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INTEGRATED BIM AND DES FRAMEWORK FOR EFFECTIVE TIME AND COST MANAGEMENT OF SLIPFORM OPERATIONS

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ABSTRACT

Effective management of Slipforming operations is critical due to operation's linearity that is considered a source of planning and proper cost management complications. This paper is presented to assist practitioners and researchers for automating the process of generation both time schedules and costs estimates simultaneously for Slipform projects by developing an Integrated BIM- based and DES software and framework. The BIM Schedule and Cost integrated (BSCI) framework reinforces both BIM and DES capabilities, enhanced by BIMs extracted information the quantities are used to generate DES input data in order to calculate the execution times for construction processes and exchange data through various software. Proposed research framework consists of: 1) Slipform BIM model that exports material quantity take-offs, schedules and required resources to an external database, 2) Discrete Event Simulation model encountering complete specification of the interdependencies between activities and resources and 3) Intelligent model that automatically collects, transfers and reserve data among various software programs. Furthermore, to illustrate the software's functionality a preliminary prototype was developed for a Slipform case of study and validation of the software was conducted for evaluation purposes that showed robust results of 98% for Schedule generation and 96% for cost estimates.

KEYWORDS: Building Information Modelling, Discrete Event Simulation, Integrated Frame work, Schedule generation, Detailed Cost Estimate

INTRODUCTION

Accurate cost estimating and schedule planning are two essential tasks of construction project management domains which directly drive construction projects success. (M. Konig et al.). Hence, in the past years several efforts were made by researchers to develop a model for schedule and cost integration in construction projects (Cho D, 2013). Although Schedule and Cost estimate share some common processes such as Quantity take off, that makes it capable to combine both processes in a single frame work, the lack of a well-developed integrated framework or system for both cost estimating and project scheduling, makes the two domains usually performed separately by construction practitioners (Cho K., 2010). Supported by the increasing popularity of Building Information Modelling (BIM), BIM-based tools for construction scheduling and cost estimating have been carried out and research studies focused on its application in the construction industry. Nevertheless, kind of development is limited to developing only one aspect such as project scheduling or cost estimating. Consequently, that leads to limiting utilization of those tools to the product element level, rather than the construction operation level. (Liu H., 2014). Therefore researches have focused on proper utilizing the power of BIM in both aspects through integrating BIM with construction operations simulation (Markus König, 2012), and (Weizhuo Lu T. O., 2014) .

However, while benefits derived from the operations simulation are recognized clearly, it is not being widely adopted by the construction industry, there has been a drawback of using the DES (Nils Bengtsson, 2009) and companies are failing to reap full benefits of this powerful technology (A. Skoogh, 2012) another obstacle is that such integration is also limited to one aspect of construction domains. One of the reasons for this lack of implementation is the amount of manual work needed to specify and maintain the interdependencies between activities and resources in the construction supply chain the process, moreover, development and maintenance is time-consuming, error-prone and it restricts the application of DES within the construction industry. (Yilin Huang, M.D. Seck, A. Verbraeck, 2011) Therefore for improving the simulation model flexibility and reducing manual and time consuming works for maintaining and editing the model the necessary input data could be linked with an external database where changes automatically appear in the model as discussed later on the Input data management for simulation models. On the other hand, one of the powerful capabilities of BIM as will be discussed later, is that BIM stores all related information in an external, accessible and reusable database where Information stored can be used further by other applications (Jongeling, 2008). Therefore the produced model provides is a data-rich parametric digital representation of a facility, from which relevant data needed to support construction simulation can be extracted and analysed (B. Ernstrom, et al., , 2006) and (H.M. Chen, 2013) Thus, BIM has the potential to provide a simulation model with design and planning data as the maintenance of simulation models has become very time-consuming, particularly due to vast amounts of data to be handled (Markus König, 2012).

This study presents a new methodology for proper management of Slipforming projects for Time and Cost project management domains by adopting an integrated framework using BIM (Building Information Modelling) -based technology and DES (Discrete Event Simulation) technique in both planning, follow-up of construction activities and for the cost estimate of the construction operation level in a single interface. In the proposed framework, a BIM product model in Autodesk Revit is integrated with a construction simulation process model EZstrobe for a Slipform operation where the objective of study is facilitating cost estimation and schedule planning. The research begins with a review of state-of-the-art research with respect to BIM technology, DES, detailed cost estimation, project scheduling, and. Second, detailed explanations pertaining to the proposed framework are presented, and a Slipform project is used as a test-bed to verify the integrated framework. Finally, findings from the mentation of the proposed framework are summarized, particularly as they pertain to potential future research.

BACKGROUND

Integrated DES by BIM

Discrete Event Simulation, referred to as simulation has proved to be an effective tool for complex processes analysis (Ericsson, 2005) besides being a well-established approach for analysing, scheduling, and improving construction processes in the AEC arena. (M. Jahangirian, 2010). In construction industry, there has been an increase in utilizing the application of simulations to support construction scheduling. (Markus König, 2012). It has been adopted as an effective technique in understanding the behaviour of systems and evaluating various strategies for their operation. One of the major aims that operations simulation is used in the construction industry is that DES assists in reducing resource idling time, improving resources utilization, site productivity and identifying logistics bottlenecks for storages and transportation. (Weizhuo Lu T. O., 2014). However, the management of data within simulation projects often becomes a major challenge. As multiple scenario analysis, a typical use of simulation models further escalates this problem as further data sets are added. (A.M. Law, 2007). Due to large amount of time consumed for gathering and extracting data in a DES model to ensure valid simulation results, there has been a decline in using DES as the effort required and costs spent on processing the input data from various data sources increases (Skoogh A. a., 2007) Furthermore, if simulation models are to be re-used then it is also necessary to keep the data sets up-to-date. This is a time-consuming process and, consequently, the re-use of simulation models is often abandoned (A. Skoogh B. J., 2009) and currently, this is considered as one of the most important obstacles for implementation of simulation in the construction industry (AbouRizk et al. 2011). In order to overpass this obstacle and benefit from the power of simulation modelling, Input data management of simulation models have to be simplified to encounter various scenarios and changes in the construction project. (N. Robertson, 2002) Identified four methodologies of input data management as shown in Figure .1 Since their study, published in 2002, there have been advances in the input data management process itself as well as in support systems such as data collection systems, databases, and simulation software. (A. Skoogh B. J., 2009). On the other hand, the process

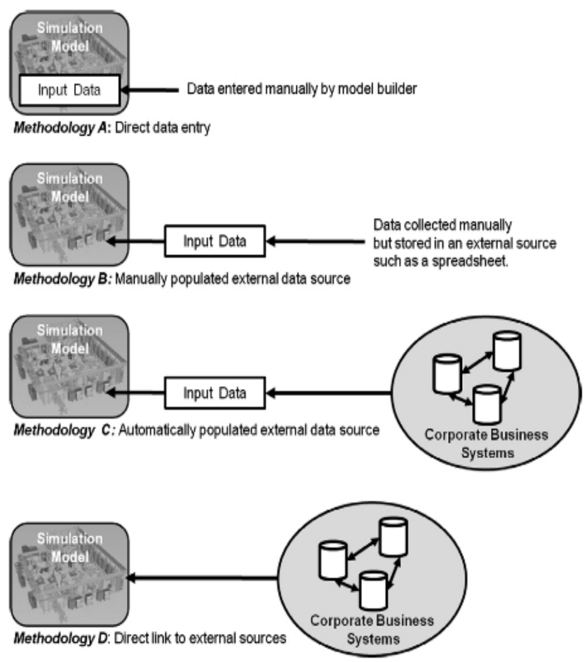

Figure 1. *Alternative DES data input methodologies*

of using BIM models to improve the planning, design and construction process is also referred to as nD modelling. BIM has the potential to facilitate the building of simulation models by providing essential input data from the design, bill of quantities and planning information, such as schedules, delivery dates and available resources (Markus König, 2012). Building information models are often used as shared data and knowledge resources to support planning, construction, management, utilization, revitalization, and deconstruction activities (Eastman, 2008). Currently BIM software like "Revit" platform supports Interoperability between the 3D BIM model and other software, where the BIM data can be exported from the Revit software through various connections and plugins to an external database in MS access. Motivated by previous research on database-driven simulations, (Skoogh A. a., 2007), (Balderud, 2008), (A. Skoogh B. J., 2009), this paper have identified BIM as a possible source of input data methodology from the third case illustrated earlier. Therefore the key for IDM is Interoperability, where it is defined as the ability to exchange data between applications, which smoothed workflows and sometimes facilitates their automation. (Eastman, 2008). Consequently, the integration between DES and BIM enforces capabilities of both systems, where BIM provides the product data in an appropriate format as for the DES data input for analysing and supporting scheduling and cost estimation of construction projects. Consequently, by Introduction of discrete event simulation the DES-based schedule approach has being increasingly utilized to support the generation of construction schedule at the on-site operation level, researchers are exploring potential means by which to integrate this approach with BIM. Exemplarily, (I-Chen Wu, André Borrmann, Ulrike Beißert, Markus König, Ernst Rank, 2010) developed a hierarchical process pattern approach for bridge construction. Process patterns are assigned to bridge components considering different levels of details. In This way, construction schedules can be determined by using an abstract simulation model based on the generated processes, including their interdependency and resource constraints. (M. Konig et al., 2012) presented a 3D BIM model that allows interactive assignment of construction methods to individual building elements. When reaching the finest detail level in the interaction process, activities and constraints (requirements to execute an activity) are created and used as inputs for a constraint-based simulation. Notably, they assume the quantities of required materials, such as concrete, reinforcing steel, and forms, for each activity are derived from the geometry of a 3D model. (I-Chen Wu, André Borrmann, Ulrike Beißert, Markus König, Ernst Rank, 2010) Presented a Building Information Modelling (BIM) and DES framework to enable the implementation and integration of DES in the planning and follow-up of construction activities, The framework consists of: (1) A building information modelling process that exports material quantity take-offs, schedules and required resources to a relational database and (2) an intelligent simulation engine that automatically reads information from the database at the start of each simulation run. (Weizhuo Lu T. O., 2014).

