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A FRAMEWORK FOR SIMULATING CONSTRUCTION PROCESSES FOR OPTIMIZING THE FLOOR CONSTRUCTION CYCLE USING BIM

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ABSTRACT: Lately, Building Information Modeling (BIM) emerges as the most promising technology, now is expected to bring a great deal of improvement of productivity in every aspect of the construction industry. One of the BIM based scheduling is to use BIM model as a base for applying to schedule analysis and simulation tools. This type of tools may incorporate a various types of information such as the building model, construction method information, resource information, productivity information, rules and constraints to optimize activity sequencing. This paper proposes a framework of BIM based simulating system which can be used to optimize construction processes, especially for the floor construction cycle. For the purpose, all of the necessary components of the system will be defined and represented, and next an algorithm will be introduced to demonstrate the principle of simulating operation. The benefits of this technique are basically two : to test and optimize construction methods in respect of the construction duration and to reduce the floor construction cycle.

Keywords: Schedule, Simulation, BIM(Building Information Modeling), Building Object, Floor Construction Cycle

1. INTRODUCTION

Scheduling is one of the key areas in every construction project. Thus, there have been numerous discussions and analyses on the construction scheduling topic for decades. A variety of techniques have been developed to support the schedule management function so that loads of software packages are now available for schedulers and construction managers. However in reality, those advanced techniques are hardly being used in daily practice in the construction industry owing to the following reasons: complexity and difficulty of the method, workload to enter additional information manually, and insufficient practicality of the analysis. Therefore, many of the construction projects are planned and scheduled mainly depending on the project scheduler's individual experience and historical data.

Problems to be addressed by advanced scheduling tools should include these three: scheduling with uncertainty on prediction of activity durations, integrated planning of scheduling and resource allocating, scheduling in unstructured or poorly formulated circumstances [1]. A great schedule management is able to be accomplished when an accurate prediction of activity durations precedes. To address the uncertainty of prediction, schedulers often adopt most likely time duration ignoring the variation, which is called the deterministic approach. In contrast to it, some of the construction planning and analysis are carried out in the probabilistic approach, in which the estimate of activity involves a contingency allowance. Another aspect of critical problem to be resolved on scheduling is integration between scheduling and resource allocating. Construction scheduling should be taken into account together with resource allocating, because an activity may have varied durations according to the type and amount of resources,. However, in most current scheduling tools the activity duration is entered as a fixed value by the user, or is generated randomly, which means a value is assigned to the duration regardless of resources. Lastly, the most important and difficult problem on construction planning and scheduling occurs when the circumstance is unstructured and not predictable. Traditional scheduling technique such as CPM and PERT can be conducted only when all of the activities for completing the project are defined and the relationships between activities are able to be clearly represented. But, in real construction processes, a number of unpredictable factors can exist due to the nature of construction project. Hence, one of the best approach to address this problem is to test physically or virtually every possible alternative with regard to potential scenarios. This method, so called simulation-based scheduling, would be expected to enhance the performance in construction processes, but usually requires considerable amount of additional effort for applying it.

Lately, Building Information Modeling (BIM) emerges as the most promising technology, now is expected to bring a great deal of improvement of productivity in every aspect of the construction industry. BIM technology can benefit construction planning and scheduling of processes as well as other management functions such as cost management, project coordination, conflicts detection, etc. Construction planning and scheduling based on BIM attempts to address the problems mentioned above, through providing the 3D building model as the basis for planning, reducing efforts needed for information entry by intelligent rules and functionalities in tools, reinforcing realism with all possible building views, and supplying interface with schedule analysis for example the progress information included in an object's property set.

2. OBJECTIVE AND SCOPE OF THE STUDY

2.1 Background

Traditional scheduling methods do not have the capability to capture the spatial components and link them directly to the activities. Without sophisticated 3D building model like BIM, Scheduling in general was advanced based on 2D drawings when the design stage is nearly completed and the quantity of materials can be calculated. Due to lack of functionalities of traditional scheduling tools, the schedule could not be related to the spatial information of building components after the geometric data was once extracted to calculate the quantity.

