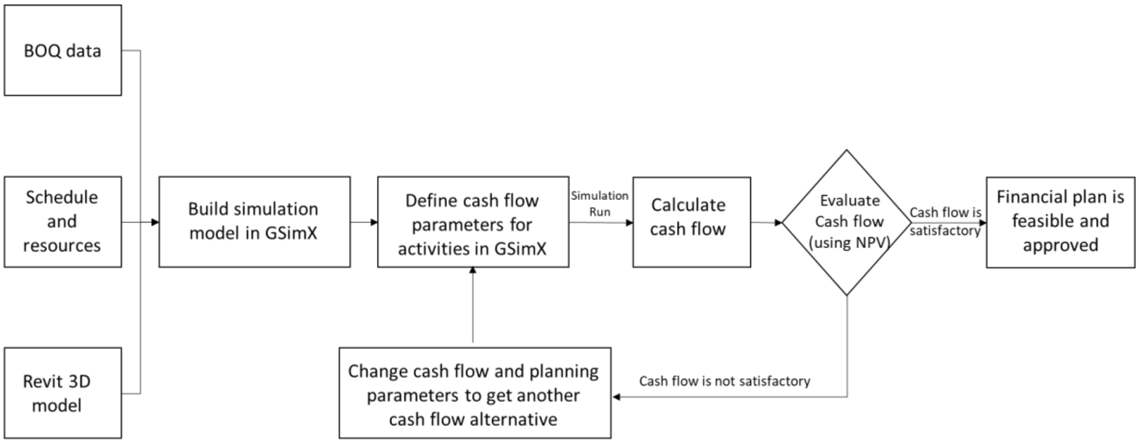

Figure 3.3 Cash flow generation and analysis process through GSimX

3.4.2. Cash flow alternative generation process in GSimX

As negotiation between project parties take place in many cases, cash flow parameters are subjected for amendment, any update or change in cash flow parameters will lead to a different cash flow analysis. Cash flow results are reviewed by contractor to check the cash outflow versus the cash inflow to decide whether it is satisfactory for contractor financial abilities and whether it is a good solution for the contractor. If satisfactory, the contractor can afford and make sufficient income based on the financial liabilities along the project timeline. Contractor can change cash flow parameters or planning parameters (e.g., sequencing, resource assignments, crew flows) and re-simulate to update the cash flow and review until getting the most satisfactory result. This gives users the ability to generate many cash flow alternatives to pick the best financial scenario among alternatives for project implementation. The best alternative would be the one that provides liquidity and high-income periods against the expenses, as well as one that has low risk and is practical to implement (Khalaf and Akbas 2019).

3.4.3. Cash Flow Alternatives Analysis

Generated cash flow alternatives have been analyzed using a simple approach relying mainly on the Net Present Value method for assessing the present capital for the contractor (Kenley 2003). Since inflow and outflow payments may have different patterns for the cash flow alternatives during construction with different payments values, contractors aim to earn the money as early as possible for executed works. For the test case, the net flow for the monthly payments is the difference between the monthly inflow and outflow payments. Each cash flow alternative has been assessed using the Net Present Value method with different value of interest rates in order to determine which alternative will provide higher profit in the future so contractor can choose it for a better financial decision. Eq. (7) is the formula for calculating the net present value for the monthly payments net flow.

$$NPV = F / [(1 + i)^n] \qquad (7)$$

where NPV is the net present value for the periodic net flow, F is the amount of periodic net flows for the n periods, n is the number of periodic net flows and i is the interest rate. Each cash flow alternative has periodic net flow values, which can be inserted into the Eq. (7). The highest NPV cash flow alternative indicates the best cash flow alternative among considered. Net flow might go negative in certain periods, when the cash inflow is lower than the outflow. Therefore, contractors must be aware of these periods and try to reduce negative net flow periods by redefining the cash flow parameters.

NPV should be calculated for all cash flow alternatives to help select the alternative to be approved as the financial plan for the project. This will reduce the financial risks on the contractor and provide a more comfortable financial plan for contractor.

3.5. Chapter Summary

This chapter defines the required information for cash flow generation process; it discusses preparing project schedule, cost and information to be integrated all together with the 3D BIM model as a main step before cash flow generation. It also defines the cash flow parameters that shape the cash flow of the project and it discusses how to involve them in the cash flow generation process through the resource integrated simulation platform GSimX and BIM. The presented methodology also describes the using this information sources to generate cash flows. and enabling cash flow alternative generation with GSimX.

Next chapter describes an experimental test case that uses the described methodology to integrate cost, BOQ and schedule with BIM and generate using GSimX cash flow forecasts with simulation on BIM.

CHAPTER IV

TEST CASE

This chapter demonstrates the proposed approach on a building test case. It includes an Excel prototype for cash flow creation, 3D BIM modeling process, CPM schedule and BOQ integration with the 3D BIM model. It also shows the process of defining cash flow parameters according to contract payment terms, the simulation process of cash flow generation via GSimX and generation of cash flow alternatives and discuss the results while evaluating the alternatives to choose the most suitable financial plan.

4.1. Test Case Description and Data Preparation

The test case for the proposed approach is a medium size residential complex. The project contains two eight story buildings and a two-story building. The total budget for the test case project is around $8,000,000. The contract type for this test case is unit price and it compliant with FIDIC contracts. This project was delivered with significant variance in schedule duration and cost, which prompted consideration as a retrospective test case to be studied and analyzed in term of the financial matters. The goal is to investigate monetary status of the project if other financial scenarios and decisions were taken. Figure 4.1 is a screenshot from GSimX for the 3D BIM model of the test case.