BIM- based Cost Estimate

Cost estimate is generally referred to as the task of determining the quantities of work to be performed, with the production rate and cost of the resources required to perform that work (Al-Mashta 2010), moreover it encounters the process of predicting the project cost at the workface level based on detailed design drawings/documents and specified construction methods/specifications Due to the fact that the internal steps of the Cost estimating process do not follow a commonly adapted structure, Researchers and practitioners are not committed to specific steps through the cost estimating process. Nevertheless, traditionally quantification is the first step for cost estimation of building projects. This first step is a time consuming task, according to (Autodesk, 2007) it consumes almost 60 % of the cost estimator's time on a project. In order to develop quantity takeoffs, estimators typically begin by digitizing the drawings or doing manual takeoffs. Being conducted manually quantities of design elements are measured based on the design drawings or the 3D model, and this manual quantification is highly error-prone. (A, Monteiro A. and Martins J. P., 2013) These methods introduce human error potential and propagate any inaccuracies there may be in the original drawings. (Emad Elbeltagi et al., 2014) Therefore by using a Building Information Model instead of drawings, the takeoffs, counts, and measurements can be generated directly from the underlying model. Therefore the information is always consistent with the design. And, when a change is made in the design, it will automatically ripple to all related construction documentation and schedules, as well as all the takeoffs, counts, and measurements that are used by the estimator. The second step task is to assign applicable unit cost regarding direct costs based on historical data or resource enumeration. Historical data can be collected from previously executed projects or obtained from third parties: manufacturers, subcontractors or database references in accordance with the specified construction method (Al-Jibouri et al., 2003). Direct cost is obtained by multiplying quantities with unit cost; other costs, such as indirect costs, are calculated by taking a percentage of the direct cost. Finally, project cost is calculated by summing up direct cost with the other costs mentioned above.

BIM- based Schedule Planning

Detailed schedule planning is the processes including identification of WBS for construction schedule, quantity survey, assessment of productivity, calculation of activity duration, and determination of construction sequencing logic and project duration in order to plan the construction schedule. In the last decade, research efforts have been developed from traditional 3D CAD model supported construction planning to BIM models with enriched information-based scheduling (De Vries, 2007) . Nevertheless, these researches are only limited to produce construction schedules at the product component level, not at the construction operation level. Recently with the technological advancement and prevalence of building information modelling (BIM) and 3D modelling in the architectural, engineering, and construction (AEC) industries new opportunities exist for improving scheduling processes. By combining the built-in intelligence of BIM with previous research efforts we can further advance the accurate generation of schedules. Currently, scheduling is still mostly accomplished manually, which can be an extensive and very time consuming process. (E. Tauscher, 2009). Today, with the discrete event simulation-based schedule approach being increasingly utilized to support the generation of construction schedule at the on-site operation level, researchers are exploring potential means by which to integrate this approach with BIM. In fact, given that cost estimation and schedule planning share some common processes, such as quantity takeoff, it is possible to combine these two processes to develop a single integrated information framework for detailed cost estimation and project scheduling. (Cho D, 2013)

Time and Cost Integration Utilizing BIM

As previously described, quantity takeoff is part of the cost estimation process. Most research regarding BIM-based quantity takeoff has actually been conducted to serve the purpose of cost estimating. Besides quantity takeoff, however, another challenge entailing a considerable amount of manual work in estimating is to find and apply appropriate cost data to the takeoff. To date, various models and systems through which to integrate cost and schedule have been developed, including an integrated cost and schedule model for repetitive construction processes (Cho K., 2010), a schedule and cost management system for steel structural construction (M.H, 2000), and an integrated database framework for cost, schedule, and performance data (Cho D, 2013).Nevertheless, these efforts have sought mainly to manage and control the construction process during the project execution stage, whereas detailed cost estimation and construction schedule planning, as two main concerns for construction project management demand a large amount of effort during the planning phase. Given that the QTO is a common factor between both Cost and schedule planning, this research utilizes the benefits of QTO in combining both cost estimate and schedule planning in a single frame work by the integration of BIM and DES. Consequently, an integrated system with the support of BIM and DES for detailed cost estimation and schedule planning would improve project planning efficiency during the planning phase and benefit all the stakeholders involved.

INTEGRATED FRAMEWORK MODULES

The integrated framework is built upon a developed author's software program that performs certain mechanisms that can collect, store, and transfer data (including the material quantities, task durations, and simulation inputs/outputs) among various software packages. Figure 2 presents the framework of the proposed system, in which the process of generating and managing information is described by using six modules, The details of each module are provided in case study at Section 3.The following sections provide a brief explanation of each module.

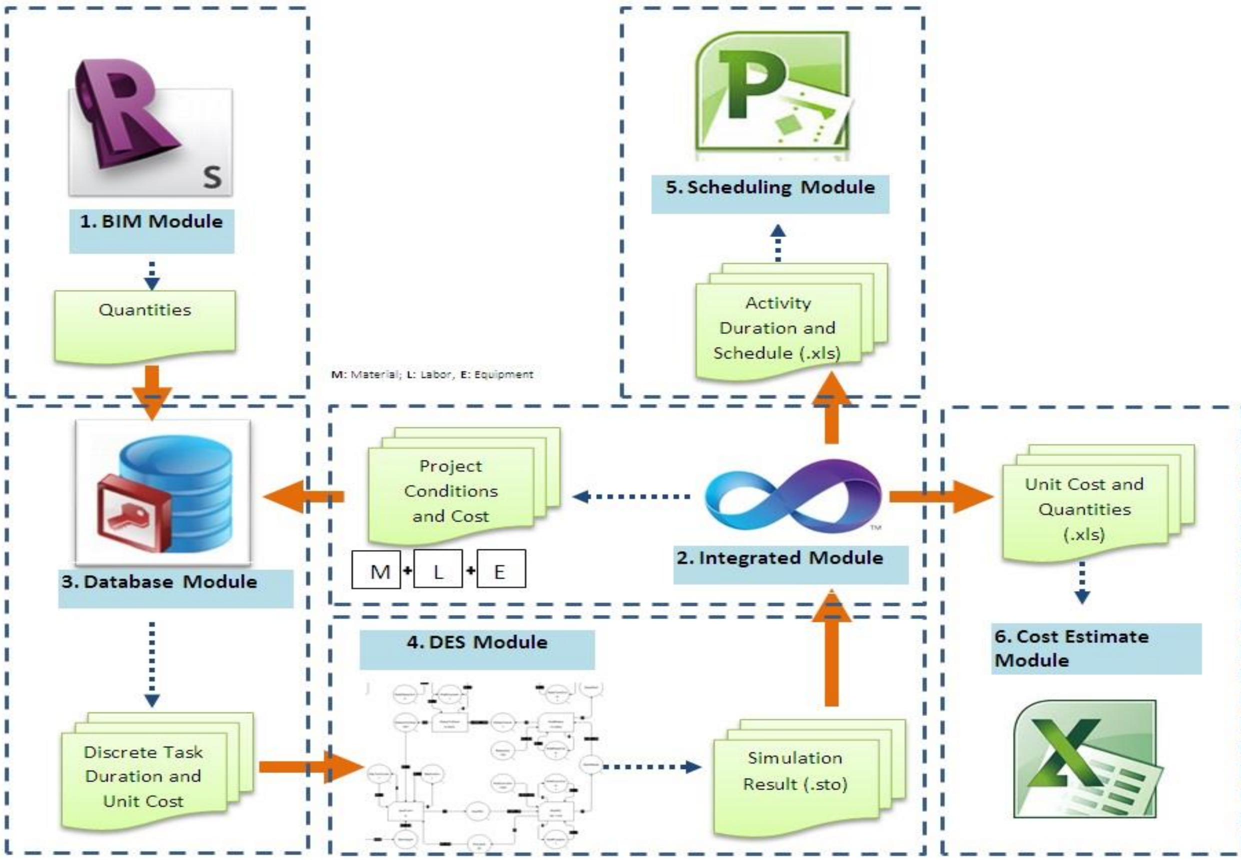

Figure 2. *Proposed System Framework*

BIM Development Module [BM]

The BIM module applies Autodesk Revit Structural 2014 to establish the BIM model of a silo construction project. This BIM model provides geometric data (i.e., length, width, and height) of each building component (i.e., Foundations, walls, and slabs) to support quantity takeoffs \. As a result, the developed BIM model stores the quantities of materials (including reinforcing steel, forms, and concrete) required for erecting foundation raft, walls, and slabs. This Module performs two major actions, first, developing the structural module of building using the selected software, second, generating the quantities take offs through various solutions. Although there are three main options to strengthen BIM for quantity takeoff and to support both cost estimate and schedule planning, that include: (1) Export building object quantities, (2) Link the BIM tool directly to scheduling or estimating software and (3) Use a BIM quantity takeoff tool. This research focuses only on the first option; Export building object quantities, as Most BIM software tools include properties for extracting Quantity take offs from the BIM Model to a spreadsheet or an external database. Nevertheless, this option requires significant modelling process as sufficient and complete information on the object models in order to generate the error-free QTO information from the model (Eastman, 2008).

Integrated Time and Cost Module [IM]

The proposed BIM Schedule and Cost estimation Integration module (BSCI) is the core of the entire system; it is developed by using (C+) sharp programming language. The BSCI module integrates the BIM model data, the MS Access database, the EZstrobe simulation language, MS Excel, and MS Project. Figure 3 illustrates the software's overall flowchart process of generating a construction schedule and detailed cost estimate. The Module interface is shown in Figure 4 where the interface is composed of seven six steps, these steps are generally categorized in to two main components: (1) Log-in component and (2) Module Main Functions component. The following section illustrates the components and functions.

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1. Module log-in component; This component automatically captures the BIM model data stored in the MS Access and utilizes it for generating the activities durations required for scheduling support. This can be referred to in the interface by Step 2, A "Quantities".
2. Module main functions component; This can be divided into three major functions as user data input for project conditions; activating discrete event simulation and saving results and generating the schedule and cost estimate reports.