BIM based scheduling have evolved in two directions to improve scheduling performance [2]. The first is 4D application, which refers to 3D geometric model associated with time dimension. Eastman et al. argued that there are five benefits of 4D models such as communication, multiple stakeholder input, site logistics, trade coordination, and tracking construction progress [2]. The biggest contribution of 4D application of BIM is primarily to enhance communication, and also it means that 4D application is not an innovative development in scheduling principle, but only a synthesis between 3D building model and traditional scheduling method. The second is to use BIM model as a base for applying to schedule analysis and simulation tools. This type of tools may incorporate a various types of information such as the building model, construction method information, resource information, productivity information, rules and constraints to optimize activity sequencing. With this type of simulation using BIM, schedulers can virtually test every possible alternative to take unpredictable conditions of the construction circumstance into account and address the problems of uncertain activity durations and relations between activities. Also, Simulation-based scheduling is able to incorporate construction planning and resource allocating, because in this approach each activity duration is not determined by the scheduler's entry but by calculation from the rules and the parameters such as productivity information and quantity of materials. Besides, this approach is expected to be potentially possible to reduce the required effort to enter information for simulating the construction schedule and to automate the generation of simulation as much as possible, because the base data for simulation is acquired from BIM, an intelligent parametric building information system which can be associated with various types of property data attached to building components.

2.2 Objective of the study

This paper proposes a framework of BIM based simulating system which can be used to optimize construction processes, especially for the floor construction cycle. For the purpose, first of all, all of the necessary components of the system will be defined and represented, and next an algorithm will be introduced to demonstrate the principle of simulating operation. In the meantime, the schematic design of the simulation system and the information flow will also be explained.

2.3 Scope

The level of scheduling simulation can vary over a very wide range. The level of detail is primarily affected by two factors: the purpose of the simulation and the level of detail of the available building model. The purpose of any kind of analysis usually depends on the stage of the project, because requirements for an analysis may be diverse according to the stage of the project at the moment. If the project is proceeding in design step, the relevant analysis on schedule will be for the entire duration of the project. If the project is ongoing at the construction stage, the scheduler may be interested in optimizing the look-ahead schedule for coming one or two weeks using simulation.

In this paper, the framework of construction process simulation is designed targeting application at the construction stage of a building project life cycle, in which the detailed design is already completed and the construction manager may want to optimize the floor construction cycle along with resource allocation. In most of the mid- or high-rise building construction projects, the floor construction cycle is always one of the critical problems in regard of scheduling, because, typically given the repetitive nature of the project, the well-balanced and optimized schedule for a standard floor often guarantee the whole project's success.

Moreover, in the paper, it was presupposed the design was delivered to the construction stage as a BIM form, which contains detailed building product (architecture) information in an accurate 3D model, with the capability to export quantity and property information.

3. LITERATURE REVIEW

Currently, a number of researches have been conducted on simulation techniques and BIM applications in respect to scheduling

Tulke et al. applied a Business Process Re-engineering approach (BPR) to identify potential areas of improvement within the current scheduling and 4D simulation practice and proposed a dynamic collaboration framework tailored for construction scheduling [3]. Jo et al. studied and developed 'the BIM based Architectural Construction Simulation System prototype' using Combinative Construction Schedule Creation Method, focusing on automatic generation of 4D visualization [4].

Jianping et al. presented an application of 4D techniques and genetic algorithm (GA) to the National Stadium of the Beijing 2008 Olympics. They argued that the operations simulation shortened about 16% of the installation duration [5]. Lee defined and represented the object libraries and the work processes for implementing 4D simulation [6]. As above, the majority of researches on BIM and 4D simulation topics have been conducted especially concentrating on developing automation of the process for generating 4D simulation by matching the breakdown structures. It means that studies so far have focused on the visualization and communication function of BIM and 4D. when the 4D topic is discussed in view of optimization, GA is often integrated with the 4D technique.