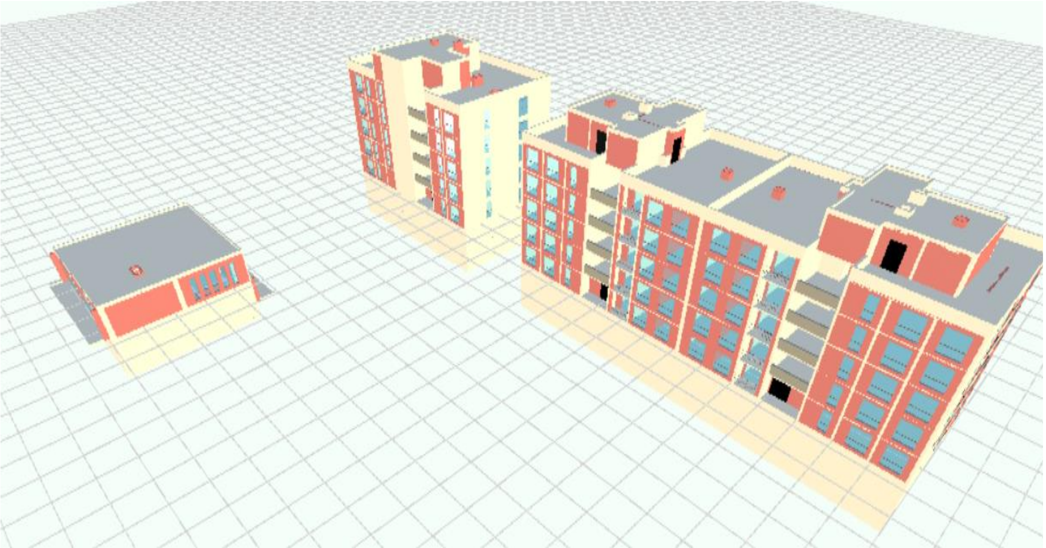

Figure 4.1 Test case 3D BIM model in GSimX

The test case has been prepared to demonstrate and validate the proposed approach of automatically generate construction cash flows using BIM and simulation. Several technical steps are required to prepare the test case data. Figure 4.2 shows the flow of information to prepare the test case model. Quantities of contract items are integrated with schedule activities to determine the duration of the activities. Project contract terms are defined in the Excel prototype and GSimX the same way. Payment terms were applied to all schedule activities to define the financial process between project parties.

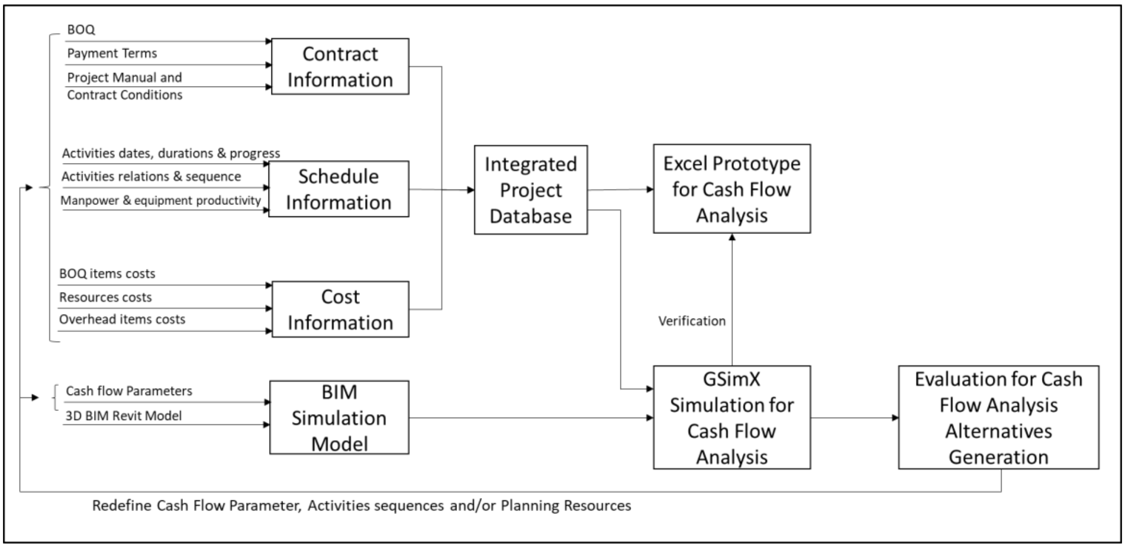

Figure 4.2 Information flow for the test case

Table 4.1 and 4.2 shows the proposed cash flow parameters and resources respectively for the test case. Each parameter for the test case has a significant role in shaping the cash flow and financial plan. The following tables also show a description and examples for cash flow parameters that have been added to the Excel Prototype and GSimX for cash flow generation.

Table 4.1 Test case cash inflow parameters

Cash Inflow Parameter	Test case values
Contract type	Unit price
Advanced payment, A_K	Owner pays to contractor 10% of the contract amount after the notice to proceed.
Retention, RG_K	15% retention deduction from each month invoice total.
Base Profit	15% of activity total cost

Table 4.2 Crew and equipment resources for the test case

Resource Name	Group	Max. Units	Standard Rate
Labor	Crew	10	$7.40/hr
Carpenter	Crew	5	$10.10/hr
Excavator	Equipment	1	$187.41/hr
Rebar	Crew	6	$10.10/hr
Electrical	Crew	4	$10.10/hr
Concrete	Crew	4	$10.10/hr
Plaster	Crew	4	$10.10/hr
Painter	Crew	3	$10.10/hr

As discussed earlier, Figure 3.2 shows the needed data to generate cash flow, with contract payment terms, planning resources, work sequences, BOQ, items cost and schedule data. Figure 4.3 shows a screenshot of test case CPM schedule showing all project main blocks, and more details about block M1-A activities.