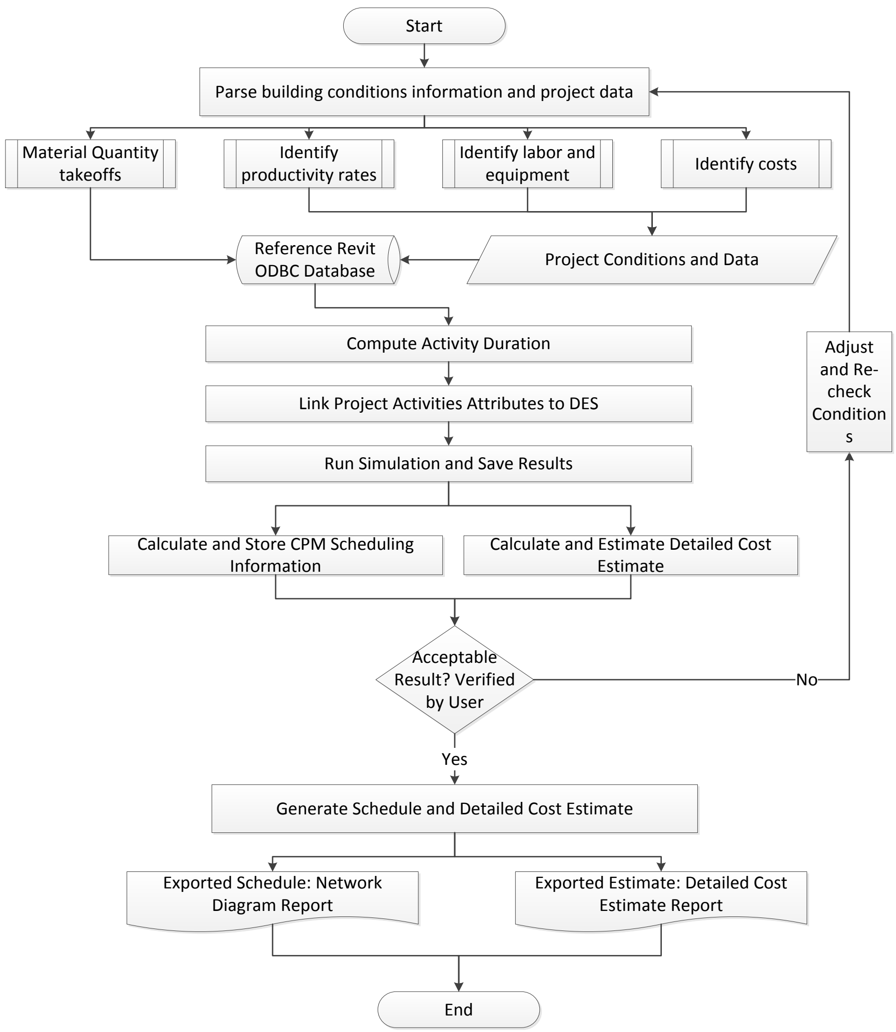


Figure 3. *Integrated module software flowchart*

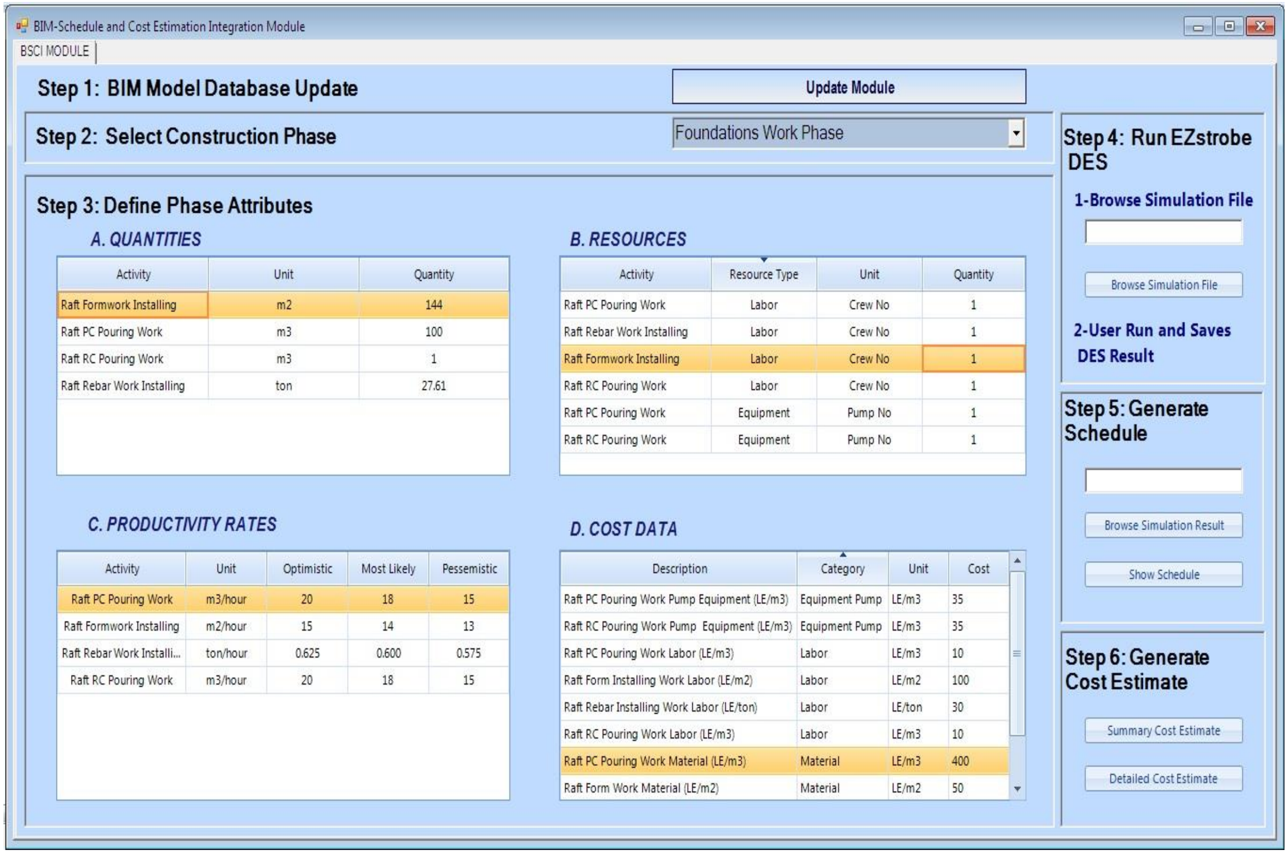


Figure 4. *BIM Schedule and Cost Integration Module (BSCI) Screenshot for Foundation work Phase*

The module interface steps are named in the interface from step 1 to step 6 in Figure 4, steps illustrations are discussed as follows:

1. Step (1): BIM Model Database Update;
- This step refreshes the BIM model database and links the model data to the interface to generate material quantities as discussed later in step no.3.
- Update Module Button checking is mandatory in case of any changes to the BIM model and therefore the database, while optional in case of no changes to BIM model.
2. Step (2): Select Construction Phase
- This step allows the user to select the phase to define its attributes i.e. (quantities, resources, productivity rate, etc.)
- In this project there are four phases user can select to add data, edit data or delete data from.
3. Step (3): Define Phase Attributes
- This step defines each project construction phase related attributes for each phase as following:

1.*Quantities*

This step generates the project material quantities automatically by retrieving the quantities from the BIM model exported database and inserts data according to phase in table A. this table automatically changes in case of any change occurs to the BIM model quantities.

2.*Resources*

This step allows user to define the project required resources as for Labor and Equipment required for project. Consequently user defines the Number of Crews for various tasks Concrete works, Form works, as a number (i.e. etc. No of steel crew s for raft foundation is One (1) Crew set) and also defines the amount of Equipment required during construction for tasks such as Crane, Pumps, etc. (i.e. etc. No of Concrete Pumps for raft foundation is One (1) Pump).

3. *Productivity Rates*

Software allows user to define each activity production rate based upon project special circumstances. User defines the required PRs based upon three points estimating for each task. With the three point estimate the user defines three productivity rates values an optimistic (O), pessimistic (P), and (M) most likely for each task as (unit/time). (i.e. the three point estimates for PC concrete pouring are (O) 25 m^3/hr, (M) 20 m^3/hr and (P) 15 m^3/hr).

4. *Cost Data*

For each phase user defines the costs based upon (1) Direct costs; Material Cost (MC): Cost of construction materials such as concrete, rebar and forms as EGP/unit; Labor Cost (LC): Cost of activities Labor such as concrete placing crew, rebar crew and formworks crew as EGP/unit or EGP/hr; and Equipment Cost (EC: Cost of equipment used in project such as crane and pumps as EGP/hr or EGP/unit. (2) Indirect Costs; it is notable to mention that indirect costs are inserted based upon percentages of the total construction fees, In this research indirect cost includes but not limited to the following; Engineering Fees (EF), Goods and Service Tax (GST), Permits (PR), Payrolls (PY), Insurance (IS) and over heads and profits (OH).

4. Step (4): Run Discrete Event Simulation
   - After generating input data for DES the BSCI module then transfers the generated simulation input data to a pre-defined Simulation Model, in order to run the EZstrobe simulation. This step allows user to operate and open the Discrete Event Simulation file and automatically run the simulation to produce required results related to schedule and cost estimate
   - Data transfer from database to the EZstrobe that runs through MS Visio interface is conducted through a built in feature in Visio named "Database Wizard" where each data is mapped to the simulation model similar item i.e. "Raft PC" duration in data base is mapped to simulation model COMBI "Name" and "Duration" through database wizard. This operation is repeated for all DES elements till the model is fully synchronized with the data in database and moreover the BIM quantities leading to flexible data extraction method.
   - This step is presented by first browsing the required simulation model location by clicking (Browse DES Location) button, then system automatically refreshes the database wizard to Map input data from database to DES model. After data is transferred to DES model then BSCI runs the EZstrobe simulation model and automatically saves the results in (.txt) format that can be retrieved through an Excel file.
   - This Excel file is also pre-formatted so that it can be retrieved by MS Project for further scheduling analyses and moreover for the cost estimate.
5. Step (5): Generate Schedule
   - This step allows user to browse the simulation results saved in an Excel format in order to map the results to a MS project file to generate the project schedule.
   - This step presents the main results required for achieving this research's objective schedule generation.
   - Show schedule button automatically presents a schedule report produced by the MS project scheduling software, showing the project activities start and end dates and total project duration encountering various calendars.
6. Step (6): Generate Cost Estimate
   - This step allows user to produce the project cost estimate based upon the project actual quantities derived from the BIM model and costs inserted by user in the Data Input step No.2.
   - Summary Cost Estimate button produces a summary estimate report for the project where main direct and indirect cost categorizations are presented in the summary estimate at a high level showing grand total sum of various elements i.e. Labor, Material, Equipment and Indirect costs.
   - Detailed Cost Estimate button produces a detailed cost estimate by presenting a detailed BOQ for every work item presented in the schedule report and showing the decomposition of each item under Labor, Equipment and Material Category.