Also, researchers have been applying simulation techniques widely. Sadeghi et al. proposed a platform that can automatically model the raw materials and the assembly process of components of a product based on the unique features of a product [7]. The author argued that the platform is used to develop a simulation based decision support system. Mohamed et al. designed a simulation-based approach for scheduling pipe-spool module assembly [8]. Using the simulation-based scheduling techniques, the paper demonstrated the significant improvement in the schedule compared to CPM-based scheduling. Akbas developed a new approach for modeling and simulation of construction processes based on geometric models and techniques [9]. The writer tried to model and simulate construction processes as sequences of crews acting on geometric work locations, which can be understood as an attempt to parametrise construction operations. The researches shown above commonly try to apply simulation to support scheduling, to overcome the shortcoming of traditional CPM-based scheduling, and report an improvement. However, each of the research was based on their own developed geometric model or data, but none of them tried to use BIM for construction processes simulation. As a summary, although there are many researches to try simulation technique to improve scheduling, few researches show the attention on integration with BIM.

4. SIMULATION MODEL DEVELOPMENT

4.1 Main elements and concept model of simulation

The schedule simulation system consists of three parts such as objects, construction method and productivity database, and simulation algorithm (Figure 1). The building model, which is composed of Objects, does not only carry the geometrical information but also contains properties as interface with other analysis tools. If the BIM generating modeler does not provide the function to create temporary component object for example formworks, those objects should be generated by BIM application add-ons or other type of application softwares. Especially, general-purpose temporary components in construction projects, such as tower cranes, hoists are scarcely able to be linked directly to any specific part of the architecture model, so that those objects should be handled in different way from BIM generating systems. When all of the necessary objects are generated and ready to represent construction processes, the next step is to link each object to its operation information database, which

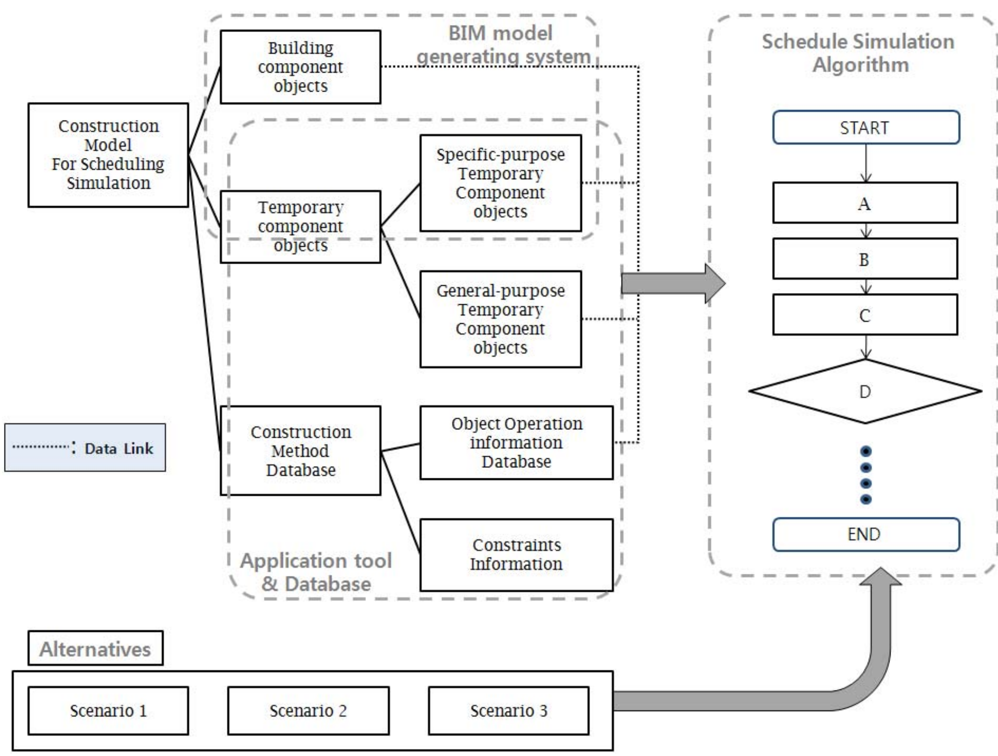

Figure 1. Main elements and the concept model of schedule simulation using BIM

includes productivity information for each activity. In the process from preparing objects to connecting them to its operation information, each construction process is parametrized by the quantity of activity and the productivity data. To analyze construction processes as practical and realistic as possible, activities for each object are broken down into 4 steps, which is called the Process Breakdown. The proposed framework of simulation system can demonstrate the optimized result of construction processes under the given conditions entered by the user. The algorithm operates assigning adequate resources to an activity which has the most priority, with checking over to meet the constraints. Therefore, schedulers can use this method to test every possible scenario and verify the optimal solution with regard of the project context.