This schedule is created in Microsoft Project and it includes the following:

1. Project activities: all project activities are listed in this schedule and classified as per its work type into three main categories: structural (concrete works), architectural (interior and finishes), and mechanical, electrical and plumbing works (MEP).
2. Activity relationships: the relationships and time lags are defined between project activities. Most activities are sequenced with Finish to Start relationship.
3. Durations: from project BOQ, the quantity of work was determined. Activity duration is calculated by assuming the productivity rate for each activity and work type. The total duration of each project activity is calculated by dividing work quantity over productivity rate.
4. Project resources: Available crew and equipment resources are defined in this CPM schedule with maximum available quantity, standard and overtime rates. In addition, resources per each activity are defined. Each activity may use multiple types of resources. For example, concrete slab activity contains concrete and steel as materials, carpenter as labors.

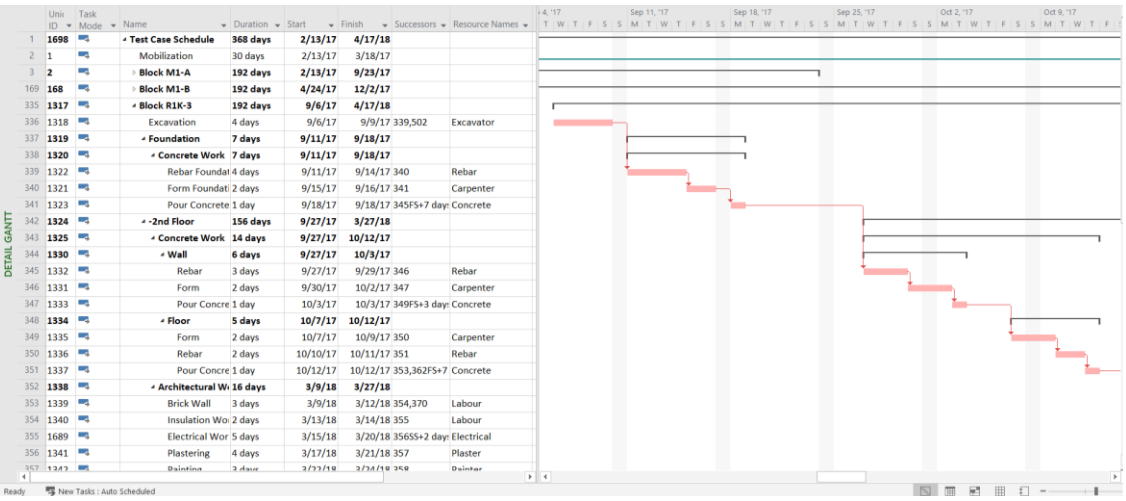

Figure 4.3 CPM schedule for the test case

4.2. Excel Cash Flow Analysis Prototype

This section discusses the steps to calculate cash flow for the test case through Excel with the data resources and assumptions. Figure 4.4 shows a sample from Excel sheet prototype for cash flow analysis of the test case. The Excel prototype covers part of the project, only two floors from the largest block (M1-A) were implemented for cash flow. Other BOQ or schedule data were ignored since they were not necessary for this cash flow generation.

Activities are imported from the project schedule and BOQ along with their durations, start and finish dates, resources cost information, and quantities. The total cost of activity is calculated by multiplying the items' unit cost with works quantity of the activity. Activity outflow payments for the Excel prototype were mainly assumed to be issued on daily basis, so the daily cost for each activity was determined by dividing the activity cost over its duration.

The cash outflow pattern that defines the recurring payments processing from contractor to suppliers or subcontractors is shown as daily for this sample, this means that the contractor will pay for subcontractors or suppliers on periodic regular basis for their work progress. Based on this, daily costs for each date can be identified for each activity. Cumulative cash outflow graph is illustrated by plotting the dates of activities time frame and their relevant periodic payments amounts.

The cash inflow calculation is similar to cash outflow. The cash inflow parameter values for the incoming payments from client to contractor are applied for the cash inflow pattern. For this test case, contractor's incoming payments are assumed to be received at the end of each month, so the amount of works according to the contract price are calculated starting from the end of the previous month works and so on. Since the contractor outgoing payments are issued and progressed, the same amount of works can be considered for the ingoing and outgoing payments. The difference is only the unit price between the ingoing and outgoing payments for each activity since the margin of profit or the contract price is used for the inflow payment works.

To consider the contract payment terms that defines the cash flow parameters, Eq's 1 to 6 in Chapter 3 are considered here to calculate the cash inflow payments. Each incoming monthly payment, client will apply the contract payments deductions such as advanced payment or retention deductions. The net cash inflow amount for each payment along with its rate is calculated, and cumulative cash inflow graph is plotted as a relation between cash inflow payments dates and amounts.

Figure 4.4 Cash flow generation in MS Excel prototype

The Excel prototype for cash flow generation as shown in Figure 4.4 is made to validate GSimX cash flow generation results and verify the applicability of the proposed approach. Cash flow alternatives for test case are evaluated according to contractor financial plan and abilities.

4.2.1. Excel Prototype Calculations

All financial data were entered manually for each activity starting from the quantities, dates and durations, costs, profits, resources, payment terms. For activity durations, sequence and dates; data was transferred from the project schedule to the Excel Prototype. Activities are also sequenced as in the schedule. For financial data like activity costs and their items unit price, resources costs; information in Excel sheet comes from either the BOQ or the schedule. Pattern of payments for activities was inserted to the Excel Prototype after studying the contract of the project and applying the payment terms of activities considering the payment delay period payment mechanism that specifies if it will be paid all at once or on several periods.