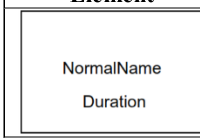
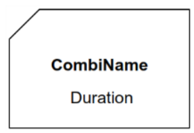
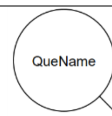
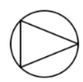
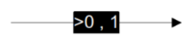
Database Module [DM]

Database module creates direct links between the Revit structure software that utilize the middleware interfacing capabilities to integrate BIM tools. These capabilities include Open Database Connection (ODBC), Component Object Model (COM) and some proprietary interfaces such as Geographic Description Language (GDL) and Micro Station Development Language (MDL) (Eastman C. M., 2010). These binary-interface programming languages link BIM tools accessible to each other for sharing data and information in the building model. Although various capabilities, this research focuses on the Open Database Connection, consequently, all project objects quantities (foundations, walls, etc.) are automatically exported to MS Project which represents project activities through the ODBC. MS Access in the proposed system represents a central data base where all other modules can export/ import data from it. Imported data are such as "productivities, Labor, project conditions, etc." while exported data are "durations" sent to DES module and "Costs" sent to Cost estimate Module. With respect to the integration with DES module, simulation result objects and its associated data (schedule, cost… etc.) can be exported to excel file to prepare the pre-defined schedule interdependencies between activities to be ready for mapping in MS project and generate schedule. Process of transferring is based upon mapping method, where Database wizard assigns each Visio object to its related database element for both Combis and Queues.

Simulation Module [SM]

EZstrobe discrete event simulation software has been applied through the proposed system in order to conduct the site-level simulation of construction operations. DES can be used to evaluate competition among resources and problems related to uncertainties (D.W. Halpin, 1992). Uncertainties through this research considers the effect of varied productivity rates of construction tasks, thus the DES model is able to generate probabilistic durations of tasks through variable Construction conditions as it will be explained later. Moreover, there is competition among resources; for instance, cranes are shared for the tasks of hoisting reinforcing steels for walls, and slab, and crews of rebar workers are considered competitive for these same tasks. In addition to schedule support the DES can support Cost estimate of construction projects through providing valuable information on resources utilization and crew idle times through the project execution period, moreover DES provides crews and equipment working time that assists in calculating direct costs related to Labor and Equipment criteria. The proposed system focuses on the structure part of Silo construction for the following elements "Foundations, Walls and Slab".

Table 1. EZstrobe Basic Modeling Elements

Element	Name	Description
	Normal	Unconstrained in its starting logic and indicates active processing of (or by) resource entities.
	Combi	Logically constrained in its starting logic, otherwise is similar to the NORMAL work task modeling element.
	Queue	QUEUE Represents a queuing up or waiting for the use of passive state resources
	Fork	Probabilistic routing element. It typically follows an activity but can also follow another Fork.
	Draw Link	Connects a Queue to a Conditional Activity.
	Release Link	Connects an Activity to any other node except a Conditional Activity.

An EZstrobe input file (formatted in a .sto file) that reflects Slipform RC construction is considered as a template where it allows practitioners and researchers to include of additional templates that reflect various types of construction operations (for example, steel-reinforced concrete construction and pre-assembled construction). A major benefit of using EZstrobe in simulation is that a simulation can be run for several times corresponding times of the duration of a project's completion will be automatically generated. Further details of the operations simulation that is applied in this work is presented later. Building a model walks through the following procedures,;(1) Drafting the model and sub model circulation using simulation software (EZstrobe); (2) Insert input parameters using IDM through Intermediate Database; (3) Insert required results formula; (4) Run the simulation and (5) Analyse the results to obtain required outputs. The case study presented in Section 5 illustrates further details of the operations simulation that is applied in this work. The elements of EZstrobe, originally developed by (J.C. Martinez) are used to model and simulate slip-form operations. As shown in Table 1. The program simplifies the simulation modelling process and makes it accessible to construction practitioners with limited simulation background (Hajjar, 1997).

Time Module [TM]

It is necessary to consider the uncertainty of construction projects when the duration of each work package is determined. Generally, There are two techniques to address uncertainty in construction scheduling on the basis of the probabilistic analysis, namely, program evaluation and review technique (PERT) and Monte Carlo simulation (MCS) (Ock, 2010). Based upon three point estimates the durations generated from the database module are those that represent the time schedule activities durations. The scheduling was developed to determine the project duration of Slipform projects.

Generation of project schedule module starts after simulation analysis module has generated the simulation result report. Then that file is transferred to a (.txt) file where the construction sequencing logic of the schedule is determined manually based on authors' experience and imported in an excel file that defines the schedule in advance. BSCI module automatically transfers simulation results to a MS project output file to generate schedule of Slipform project. The construction tasks defined in EZstrobe simulation model are also the activities in the MS project schedule. The generated schedule can be either transferred to a high level or a more detailed schedule through grouping and creating mile stones as required by user. Therefore, after the activity quantities, names, durations, and sequences are defined, the output can be produced. The system exports activity list of data to the format of a Microsoft Project file. The activities are defined by phase constructed and then by element. This also produces a Gantt chart and network diagram with the critical path indicated.

Figure 5 presents the generation of schedule activities approach where; step (1) results are produced after DES run and; step (2) activities durations and sequence are connected to the pre-organized schedule in excel file. MS project has the capability to generate schedules by mapping relevant data from excel file with a definite order to facilitate the schedule generation. Therefore the order and type of data imported to the excel file from simulation result has to be considered carefully.

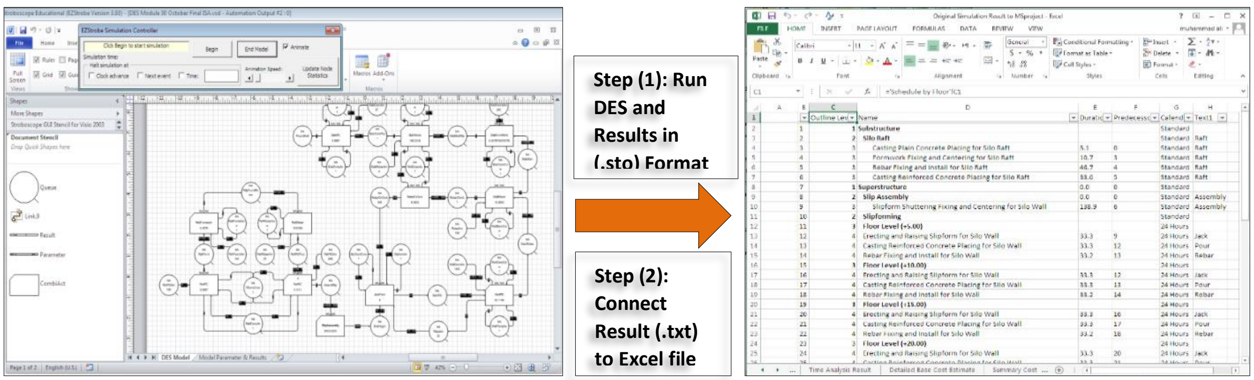


Figure 5. *Generating Preliminary Schedule Cycle*

Cost Module [CM]

The cost-estimating module is designed to estimate the project cost for the Slipform construction project with respect to two aspects: (1) the direct costs and (2) indirect costs.

1. Calculating Direct Costs

Direct costs in the estimation are grouped into three categories - namely, Labor (LB), material (MT), equipment (EQ) and subcontractor cost (SB) are calculated separately, following Equation (1), nevertheless the Subcontractor cost is eliminated through this study

$$Direct\ Cost_{\ t} = \sum_{t=1}^{n} C_t \times Qty_t \qquad (1)$$

Where, t in Equation (1) represents the category of cost, (Labor, material, or equipment); n is the number of cost items, C is the bare rate from User cost input as described earlier in the Integrated module; and Q denotes the quantity from the BIM model. Equation (2) presents an expansion of equation (1) showing in detail separate elements.

$$\text{Direct Cost}_{\text{ total}} = \sum_{t=1}^{n} [\text{C(MT)} + \text{C(LB)} + \text{C (EQ)}] \times \text{Qty} \qquad (2)$$

2. Calculating Indirect Costs

Indirect costs are calculated by taking a percentage of the basis. The assumptions pertaining to various types of indirect costs considered in the project and the cost results are presented. In general, the indirect cost consists of the general overhead costs and the job overhead cost; moreover, the indirect cost is be calculated by multiplying the direct costs and the rate of indirect costs (Holland and Hobson 1999). This research has categorized indirect costs in to Engineering Fees (EF), Goods and Service Tax (GST), Permits (PR), Payrolls (PY), Insurance (IS) and over heads and profits (OH).

CASE STUDY PROTOTYPE

To demonstrate the software model capabilities a Slipform case of study was chosen to apply the proposed software to a silo project located in Bandar Abbas, Iran for the Hormozghan cement factory project. This building built with Slipform concrete and has a height of 50 m and duration of 14 days of Slipforming the concrete shell by an average productivity of 0.15 m/hr. Table 2 presents the case of study. The following subsections present the evaluation results of this case study.

Table 2. Case of Study Data

No	Activity	Duration (min)
1	Jacking Rate (min)	5
2	Concrete Placing (min)	Triangular [7,7.5,7.8] (Crane) /m^3
3	Rebar Installation (min)	Triangular [7,8,9]
4	Material Lifting (min)	Triangular [5,6,7]

BIM Model Development

First, a 3D BIM-based model was built using Autodesk Revit Structure, as shown in Figure 6. This BIM 3D model provides the relevant parameters (such as length, width, height, area, and volume) needed to perform the quantity takeoffs of the weight (in tons) of steel, the area (m) of the forms, and the volume (m^3) of concrete for each construction element (i.e., column, beam, wall, and slab). As indicated earlier, the quantity take-off process is performed using mathematical equations that are already built into Autodesk Revit, or are provided by the proposed system. Second, through the data-exporting function of Revit (ODBC), the calculated material quantities of each building element is exported to an MS Access file where data is stored and retrieved by software on step 2, Quantities section..