4.2 Parametrization of construction processes

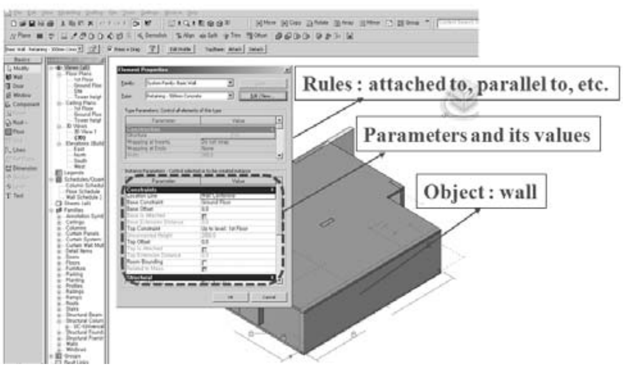

Figure 2. Parametric modeling in BIM tools

The construction process simulation concerned with the resource allocation is able to be achieved when the construction activity can be defined by its parameters to represent the process. As it represents an object by parameters and rules for defining both of geometric and non-geometric properties in BIM parametric modeler (Figure 2), construction processes can be defined by parameters such as the quantity and productivity, etc, and rules such as productivity growth curve. In this paper, a parameter set to parametrize construction processes is proposed as the following

1. *Quantity Parameter of Work (extracted from objects)*
   - *Quantity of Activity*

2. *Activity Method Parameter (fed from Object Operation Information Database)*
   - *Equipment ID.*
   - *Average Required Labor*
   - *Range of the Number of Labors Working Together with the equipment*
   - *Productivity Information for Unit Work by a labor*

3. *Priority Parameter (assigned by embedded rules in the simulation system)*
   - *Priority of Activity (governed by rules)*

4.3 Construction process breakdown

For developing a beneficial simulation system, as mentioned above, it is vital to make the level of detail of the model to meet the purpose of simulation. The simulation system proposed in this paper targets on optimizing the floor construction cycle, so that the required level of detail is of sequencing detailed activities such as an installation of reinforcement for a wall object, placement of formworks for a zone of a floor object, transportation of Gang-forms to the next position, etc. As a result of research to seek for the effective representation of construction activities in detail, it is found out that every activity related to an object can be in general divided and represented as 4 steps as follow: Transportation, Installation, Cure, and Removal. For example, activities for formworks follow the four steps (Figure 3).

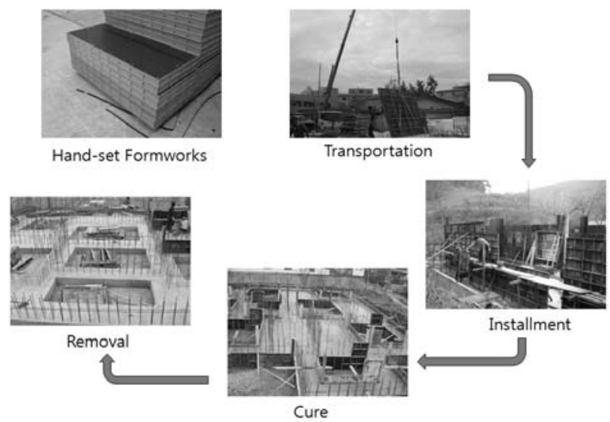

Figure 3. Formwork process breakdown

Owing to the detailed definition of construction activities, the result of the simulation is expected to be a detailed reference. The scheduler can apply diverse combinations of alternatives of each activity, and the optimized solution can be brought in micro view. In addition, this model to divide the sequence as 4 steps has strength in respect that the method or the equipment usually changes according to the type of work for each operation. Therefore, this reasonable classification helps to structure the construction method database which should be prepared for the simulation serving possible alternatives for each unit activity.