Cash inflow and outflow have been calculated through this Excel prototype by measuring the executed quantity at site for a specific period, and then multiplying this quantity with its unit price, the resulted number is the amount of works. Each value for the periodic amount of works is listed as a payment that is managed and issued according to the its defined payment delay period. In Figure 4.6, payment delay period is defined as 15 days for inflow and outflow payments. The cumulative cash inflow and outflow values are calculated by summing up each periodic payment with its previous amount.

The combined cash inflow and outflow diagram can indicate the test case financial status at any time period of the project. It can be noticed that the contractor will lose money by implementing this project upon the inserted financial inputs and scenario since the cash final cumulative cash outflow is higher than the cash inflow amount. This graph is created mainly to verify GSimX cash flow analysis results given the same inputs, which will be discussed in cash flow analysis comparison between Excel prototype and GSimX simulation (Khalaf and Akbas 2019). Cash flow analysis for the test case has been conducted through the proposed Excel prototype, the result is illustrated in Figure 4.5.

This method consumed a lot of time and many mistakes were found and fixed. For example, human error in entering wrong values for cash flow data of project activities are not easy to detect in these calculations.

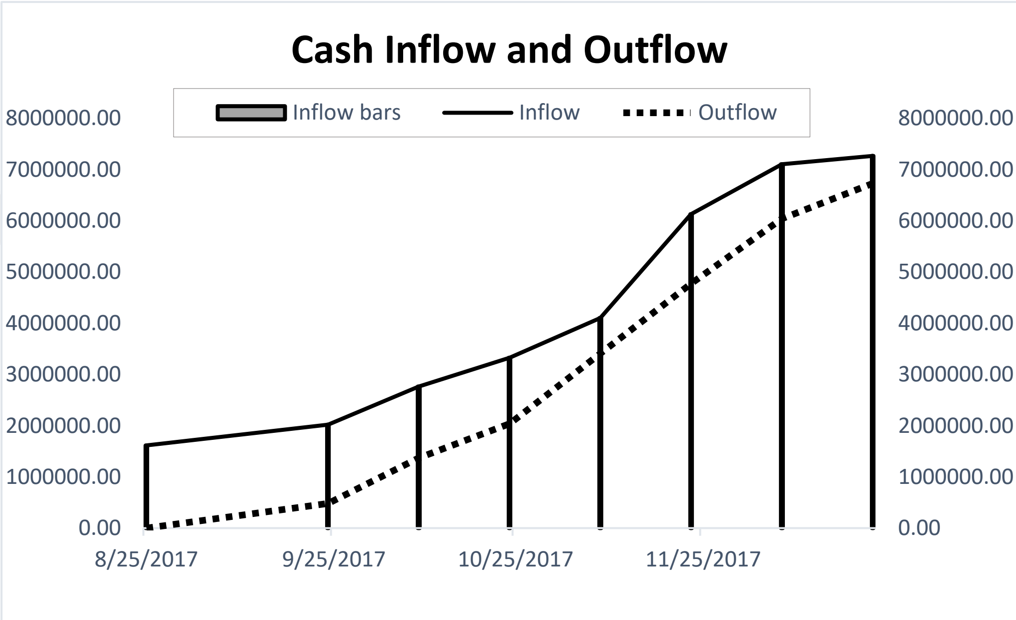

Figure 4.5 Cash Inflow and outflow for the test case by the Excel prototype

4.3. GSimX Simulation for Cash Flow Analysis

In order to generate cash flow analysis for the test case, certain steps were followed. Related finance and schedule project data was prepared and imported into GSimX along with the 3D BIM Model.

4.3.1. Data Input

To generate cash flow, two data files have to be prepared and imported into GSimX: MS Project file and 3D Revit BIM. The integration of project activity and resource cost/quantity information with schedule data is prepared in MS Project. Resources from Figure 4.1 have been defined within MS Project. Each resource has a maximum number of available units, either as number of crews or material quantity. Afterwards, Revit 3D model and XML exchange file exported from MS Project have been imported into GSimX. Each group of elements in the 3D BIM model has to be linked to related activities in the schedule. In case all elements are linked, activities resources and cost information will be integrated to 3D BIM model elements.

4.3.2. Cash Flow Parameters Definition

Cash flow parameters shown in Figure 2.1, Table 3.1 and Table 3.2 are important factors that shape the project cash flow. For this test case, cash flow parameters are defined as shown in Figure 4.6. Each parameter value is inserted as per the project contract payment terms. Those parameters values were applied for the first simulation run to generate the cash flow analysis for the test case. Once BIM model data integrated and cash flow parameters are defined, test case will be ready for the first simulation run to generate cash flow. The inserted cash flow parameters are applied for the first run in GSimX, the percentages and values are modified later on to generate the cash flow alternatives. In GSimX, project resources and items costs are loaded and integrated with the schedule according to each activity assigned items and resources. Activities and their relationships are also exported to Excel prototype and GSimX. 3D BIM model in GSimX is integrated with the cost and time information. All 3D BIM model elements are linked with their related schedule activity, cost information, resources and payment terms.