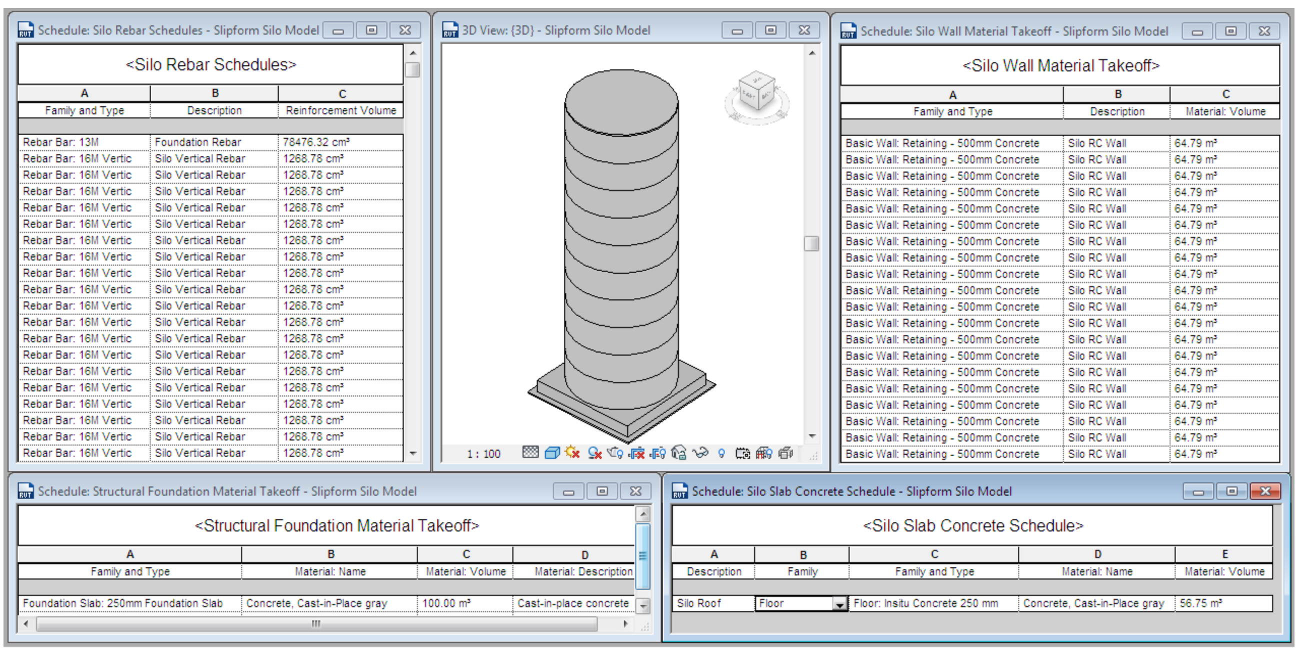


Figure 6. *Case of Study 3D BIM Model*

Define Project Phases Attributes

As illustrated earlier the user manually inserts the phase's attributes (Resources, Productivity rates and Cost Data) as shown in step 2 in Figure 4 as for four work phases. Figures 7, 8, 9 and 10 presents the phases attributes for Foundation Phase, Slip Assembly Phase, Wall Slipforming Phase and Slab Work Phase. In this step users can

1. Input the number of the sets of crew workers and the number of equipment step (B. Resources)
2. Input the three point values of productivity step (C. Productivity Rates), for each task. These productivity data were provided by the contractor's supervisor of this case project. For instance, the optimistic, most likely, and the pessimistic productivity levels for placing the reinforcing steel for the raft foundation work are 625.01, 600.26, and 575.50 kg/man-hour, respectively

3. Input the cost data as cost per unit for each Item step (D. Cost Data), For instance the cost of Concrete material for foundations RC pouring is 500 EGP.

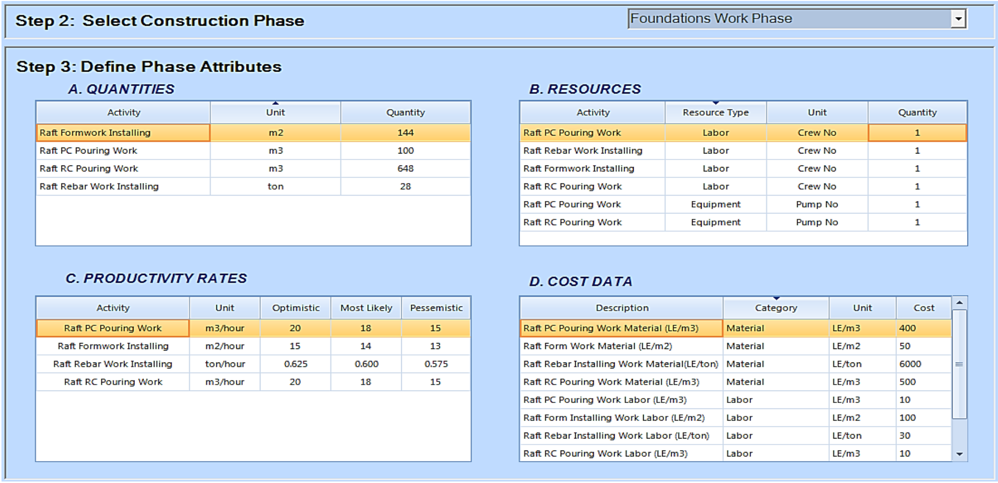


Figure 7. *Foundation Work Phase Attributes Data (Module Screenshot)*

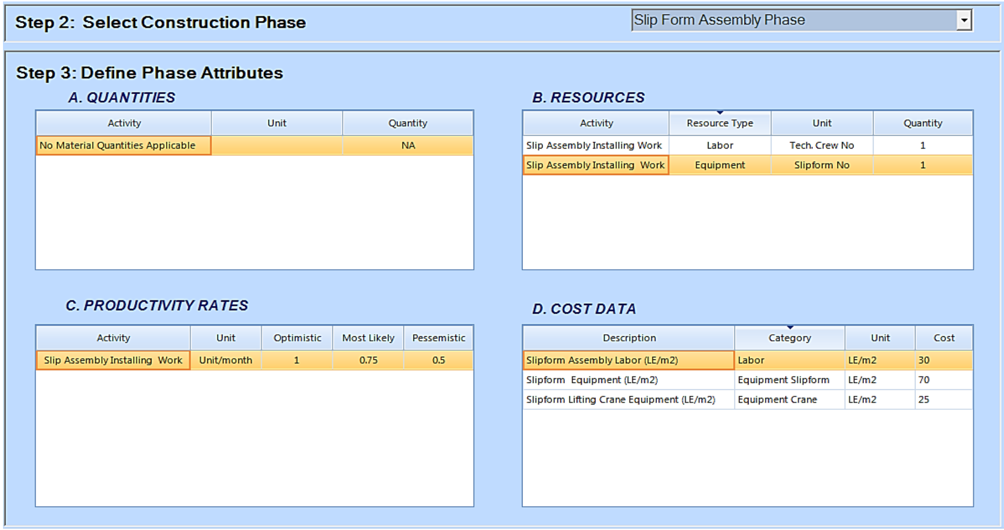


Figure 8. *Slip form Assembly Work Phase Attributes Data (Module Screenshot)*

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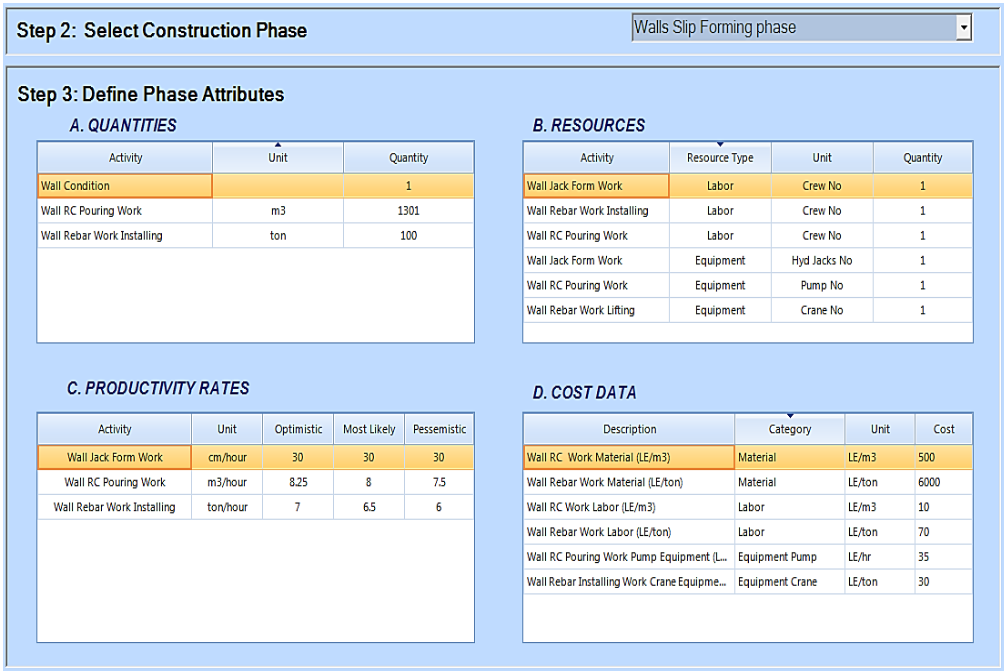

Step 2: Select Construction Phase — Walls Slip Forming phase

Step 3: Define Phase Attributes

A. QUANTITIES

Activity	Unit	Quantity
Wall Condition		1
Wall RC Pouring Work	m3	1301
Wall Rebar Work Installing	ton	100

B. RESOURCES

Activity	Resource Type	Unit	Quantity
Wall Jack Form Work	Labor	Crew No	1
Wall Rebar Work Installing	Labor	Crew No	1
Wall RC Pouring Work	Labor	Crew No	1
Wall Jack Form Work	Equipment	Hyd Jacks No	1
Wall RC Pouring Work	Equipment	Pump No	1
Wall Rebar Work Lifting	Equipment	Crane No	1