Table 1. Construction process breakdown

	Transportation	*Installation*	*Cure*	*Removal*
Concrete	o	o	o	x
Reinforcement	o	o	x	x
Form	o	o	o	o

The same way to breakdown construction processes can be applied to every object (Table 1). However, some of the activity may not exist because of the nature of the object. For example, an object which represents concrete does not need to have an activity of removal, because concrete forms a part of the complete architecture. On the contrary, if an object represent a piece of form, the removal step should be included in the activities because the formwork is a temporary component amongst the construction processes.

4.4 Definition of Objects, properties, and data link

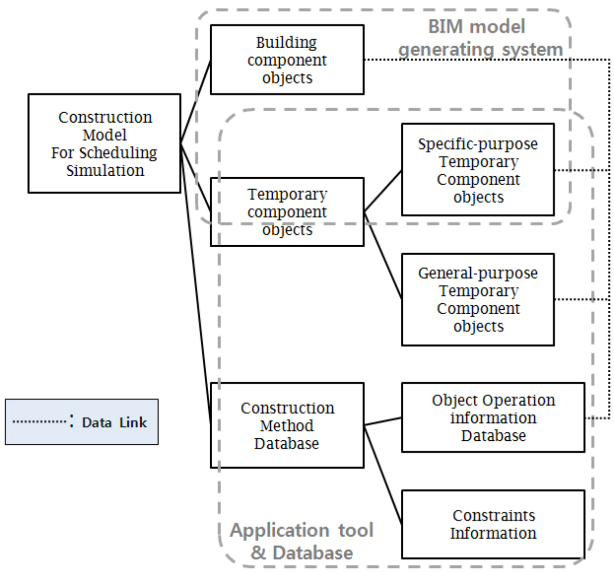

Figure 4. Objects and data link

As mentioned above, the parametrization and construction process breakdown are implemented by defining objects, their property, and the data link between objects. In other words, the format and property set embedded in objects reflect the main principle of the construction process simulator. Building component objects are designed in BIM generating tools, but most BIM tools are not capable of generating temporary component objects. There are two types of approach to resolve this problem. The first is using user-defined parametric objects. All BIM generation tools support creating custom object families. The Second way is to create an data object in the simulation tool, ignoring of visualization.

All components have a set of properties embedded in the object. For developing the construction process simulation system, all of the component objects should be linked to the 'Object Operation Information Database' which contains the construction method-related information. This method-related data are collected and stored to realize the parametrization of construction processes, so that the structure of the database should be designed to reflect the parameters shown in **4.2**.

Also, activities for each object are defined as four steps so that the database should have information for each step of activities separately.

The data link between objects' property set and the construction method database should be automatic as much as possible, because the process must be very time-consuming and tedious if every link between relevant data is achievable only in manual manners.

Proposed in this research is that the scheduler or construction planner can choose an alternative among the practical options in the property window of the object, as the same way to handle properties and parameters in BIM.

4.5 Simulation algorithm

Before operating the simulation algorithm, the user has to choose a scenario, which means the user decides and chooses for every optional item such as construction method for each activity, the number of on-site labors, etc. The simulation process begins with data feeding from the building model, construction method database, and constraints entered by users.

The simulation algorithm functions as a resource allocator. The followings are the main factors reflected in the algorithm,

- Identification of each activity (queuing, in-progress, finished)
- Allocation of resources to activity according to priority of the activity and availability of resources
- Constant tests for every hour to prove the optimization of resources under given circumstances
- Accounting for practical constraints: working