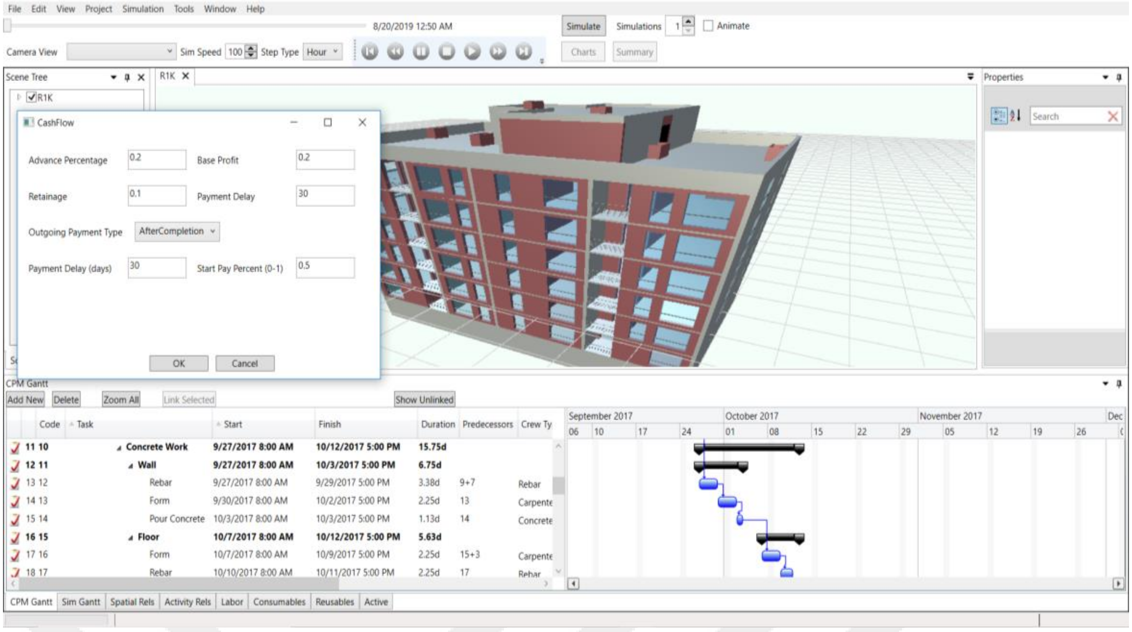

Figure 4.6 Cash flow parameter values for the test case

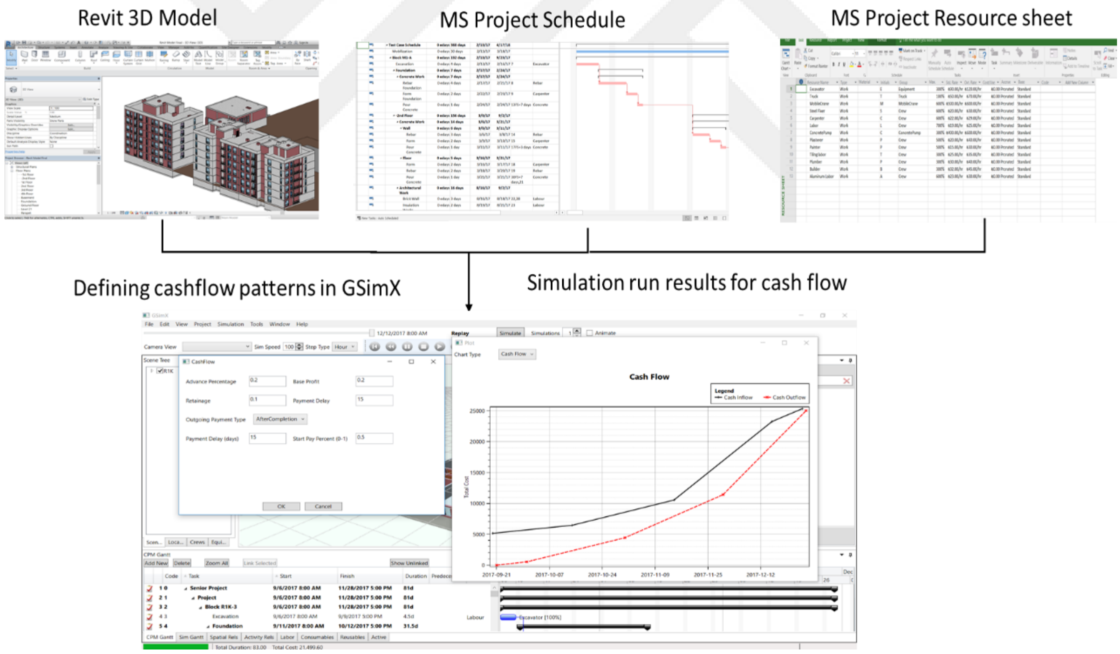

Figure 4.7 Cash flow generation process for test case through GSimX

4.3.3. GSimX Cash Flow Generation

An example for defining necessary elements for cash flow calculation is in Figure 4.6. GSimX identifies payments amount and dates for each activity location and sums up values by each payment period. As shown in Figure 4.7, each simulation run generates an S-Curve and cash inflow for the whole project showing graphs for the sequence of payments, their quantity and dates, with accumulated cash inflow. Cash outflow implementation within GSimX is currently in progress.

With the implemented cash flow parameters in GSimX (advanced payment percentage, base profit, retention percentage, and payment delay period), simulation generates cash inflow forecast graphs. We demonstrate that GSimX graphs and simulation results match the manual process results. After each simulation run, the cash flow for the test case shows in graphs and tables the expected financial status according to the input data. Stakeholders can study the results and decide if this scenario is acceptable, and if not, they can modify cash flow parameters and project data and run more simulation runs to get other cash flow alternatives. Moreover, as GSimX provides the ability to quickly modify the parameters and change the cash flow patterns to come out with different alternatives for the contractor, this will allow the contractor to adjust liabilities according to the company liquidity and financial capability (Khalaf and Akbas 2019).