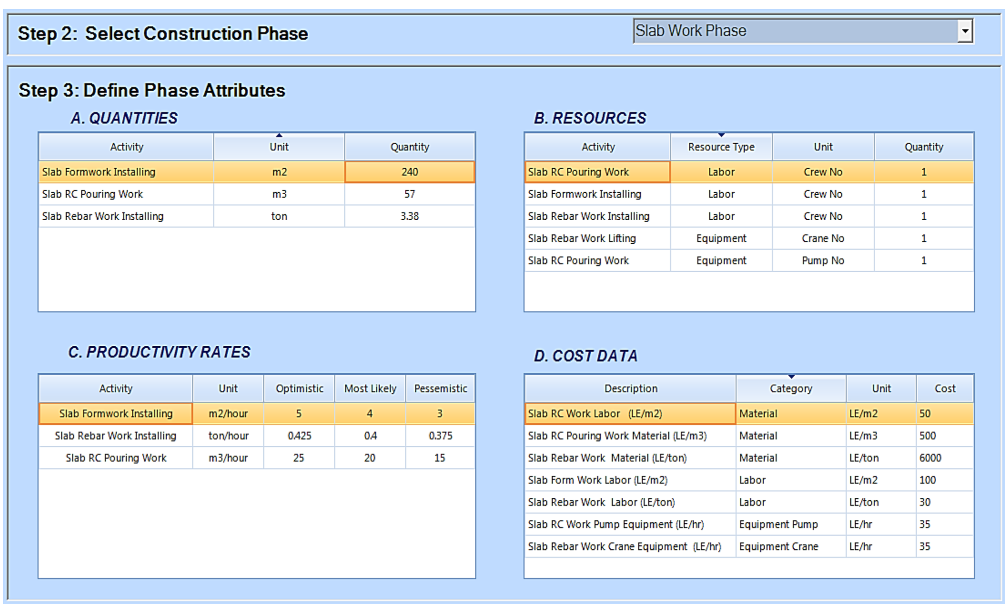
C. PRODUCTIVITY RATES

Activity	Unit	Optimistic	Most Likely	Pessemistic
Wall Jack Form Work	cm/hour	30	30	30
Wall RC Pouring Work	m3/hour	8.25	8	7.5
Wall Rebar Work Installing	ton/hour	7	6.5	6

D. COST DATA

Description	Category	Unit	Cost
Wall RC Work Material (LE/m3)	Material	LE/m3	500
Wall Rebar Work Material (LE/ton)	Material	LE/ton	6000
Wall RC Work Labor (LE/m3)	Labor	LE/m3	10
Wall Rebar Work Labor (LE/ton)	Labor	LE/ton	70
Wall RC Pouring Work Pump Equipment (L...	Equipment Pump	LE/hr	35
Wall Rebar Installing Work Crane Equipme...	Equipment Crane	LE/ton	30

Figure 9. *Wall Slipforming Work Phase Attributes Data (Module Screenshot)*


Step 2: Select Construction Phase — Slab Work Phase

Step 3: Define Phase Attributes

A. QUANTITIES

Activity	Unit	Quantity
Slab Formwork Installing	m2	240
Slab RC Pouring Work	m3	57
Slab Rebar Work Installing	ton	3.38

B. RESOURCES

Activity	Resource Type	Unit	Quantity
Slab RC Pouring Work	Labor	Crew No	1
Slab Formwork Installing	Labor	Crew No	1
Slab Rebar Work Installing	Labor	Crew No	1
Slab Rebar Work Lifting	Equipment	Crane No	1
Slab RC Pouring Work	Equipment	Pump No	1

C. PRODUCTIVITY RATES

Activity	Unit	Optimistic	Most Likely	Pessemistic
Slab Formwork Installing	m2/hour	5	4	3
Slab Rebar Work Installing	ton/hour	0.425	0.4	0.375
Slab RC Pouring Work	m3/hour	25	20	15

D. COST DATA

Description	Category	Unit	Cost
Slab RC Work Labor (LE/m2)	Material	LE/m2	50
Slab RC Pouring Work Material (LE/m3)	Material	LE/m3	500
Slab Rebar Work Material (LE/ton)	Material	LE/ton	6000
Slab Form Work Labor (LE/m2)	Labor	LE/m2	100
Slab Rebar Work Labor (LE/ton)	Labor	LE/ton	30
Slab RC Work Pump Equipment (LE/hr)	Equipment Pump	LE/hr	35
Slab Rebar Work Crane Equipment (LE/hr)	Equipment Crane	LE/hr	35

Figure 10. *Slab Work Phase Attributes Data (Module Screenshot)*

EZstrobe Simulation Model Development

An EZstrobe simulation network for Silo Slipform construction was built, as shown in Figure 11. The BSCI software retrieves the Model's activities durations and quantities from the Database after user defines all project attributes as described in previous section. The model consists of four phases (1) foundations work phase, (2) Slipform Assembly work phase, (3) Wall Slipforming phase and (4) Silo slab work phase. This model indicates the construction tasks, the logical links between activities and required resources for the project. The model starts with the following; phase (1) Foundations work phase

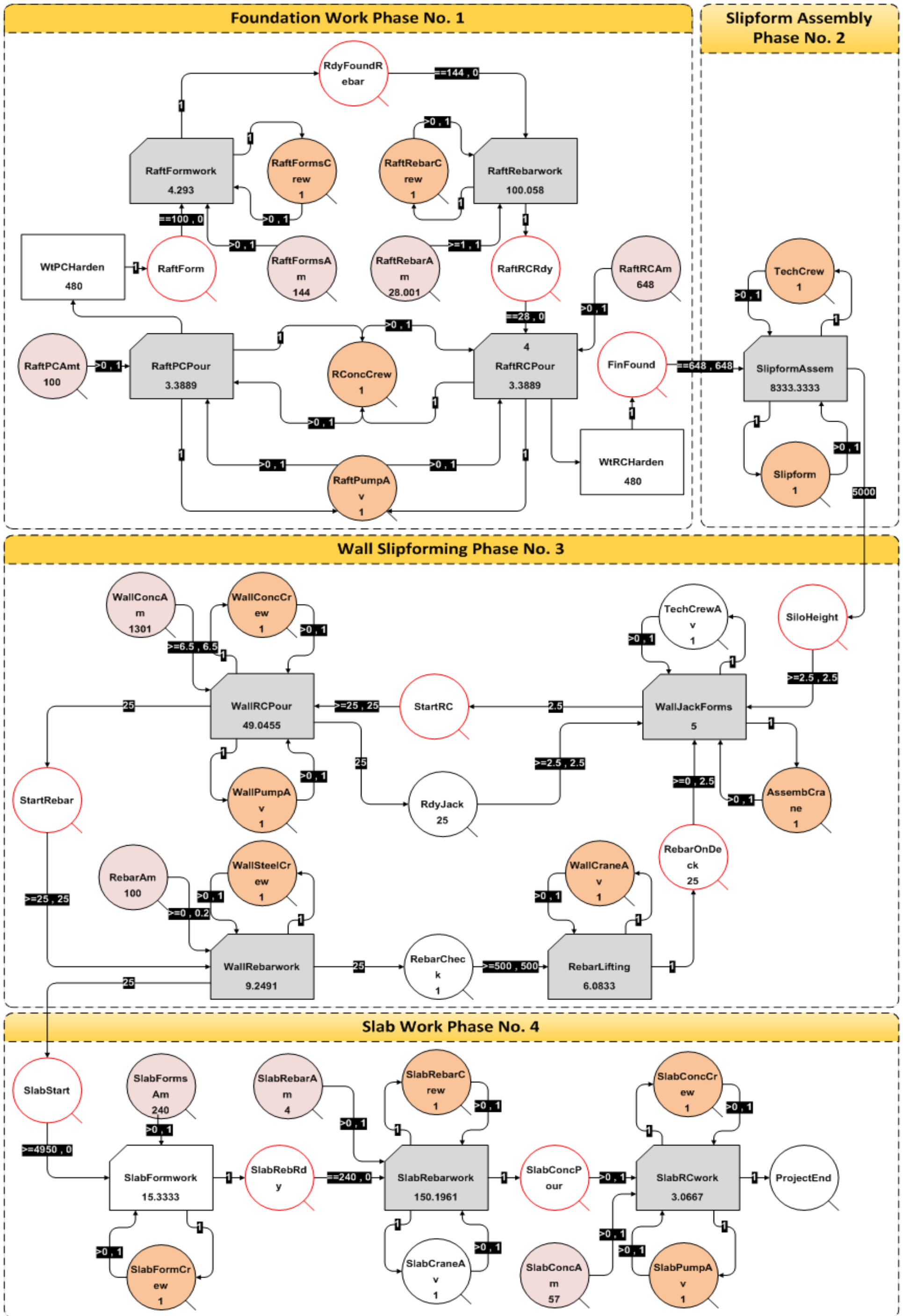


Figure 11. *Slipform Discrete Event Simulation Module Phases*

where it encounters the plain concrete pouring under foundations, steel and rebars works for foundations, form work and Reinforced concrete pouring for foundations; phase (2) Slipform assembly work phase where it encounters raising the jacks and connecting it using horizontal straps, installing panels, installing hydraulic jacks and platform; phase (3) Slipforming work phase where it encounters jacking forms based on jacking rates and layer thickness and concrete setting time, moreover concrete placement, rebar work and raising rebar to working decks; Lastly phase (4) slab work phase where it encounters the slab formwork, steel rebar work for slab and finally pouring RC for silo slab. The four models are shown in Figure 11 graphically describing the aforementioned illustration.

COMBI-FINAL

ID	Name in Interface	Productivity	Productivity	Min Duration / min	Avg Duration / min	Max Duration / min	Task Dur Min
1	Raft PC Pouring Work	Concrete	m3/hour	3.0	3.3	4.0	3.4
2	Raft Formwork Installing	Formwork	m2/hour	4.0	4.3	4.6	4.3
3	Raft Rebar Work Installing	Rebar	ton/hour	96.0	100.0	104.3	100.1
4	Raft RC Pouring Work	Concrete	m3/hour	3.0	3.3	4.0	3.4
5	Slip Assembly Installing Work	Slipform	Unit/month	6,000.0	8,000.0	12,000.0	8,333.3
6	Wall Jack Form Work	Slipform	cm/hour	5.0	5.0	5.0	5.0
7	Wall RC Pouring Work	Concrete	m3/hour	7.3	7.5	8.0	49.0
8	Wall Rebar Work Installing	Rebar	ton/hour	8.6	9.2	10.0	9.2
9	Wall Rebar Work Installing	Slipform	ton/hour	5.0	6.0	7.5	6.1
10	Slab Formwork Installing	Formwork	m2/hour	12.0	15.0	20.0	15.3
11	Slab Rebar Work Installing	Rebar	ton/hour	141.2	150.0	160.0	150.2
13	Slab RC Pouring Work	Concrete	m3/hour	2.4	3.0	4.0	3.1

Figure 12. *Activities Duration MS Access (Snapshot) view*

After project conditions are completely gathered and organized and all project objects quantities (foundations, walls, etc.) are exported to MS Access, the IDM method is considered ready to pass the information from database to the simulation model. Simulation model activities durations are shown as (Task Dur Min) in Figure 12 where these productivity data were provided by the contractor's supervisor of this similar case of study project. For instance, the optimistic, most likely, and the pessimistic productivity levels for placing the reinforcing steel for the raft work are 425, 400, and 375 kg/crew-hour, respectively. The system automatically estimates the three point durations of each work task by multiplying the quantities required to be completed and generates the task duration by PERT technique.
For simulation model running user executes step 4, where the user browses the simulation filename before executing the simulation. After opening the simulation file, the system automatically produces the model elements values i.e. (1) Activities (Combi) durations; system estimates the three point durations of each work task by multiplying the quantities required to be completed by the productivity data for the task. The task durations are then automatically transferred into the shapes of simulation model through Database wizard as explained earlier, (2) Activities (Queues) Amounts the BSCI module transfers all input conditions and project attributes of each work task to produce an EZstrobe input file. In this case study After Run, the user saves the simulation results in excel format, which allows the system to read and extract the results for further actions.