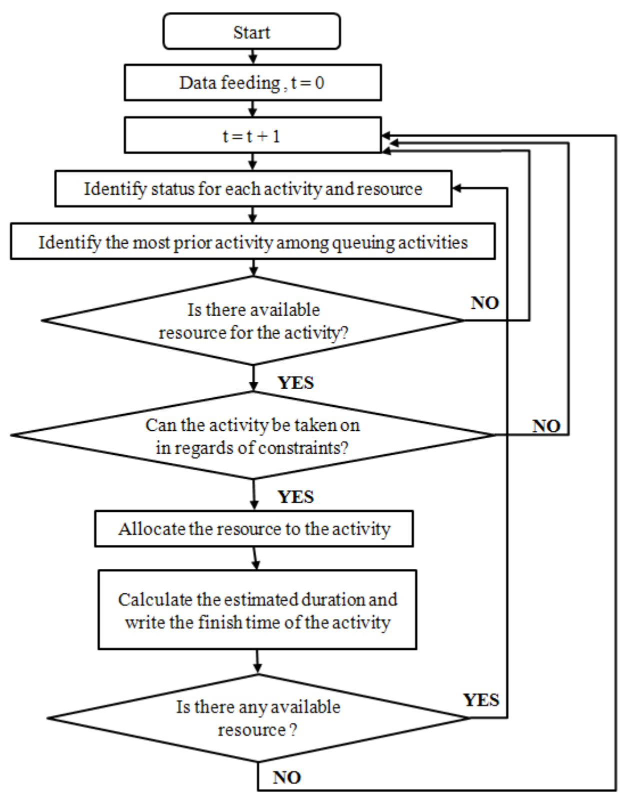

Figure 5. Simulation model process

hours per day, physical restrictions for activities, etc.

The simulator can identify the most prior task to be done first, assign the necessary resource to it, calculate the duration, and report the status of each activity (Figure 5).

5. CONCLUSION

In this paper, a framework of BIM-based simulating system is developed. The simulation uses the ability of BIM to capture geometric information of every building component and various properties attached to the object. Because BIM modeling tools do not yet serve the overall functionalities to support the construction industry, main elements and the structure are proposed to develop a construction process simulation which can benefit construction managers. The objects and properties for schedule simulation are defined and an algorithm is developed to improve traditional scheduling methods.

The construction process simulation system is expected to improve construction practices in two aspects. The first is to test and optimize construction methods in respect of the construction duration. At the construction stage of projects, most of the construction managers may meet a problem to adopt a construction method. Because the risk to use innovative technique on the site is too big, most of the construction managers who have to make decisions tend to prefer traditional and familiar construction methods. One of the way to verify the strength of the new technique is to take a mock-up test, which requires too great deal of money and effort. Under this context, an efficient and effective way to test the construction method can be the virtual test using simulation software. If the result of the simulation is reliable and able to provide detailed information about feasible alternatives, it can be regarded for the construction industry to solve one of critical problems about construction planning. Because the proposed simulation model is based on reliable and accurate building model, BIM, If the practical data is measured in a consistent and reliable way, then the simulation can demonstrate a very realistic result and be applied to daily practice.

The second is reducing the floor construction cycle. The simulation is developed to optimize the resource allocated to activities. Also, users can enter any combination of possible alternatives, and find out the best way to reduce the construction duration under given context. Because the simulation model utilize the very detailed activity, the result of the simulation can show the most desirable sequence of construction operations in detail.

REFERENCES

[1] Hendrickson, C., *Project Management for Construction,* Prentice Hall, 1998.

[2] Eastman, C. et al., *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, John Wiley & Sons, Inc., 2008.

[3] Tulke, J. et al., “A Dynamic Framework for Construction Scheduling based on BIM using IFC”, INPRO., 2008, http://www.inpro-project.eu/media/IABSE_sep08_long.pdf

[4] Jo, J. et al., “A study on the BIM based Architectural Construction Simulation System using Combinative Construction Schedule Creation Method”, Architectural Institute of Korea, 2008.

[5] Jianping, Z. et al., “Construction Management Utilizing 4D CAD and Operations Simulation Methodologies”, Tsinghua Science and Technology, pp241-247, Vol. 13, Number S1, 2008.

[6] Lee, J., “Definition and Implementation of Object Libraries for 4D Simulation”, Architectural Institute of Korea,pp149-156, Vol.18, 2002.

[7] Sadeghi, N., “A Framework for Simulating Industrial Construction Processes”, Proceedings of the 2008 Winter Simulation Conference, pp. 2396-2401, 2008.

[8] Mohamed, Y. et al., “Simulation-based scheduling of module assembly yards: case study”, Engineering, Construction and Architectural Management, Vol. 14, No.3, p293-311, 2007.

[9] Akbas, R., “Geometry-Based Modeling and Simulation of Construction Processes”, CIFE Technical Report #151, February, 2004.