4.4. Discussion of results

The results of this test case have been made by the Excel prototype and several simulations runs to generate cash flow analysis. Simulation has been performed considering the project original contract conditions and plan. GSimX generated outputs for possible alternative for cash flow analysis taking in consideration different defined cash flow parameters, planning resources or activities sequences values per each simulation run. Then, the generated results and identified parameters are analyzed and evaluated by construction project commercials participants.

4.4.1. Cash Flow Alternatives Through GSimX

Cash flow is shown to be easily and quickly generated in GSimX. Multiple cash flows for a project can be generated, so the project stakeholders, typically the contractor, can choose among several financial scenarios what looks more attainable to perform.

The generation of cash flow alternatives for the given test case follows the same described steps of cash flow parameters definition in GSimX; each alternative is generated by changing the value of cash flow parameters, planning resources and/or activity sequence for every simulation run. This enables implementing many patterns of cash flow parameters for simulation and analyzing the best cash flow alternatives consequently.

Figure 4.8 to Figure 4.10 shows three different cash flow simulation runs graphs were chosen as a sample for potential pattern of the payment terms for the test case. In each run different delay period of payments values have been entered as shown in the figures.

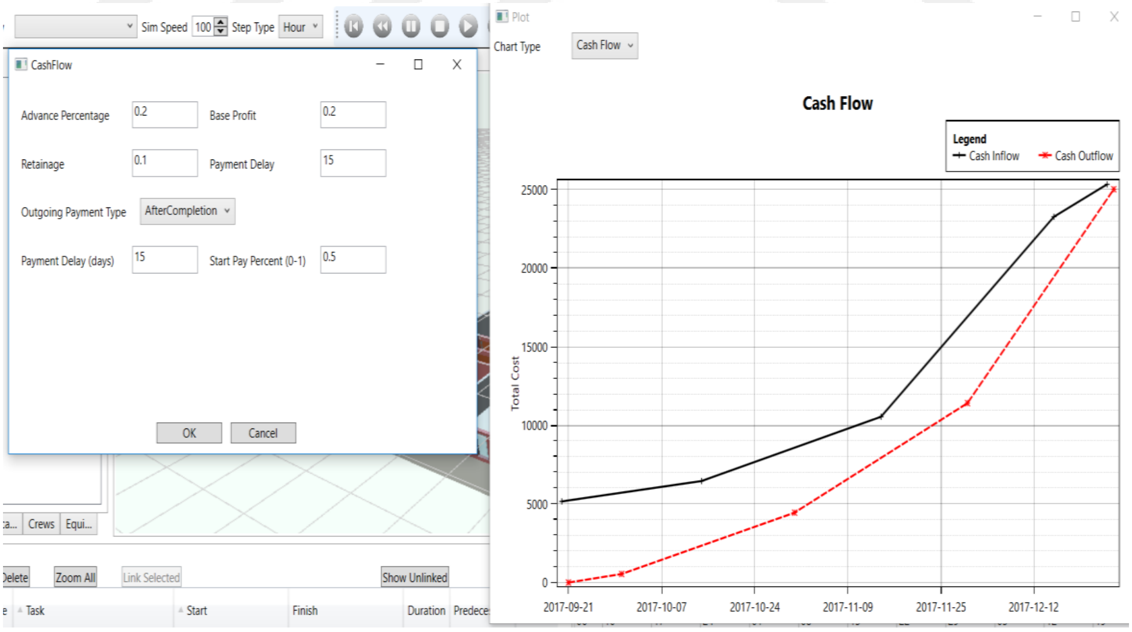

Figure 4.8 Cash flow alternative 1

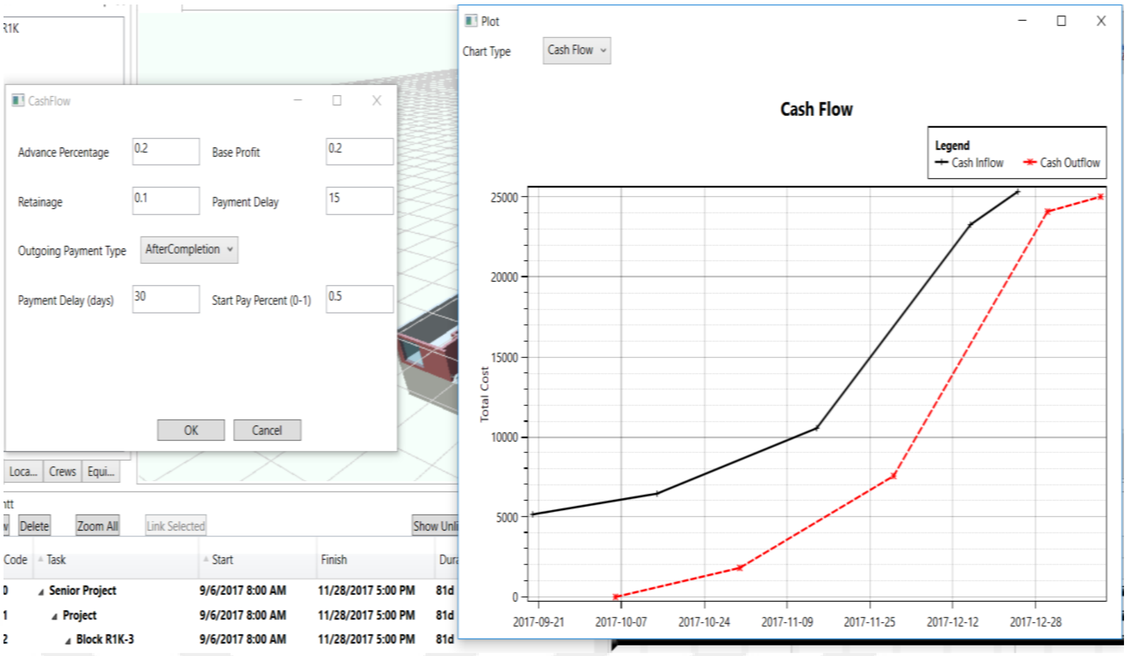

Figure 4.9 Cash flow alternative 2

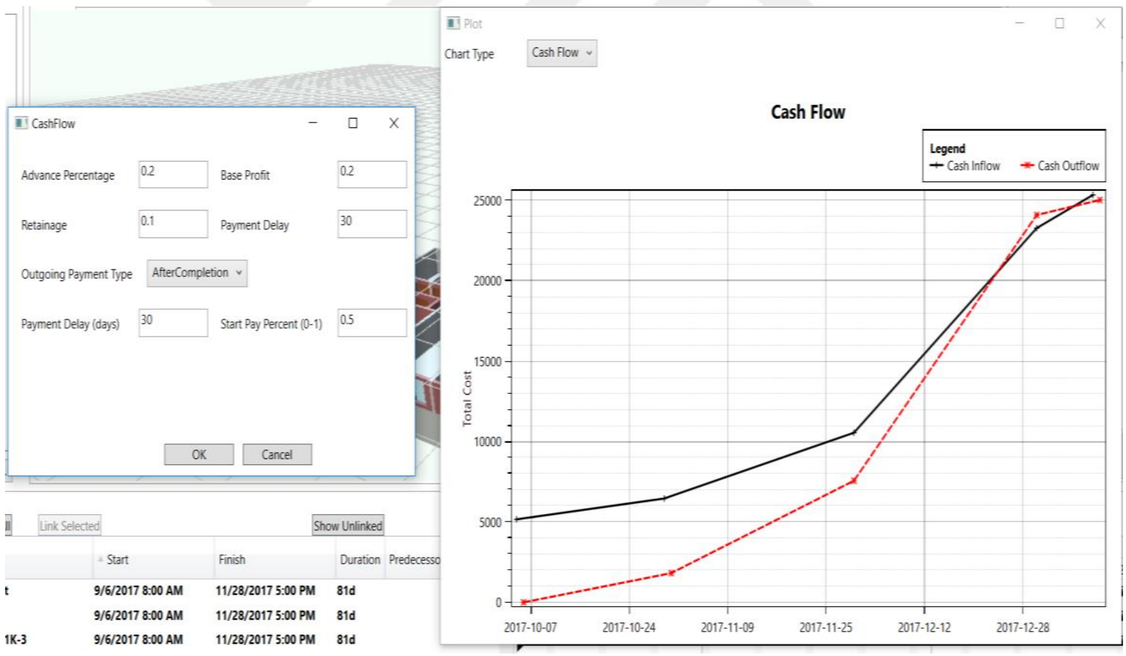

Figure 4.10 Cash flow alternative 3

These figures show that the effect of changing the payment delay period value on the cash inflow and outflow curves make them either more convergent in Figure 4.8, divergent in Figure 4.9 and crossing to each other in Figure 4.10.

In Figure 4.8, contractor receives his cash inflow in advance and stay in positive net flow, also his last outgoing payment is due in a close date for the last incoming payment. In Figure 4.9, contractor has more flexibility with his financial plan due to the longer period of payment delay. The figure also shows that the contractor has one-month gap between last incoming and outgoing payments. Figure 4.10 shows that the cash outflow curve cross above the cash inflow for a small