Simulation Model Results

In this case study, EZstrobe took approximately 55.00 s to run 1000 simulation iterations. After this, the user browses the simulation (Excel) result file, which allows the system to read and extract the results. Next, the user clicks Browse Simulation Results to examine a summary of the simulation results in Excel file. For instance, minimum duration, average duration, and maximum duration of this total silo construction project construction project are 50.26, 55.62, and 62.26 days with an average of 55.88 days , respectively while for the Slipforming duration it took an average duration of 13.65 days. Moreover 27 simulation alternatives associated with multiple resources combination and results are produced based on complete factorial design of a three factor with three levels operation as shown in Table 3 to examine multiple scenarios configurations, The selected combinations between factors levels of the complete factorial design based on the principal block together with the value of the factors of each trial are shown in Table 3. For each scenario configuration, a Monte-Carlo analysis consisting of 1000 simulation runs was performed, where each run results in a different schedule. Eventually, scenario No. 13 was the initial plan prepared in the research with a total Slipforming operation duration of (13.65 Days). This ends with a conclusion that among the analyses of 27 alternative No. 13 is suggested because it is close to the contractual duration (14 days) without changing any resources combination (i.e., using same concrete pouring method and jacking rate) without changing concrete layer thickness.

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For defining parameters significance and impact on Slipforming duration that could affect duration, this study adopted sensitivity analysis for guiding the scheduler to a set of possible solutions to properly estimate the project duration through an acceptable time frame by varying the amounts of resources and activities durations. The effectiveness percentage of each factor level on schedule results for Slipforming Duration in Days is illustrated in Table 4. The average impact is calculated as the average of the 9 configurations with the same factor level for the required factor i.e., the average impact of Factor A (Slipform Jacking Rate) for the Factor Level (0) is the average value of the nine results of the same Factor level on the Same Factor among the 27 scenario in Table 3.The effectiveness degree is calculated as illustrated in table 4 where the percentage of effectiveness is the result of dividing the difference between highest and lowest response for each factor by the sum of difference. The degree of effectiveness of the three factors under study is shown in Figure 13 where the effective degree of each factor on schedule results are shown in the pie chart as percentages, consequently from this chart it is clear that the most emerging factor among the three factors under study factors is B: Concrete placing method (45%), then the Concrete Layer thickness (32%) and lastly the Slipform Jacking rate (22%). Figure 14 provides another illustration for the effectiveness and impact of each factor level on the Slipforming duration.

Table 3. *Simulation Configuration Levels*

Scenario	Factors Value			Schedule Results	
	A	B	C		
	Slipform Jacking Rate (cm/hr)	Concrete Placing Method	Layer Thickness (cm)	Slipforming Duration (Days)	Total PD (Days)
1	20	Pump	5	***14.1***	***57.5***
2			10	***10.7***	***54.0***
3			20	***10.8***	***54.2***
4		Bucket	5	***17.1***	***60.5***
5			10	***10.8***	***54.1***
6			20	***11.0***	***54.4***
7		Hoist	5	***24.4***	***67.7***
8			10	***14.3***	***57.7***
9			20	***14.7***	***58.1***
10	30	Pump	5	***10.7***	***54.1***
11			10	***7.2***	***50.6***
12			20	***7.3***	***50.7***
13		Bucket	5	***13.65***	***55.90***
14			10	***7.3***	***50.7***
15			20	***7.5***	***50.9***
16		Hoist	5	***20.9***	***64.3***
17			10	***14.2***	***57.6***
18			20	***14.5***	***57.8***
19	40	Pump	5	***8.9***	***52.3***
20			10	***5.5***	***48.8***
21			20	***5.6***	***49.0***
22		Bucket	5	***11.9***	***55.3***
23			10	***6.9***	***50.3***
24			20	***7.1***	***50.5***
25		Hoist	5	***19.2***	***62.6***
26			10	***14.2***	***57.5***
27			20	***14.3***	***57.7***

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Table 4. *Percentage of Effectiveness of Factor Impact on Slipforming Duration*

Factor	Factor Level	Factor Value	Average Impact (Days)	Difference (High Impact - Low Impact)	Effectiveness (%) (Difference /Sum of Diffs.)
A: Slipform Jacking Rate (cm/hr)	0	20	14.2	3.8	22%
	1	30	11.5		
	2	40	10.4		
B: Concrete Placing Method	0	Pump	16.7	7.8	45%
	1	Bucket	10.4		
	2	Hoist	9.0		
C: Concrete Layer Thickness (cm)	0	5	15.7	5.5	32%
	1	10	10.1		
	2	20	10.3		
			Sum of Diffs.	*17.1*	

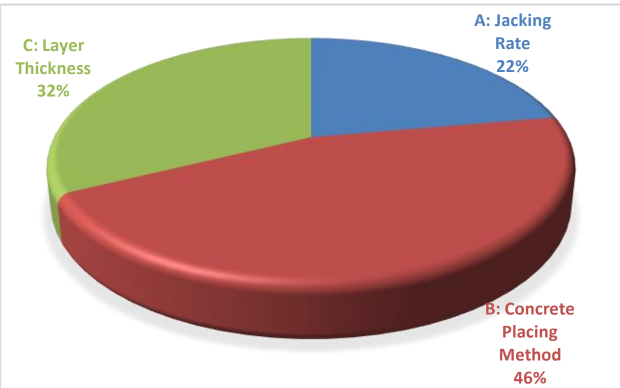

Figure 13. *Factor Impact Percentage on Slipforming Duration*

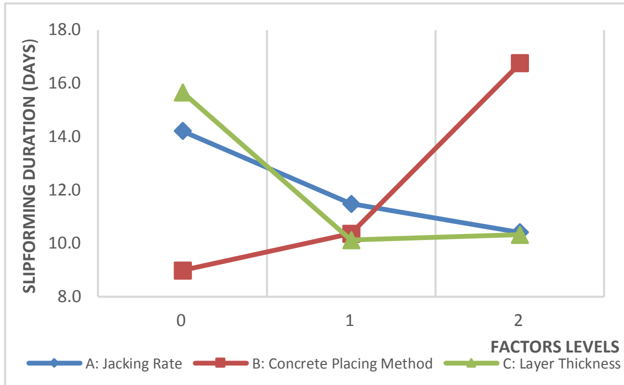

Figure 14. *Effective Degree of Each factor on Slipforming Duration*

Schedule generation Facilitated by BIM

Within these simulation runs, the same activities, constraints and material are used. For each simulation run, the work step schedule and the workload of employees was recorded and evaluated afterwards. However, this approach generates a multitude of practical schedules that can be analysed and visualized to identify good solutions manually. Planners can select the best solution according to the objectives of their particular project. The selected schedule can subsequently be imported into standard scheduling systems for further modifications and evaluations. Consequently, the proposed system can convert simulation results into an MS Project schedule for Alternative No. 13 (the adopted resource allocation strategy). Therefore, after simulation results are saved in excel format the user clicks Show Schedule on Step No. 5 Figure 15 (Top left). Notably, at this moment, name, duration, and the predecessors of each work task in the Excel file Figure 15 (middle) are retrieved automatically by MS Project using the BSCI function. Figure 15 (bottom) presents the generated schedule as viewed in MS Project. Proposed system exports activity list of data to the format readable to Microsoft Project Each activity lists the activity name—description, duration in days (assuming 40-hour workweek) for standard calendar and (assuming 168-hour workweek) for 24 hour calendar, start date, end date and predecessors. By exporting the output in Microsoft Project format, all of the functions of this popular and powerful scheduling tool may easily be applied to the generated preliminary schedule.