period of time at the end of the project, thus, contractor financial status get into negative cash flow at the end of the project and then once he receives his last payments from client, cash inflow curve go back above the cash outflow curve. Normally contractors avoid negative cashflow and they prefer to receive money as early as possible and delay their outgoing payments as much as they can.

Another evaluation for the cash flow alternatives has been made using the Net Present Value method and its formula has been used to assess the periodic cash net flow data. This data has been exported from GSimX summary results of each simulation run given the same parameters that have been applied for the previous cash flow alternatives in Figure 4.8 to Figure 4.10.

Table 4.3 Net Present Values (NPV) for cash flow alternatives.

	Cash Inflow Delay Period	Cash Outflow Delay Period	Interest Rate %	
			0%	10%
NPV for Alternative 1	15	15	$313.42	$1381.80
NPV for Alternative 2	15	30	$313.42	$1563.27
NPV for Alternative 3	30	30	$313.42	$474.44

Table 4.3 illustrates the different results for the Net Present Values given the different interest rate for the cash flow alternatives periodic net flow payments. Cash flow alternative 2 has the highest value at 10% interest rate, which is consistent with Figures 4.8 to 4.10 in that it indicates the best alternative since the contractor get his inflow earlier and fulfills his dues the latest.

CHAPTER V

CONCLUSION

Current automated cash flow generation approaches for construction projects lack important features and have applicability challenges. The need for a computerized and automated tool to generate cash flows is significant especially for mega projects that are recently becoming more common. Also, the gap in coordination between project data and deviation between the designed and planned project and the on-site implementation is a challenge. This deviation is caused by design changes, site conditions, and resources availability to name a few. As a result, site management may face construction delivery delays, financial bankruptcy risk and significant waste of project cost and resources if planning and financial decisions are not based on a proper scheduling together with cash flow forecast.

In this thesis work, BIM integrated into construction financial and control systems is demonstrated for better and more effective cash flow generation process. This affords better design and construction information management system for cash flow generation process.

Through an effective BIM implementation in construction projects, the presented approach aims for better participation and coordination between different project departments from design to project delivery processes for cash flow generation. In this thesis work, BIM is used to manage and process project data such as design details, BOQ, specifications, project schedule and contractual aspects.

Although there are many studies discussing construction cash flow forecasting and analysis, practical use of simulation for cash flow generation is not common. In this thesis, existing simulation approach of GSimX has been extended to support the presented approach of cash flow generation. This multi-modal simulation platform on BIM, which implements discrete-event and agent-based simulation at the same time, can now generate cash flow alternatives. Also, to provide a better financial plan for project participants who aims to avoid risks during constructions, increase the project profit, achieve a better cash flow and maintain financial liquidity.

5.1. Contributions

Using the results of this thesis, project stakeholders will be able to apply this approach to generate cash flow forecasts, analysis and alternatives within a BIM environment through simulation scenarios. This provides an ability to verify the feasibility of the financial scenario and perform comparison with alternatives.

The proposed cash flow generation approach requires integration of the project BOQ, schedule financial and contractual data to make automatic generation possible. Moreover, it enables the creation of cash flow alternatives which can be analyzed and compared to illustrate the financial situation of the project.

This thesis work may enhance the financial perspective and cost estimation process, through generation of cash flow considering the cash flow parameters, cash flow alternatives, and evaluation of each alternative to select the one that is most convenient and applicable for the user.

Contributions can be summarized as follows:

(1) Identify necessary data for cash flow generation process, including cash flow parameters, integration of BOQ, specifications and schedule data and processing from

scheduling platforms like MS Project or Primavera and 3D BIM model. Additionally, describes the process of information management with coordination between design, planning and cost estimation data.

(2) Demonstrate through an MS Excel Prototype that can cash flow can be calculated given project data and parameters and use it as a baseline for evaluation for automated cash flow.

(3) Describe an approach to implement cash flow generation on a BIM-based simulation platform, which results in a faster and more realistic and parametric cash flow forecast. BIM-based simulation model contains all needed data for cash flow generation including the cash flow parameters, work sequences and resources.

(4) Describe ways to generate and evaluate cash flow alternatives based on project cash flow parameters, work sequences and resources allocation. This will allow selection of the best cash flow alternative and provide ways to approve project cash flow for better financial decision with less risk and more applicability.

5.2. Implications

This approach has a great potential in reducing financial risks on the contractor, accelerating the process of generation cash flows in the preconstruction phase, and improve financial decision-making process for projects. Applying this approach in construction will lead the contractors to be aware about their financial status before the construction starts and help them to avoid negative net cash flows as much as possible. This approach will also help contractors in negotiation process with owners before signing the contract for better payment terms. Owner at the end of the day aims to optimize the project design and related project matters such as the financial plan. When the contractor proposes the best cash flow alternative, owner would consider it for reducing the financial risks for project best delivery. Also, the contractor usually looks for different subcontractor or suppliers for executing project activities, when he becomes aware of the best payment terms to follow, he can also bargain with subcontractor and suppliers to consider the best cash flow alternative payment terms. Developing this approach will lead to cash flow related research for various aspects by considering parameters in cash flow generation through BIM and simulation.

5.3. Limitations

The proposed approach is tested on a residential project, which has a full 3D BIM model, cost and schedule information. Despite its advantages, this approach has certain limitations. First, it is difficult to create and prepare a simulation BIM model for other types of projects like heavy civil engineering construction projects such as infrastructure or pipelines. Moreover, the implemented activity costs and durations were assumed to be fixed, but those values are subjected for change due to the various uncertainties during the project execution. Another limitation is that the discussed cash flow parameters that are related mainly to the contract payment terms; other parameters like design changes effect on cash flow can be considered. Moreover, this approach does not optimize for the best cash flow alternative according a defined criterion of evaluation.

5.4. Future Work

This thesis aims to calculate improved cash flow alternative that considers main project constraints and cash flow parameters by enabling BIM and resource integrated location-based simulation approach. It does not calculate the best possible financial scenario, only the best among cash flow alternatives considered.

This work can be expanded with parameters that support larger set of cases and more ways to analyze cash flow alternatives. It is possible consider the contractor financial capabilities and automatically optimize through its simulation the best cash parameter alternatives considering the project constraints. Another potential area of research is analyzing financial risks and uncertainties for a project through stochastic simulation with GSimX and generated cash flow.

5.4.1. Cash Flow Automated Optimization

There may be very large number of generated cash flow alternatives because of the wide range of cash flow parameter values, possible work sequences and different resource allocation options. In this thesis, cash flow alternatives have been generated upon assuming different values for the cash flow parameters. Resulting alternatives were analyzed and the best-case scenario has been recommended. For future work, iteration for cash flow parameters values can be optimized and GSimX may provide the best cash flow parameters values automatically by analyzing cash flow alternatives under certain criteria that ensure the profitability for contractor. User can define preferred difference in values between cash inflow and outflow during the execution of the project and a liquidity limit to be inserted as a minimum value to improve results.

5.4.2. Stochastic Simulation for Cash Flow

As engineering projects have many risks, variations and deviation from the original plan, stochastic analysis has been implemented by other researchers earlier to provide more reliable forecasts. For example, scheduling for activity duration by giving a probable minimum, average and maximum values for each project activity. This may result in more realistic schedules. GSimX also supports stochastic production rates but that was not considered as part of this thesis.

Incoming and outgoing payments have different uncertainties like; payments delay period, materials delivery delay on site which might increase the duration of payment delay of activity duration itself. A similar simulation for different values can be applied for project activities to generate cash flow forecast that consider those uncertainties using statistical methods to provide more realistic results especially for activity durations, payment delay periods or time lag.

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VITA

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