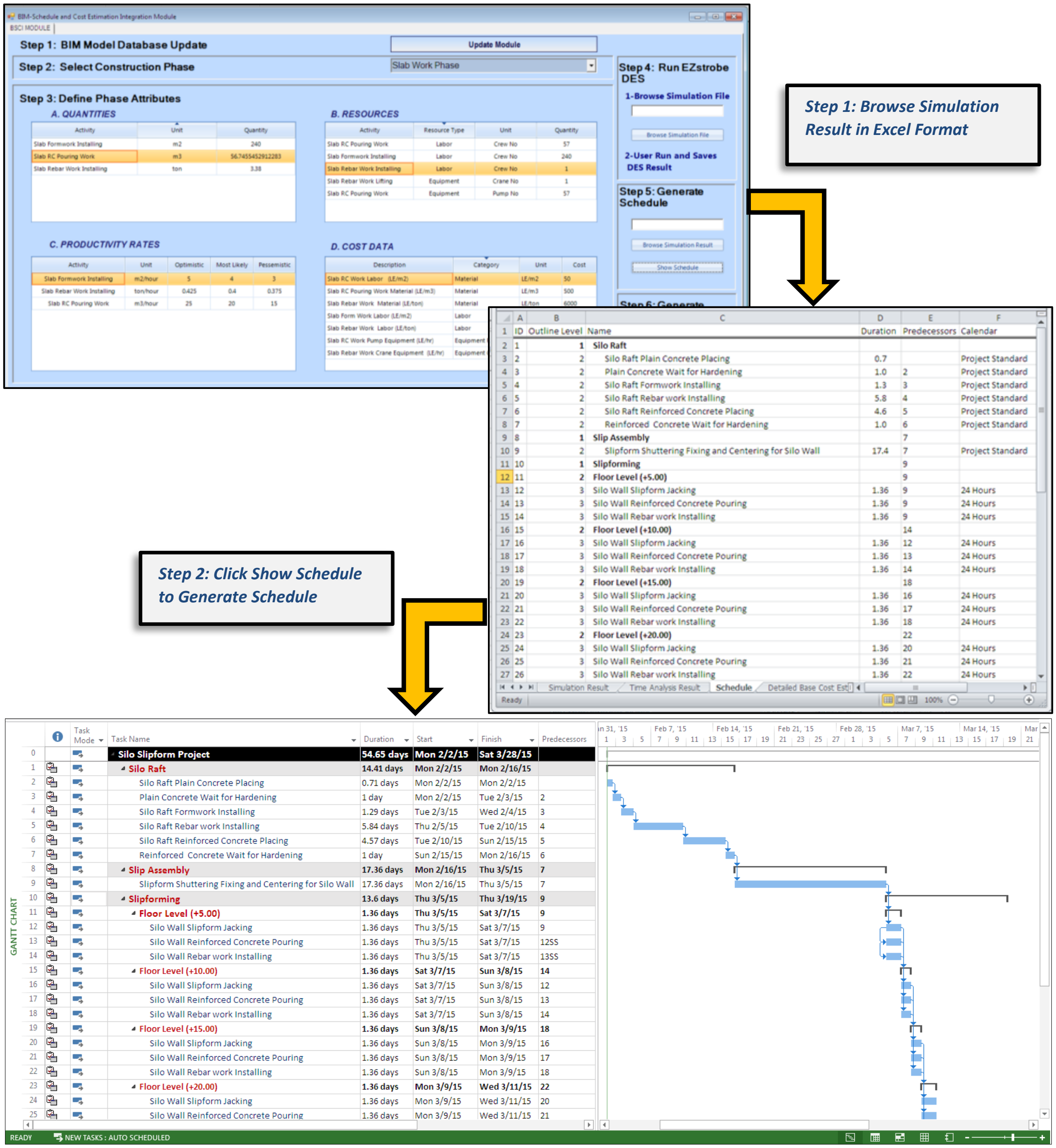

Figure 15. *Schedule Generation from Simulation Results for Scenario Alternative No.13*

Cost Estimate generation Facilitated by BIM

The last step in the module is producing cost estimates by allowing the user to determine the preferred view as (1) summary cost estimate or (2) detailed cost estimate this step is performed by clicking the buttons on step No.6 on Figure 4. The module produces two reports as following

1. Summary Cost Estimate

The summary cost estimate is presented by categorizing the total cost in to direct costs and indirect costs as shown in table 5. While the direct costs are estimated based upon Equation 1, the indirect cost is calculated by a percentage of the basis. Cost basis for indirect cost is presented in table 6 where each item is cost is justified under column "Cost Basis".

Table 5. *Direct Cost Estimate Summary*

No	Description	Amount (EGP)	Total (EGP)	Cost Basis
1	Labor	EGP 185,300.00		Total Labor Cost (Table 7)
2	Material	EGP 1,835,000.00		Total Material Cost (Table 7)
3	Equipment	EGP 491,830.00		Total Equipment Cost (Table 7)
			EGP 2,512,130.00	Total Direct Cost (Table 7)

Table 6. *In-Direct Cost Estimate Summary*

No	Description	Amount (EGP)	Total (EGP)	Rate %	Cost Basis
1	Engineering Fees	EGP 175,849.10		**7%**	Percent from Total Direct Cost (table 5)
2	GST	EGP 91,750.00		**5%**	Percent from Material Cost (table 5)
3	Payroll	EGP 50,031.00		**27%**	Percent from Labor Cost (table 5)
			EGP 317,630.10		
4	Insurance	EGP 56,595.20		**2%**	Percent from Current Total Cost
			EGP 374,225.30		
5	Overheads and Profits	EGP 865,906.59		**30%**	Percent from Current Total Cost
			EGP 1,240,131.89		

2. Detailed Cost Estimate

The detailed cost estimate is presented in table 7 by decomposing construction elements into Material, Labor and Equipment Cost. The total cost is calculated as illustrated earlier in Equation No.1 on Cost Estimate Module by multiplying the bare item cost by the quantity retrieved from the BIM model. The total cost of each cost element is that found in the summary cost table on table 5.

Table 7. *Detailed Direct Cost Estimate*

No.	2014 Master Format Code	Description	Unit	Qty.	Material EGP/Unit	Labor EGP/Unit	Equipment EGP/Unit	Total (EGP)
1	**SILO RAFT FOUNDATION**							
1.1	**03 30 53**	Providing and laying in position machine plain concrete works under Raft.	**CUM**	**100**	400.00	10.00	35.00	**EGP 44,500.00**
1.2	**03 71 00**	Providing and laying in position machine reinforced cement concrete works.	**CUM**	**648**	500.00	30.00	35.00	**EGP 366,120.00**
1.3	**03 21 11**	Providing and fixing Steel reinforcement for R.C.C. work.	**MT**	**28**	6,000.00	35.00	-	**EGP 168,980.00**
1.4	**03 11 13**	Providing and fixing Centering and Shuttering and removal of forms.	**SQM**	**144**	-	100.00	-	**EGP 14,400.00**
2	**SILO SHELL WORK**							
2.1	**03 30 53**	Providing and laying in position machine reinforced cement concrete works for Wall.	**CUM**	**1301**	500.00	10.00	35.00	**EGP 709,045.00**
2.2	**03 21 11**	Providing and fixing Steel reinforcement for R.C.C. work of Wall.	**MT**	**100**	6,000.00	70.00	35.00	**EGP 610,500.00**
2.3	**03 11 13.13**	Providing and fixing Slip form shuttering arrangements with all tools & tackles for silo shell at all heights.	**SQM**	**10362**	-	10.00	40.00	**EGP 518,100.00**
3	**SILO DECK SLAB**							

3.1	**03 30 53**	Providing and laying in position machine reinforced cement concrete works.	**CUM**	**57**	500.00	30.00	35.00	**EGP 32,205.00**
3.2	**03 21 11**	Providing and fixing Steel reinforcement for R.C.C. work.	**MT**	**4**	6,000.00	35.00	35.00	**EGP 24,280.00**
3.3	**03 11 13**	Providing and fixing Centering and Shuttering and removal of forms.	**SQM**	**240**	-	100.00	-	**EGP 24,000.00**
Total								**EGP 2,512,130.00**

Results Validation

Validation was conducted for both Time and Cost purposes, therefore First for Time Scheduling validation, the case of study data was collected from Hormozghan Cement Project which had more than twenty towers and silos that were constructed using Slipforming technique considering jacking Rates and productivity in meter per hour. (T. Zayed et al, 2008). Second for Cost Estimate validation, the cost data was collected from practitioners, contractors and specialized Slipforming companies for estimating and validating based upon the average price of One RC cubic meter in Egypt for the year 2014-2015. Validation results for duration and cost estimates are presented in tables 8 and 9 respectively. Where the duration validity is especially for the Slipforming operation duration and the cost estimates are based upon cost of one cubic meter of two types of concrete; first typical type for foundations and slabs ; second for the Slipforming concrete encountering the Slipform. Results show the advantage of utilizing the BSCI module to time and cost prediction of slip-forming operations with robust results of an average of 98 % validation for Time and 96% for Cost estimates.

Table 8. *Slipforming duration validation result*

Result / Source	Schedule Duration (Days)
BSCI Module	13.65
Case of Study	14
Validity (%)	**98%**

Table 9. *Cost Estimate validation result.*

Result / Source	**Foundations and Slabs Concrete** (EGP/m^3)	**Slipforming Concrete** (EGP/m^3)
BSCI Module	EGP 1,450.00	EGP 2,100.00
Current Market Price	EGP 1,500.00	EGP 2,000.00
Validity (%)	**97%**	**95%**

RESEARCH SIGNIFICANCE

The integrated BIM–DES framework significance stems from: BIM provides DES with the product and process information that facilitates the building and maintenance of the DES model; then DES model evaluates the construction performance and provides valuable feedback and decision support to the BIM process resulting in reinforcing both elements by providing more accurate and updatable schedules and cost estimates. Proposed model is applicable for small to medium projects and it is complex to apply to a large projects. Detailed research significance can be listed as following;

- Computerized automated model could support decision making by enabling project parties to test and evaluate any alternative scenario rapidly in the search for an optimum solution Provide Slipform construction practitioners, contractors and consultants with a validated and adaptable automated model and interface for estimating and predicting the Slipform process and project productivity duration and Cost.
- The integrated BIM and DES framework provides a more efficient platform than the traditional simulation approach, as the manual specification and maintenance of the simulation model is substituted with a dynamic database read by the DES model.
- Demonstrate model capability in facilitating sharing building information models' data through BIM platforms and Produced interface

- Demonstrate the power of integrating BIM and DES in a single tool showing power of each tool.
- Increase the effectiveness of Utilizing the DES as a planning and decision Making tool for construction operations.
- Minimize time required for maintaining the DES models by developing an automatic updatable DES model.
- Automatic generation of construction schedules and cost estimates of site work activities through better utilization of the 3D BIM model in Scheduling based upon actual quantities

CONCLUSIONS

By the development of BIM the AEC industry perspective has changed and many new advances in technology are now available. Although this technology has influenced researchers to investigate the application of BIM on automatic generation of schedules and cost estimation reports, it has been only conducted for single aspect as schedule or cost.

The research findings contribute to the understanding of the potential use of BIM and DES in construction schedule and cost estimation management and fill an existing gap in the knowledge on the use of BIM for construction schedule management. This paper explored the implementation of BIM in schedule management and proposed integrated solutions to improve current schedule and cost estimates generation processes with assistance of a DES and a developed software working environment In this research software for BIM-based integrated framework with discrete event simulation was developed and verified through a case study of a Slipform project for scheduling planning and cost estimation. As the core of the proposed framework, the integrated BSCI module achieves cost and schedule integration as well as the integration between the product model and the construction process model.

The integration provided by this system is significant in four aspects; First, BIM can support EZstrobe simulations in providing the material quantities of construction elements to evaluate task durations in a prompt and accurate manner; second, the operations simulation allows for the evaluation of various resource allocation strategies and considers the competition among resources in generating a suitable schedule. Third, the developed Schedule model, presents reliable working sequences of construction activities. Fourth, the developed cost estimate presents a cost budget for such project. Overall, the proposed system demonstrated its effectiveness in enhancing the current Schedule and cost estimate generation and applications. The developed BSCI software is essential to practitioners and researchers working in Slipform operations because it provides practitioners with a planning and scheduling tool besides a cost estimate tool for preliminary project phases. .

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