Optimizing Construction Planning and Scheduling through Combined Virtual Prototyping Technology and Building Information Models

Neo Chan  
The Hong Kong Polytechnic University, Hong Kong  
(email: neo.kychan@polyu.edu.hk)

Heng Li  
The Hong Kong Polytechnic University, Hong Kong  
(email: bshengli@polyu.edu.hk)

Abstract

As the design of building has become more complex nowadays, it is very difficult for project managers to compute the time of construction planning and scheduling accurately. There is a pressing need of high level computer-assisted technologies to develop a comprehensive construction planning and schedule before a project is actually built. Currently, these computer-assisted technologies are often limited to the function for the examination of constructability or so. This paper introduces the use of combined virtual prototyping (VP) technology with Building Information Models (BIMs) to optimize the construction planning and scheduling. A real-life case study is adopted in the paper to show how the VP technology and the BIMs are used to conduct construction planning and scheduling, particularly focusing on arranging tower cranes to achieve the construction floor cycle.

Keywords: construction planning and schedule; virtual prototyping, building information models
1. Introduction

Currently, undertaking of a building project is similar to a gamble; contractors cannot predict the result at the beginning of a construction project owing to its characteristics (e.g. need for coordination of multidisciplinary teams, complex nature). This emphasizes the importance of project planning and scheduling. Project planning and scheduling is a critical process that determines the successful implementation and delivery of a project [1]. However, currently project planners are left without effective technologies to do the job, although planning approaches such as the critical path method (CPM) and bar charts are always employed. This in turn leads to the fact that in the construction sector design errors or imperfections are prevalent in construction plan and schedule; in practice, project planning and scheduling relies heavily on rules of thumb by experienced individuals. There is a pressing need calling for effective technology to conduct construction planning and scheduling.

Project planning and scheduling, by definition, is to involve the choice of construction technology, the definition, the estimation of required resources and durations and the estimation of costs [2]. It concerns the optimal configuration of construction process, activities, and available resources to achieve project goals such as time, cost, and quality. Traditional planning approaches such as CPM and bar charts have been devised and are still using in construction practices. With the increasing complexity of modern construction projects, computers were identified as an efficient tool to help project planner. However, the traditional approaches like bar charts and CPM cannot provide the spatial construction features, the resource and working space requirements [3, 4]. The traditional techniques of resource management have been classified into three categories: resource allocation, resource leveling and Time-cost trade-off analysis. Chan et al. [5], Hegazy [6], Leu and Yang [7] combined resource allocation and leveling using GAs. Li and Love [8] proposed GAs for the time-cost optimization problems. Hegazy and Kassab [9] combined a flowchart based simulation tool with GA technique. Wang et al. developed 4D Management for Construction Planning and Resource Utilization (4D-MCPRU) system which links 3D geometrical model with resource to compute the resource requirement [10].

All of the previous resource planning and allocation did not take the real productivity rate into account to analyze the resource. The application of VP technology should assist planner to identify construction method and prepare construction schedules [11]. Based on the present VP technology, adding real
productivity rate into the system can increase the objectivity of the construction planning and scheduling. The VP system furnishes the project planners a useful tool to plan the construction planning and scheduling. It allows them to consider objective productivity data to predict the potential constructability problem and analyze resource allocation including tower cranes to modify construction sequence to accomplish a comprehensive construction planning and scheduling.

The aim of this research is to introduce VP technology into the optimization of construction planning and scheduling. The research methodology taken was an “action research” approach. The paper first describes the framework of construction planning and scheduling through combined VP technology and BIMs. Next, a case study showing how the construction planning and scheduling is optimized through VP technology is presented. Finally, the future improvement on VP technology is discussed and concluded.

This idea achieves the vision for Integrated Design Solutions (IDS) as the construction planning and scheduling integrated two new technologies that are VP technology and BIMs to minimize the planning errors and mistakes. Also, this solution can be applied on different construction projects during the construction stage.

2. Method

The research methodology taken was an “action research” approach where the researchers and developers were actively involved in the production of the virtual prototypes on behalf of the contractor thereby gaining consistent access to the decisions of the planning staff. The experiences from the case study were considered together with similar research on other construction projects.

3. The framework of construction planning and scheduling through combined VP technology and BIMs

3.1 Definition of BIMs

BIMs (Building Information Models) contain precise geometry and relevant data needed to support the construction [12]. However, in this paper, the BIMs are identified into two categories: construction model and resource model.
Definition of construction model

There are two types of digital models for construction. The first type is same as BIMs which help evaluate performance by using information embedded in 3D models. The key function of BIMs on construction field allows the planners to view their static realistic images and check the design error and collision. However, the temporary works are the critical element in the whole construction planning [3]. This type of model is to develop the temporary work models generating by the parametric models. The details of temporary work model are available in Huang et al. [1].

The second type of digit models is similar to BIMs but this type of model is a detailed building component models which are related directly to construction activities. The purpose of these models is not only to be uses on the design check, but is also closely associated with the construction planning and scheduling. These types of models decompose serial assembly models developing a detailed construction activity. The decomposition of a product is the precondition of goal of simulation and assembly of parts is closely related to simulation process. As such, the purpose of the simulation is to display the sequence of pouring concrete. One floor of 3D concrete model will be decomposed into different assembly models (i.e. inner slab, half of outer slabs, outer wall, inner wall, each column) which are related to the sequence of the simulation (Figure 1).

![Figure 1. Decomposition of BIMs.](image)

Definition of resources model

Two resources models can be identified: equipment-based model and activity-based model.
Optimizing Construction Planning and Scheduling through Combined Virtual Prototyping Technology and Building Information Models

Equipment-based Model – The characteristic of the equipment-based Model is a 3D-geometry equipment model linked with the productivity rate of equipment in database Excel library and physical capacity data. As such, tower crane contains the graphical information that is the exact geometry, shape and dimension for space analysis as well as the equipment capacity (i.e. maximum capacity, maximum lifting height and maximum radius) for testing the operating capacity.

Activity-based Model – The characteristic of the activity-based Model is a non-physical model linked with the productivity rate in database Excel library like the fixing reinforcement activity. Then, the activity-base model will be linked with construction model by users when generating the simulation process in virtual prototyping system to develop one process activity in the system.

3.2 Implementation

The database of the productivity rate and the construction planning and scheduling stores into Microsoft Excel format. The virtual prototyping system was implemented by using Visual Basic for Applications (VBA) in DELMIA V5 environment, and Microsoft Excel to develop the productivity database and the planning and scheduling linking with 3D Model. VBA is an object-oriented programming language to develop specific function. VBA provides a seamless link between the components of the model, supported by a powerful graphical user interface (GUI). The equipment-based model and the activity-based model will link with the productivity rate of equipment and the activity’s productivity rate respectively.

3.3 Integrated construction planning and scheduling, site layout planning and all construction process activity

The 3D site layout model is developed based on the 2D site layout planning on VP system. Through the VP technology, a process activity is generated by linking a construction model and an activity-based model or by putting a construction model and an equipment-base model together. Combining each process activity with the construction planning and scheduling, along with the 3D site layout planning, a process simulation is developed (Figure 3).
3.4 Resource analysis

In construction field, all activity duration is based on the experience of the project managers. The duration of activities is therefore often uncertain. One major function of VP system utilizes the real productivity data from system database to verify and then adjust the resource allocation to optimize the construction planning and scheduling. Through the process simulation, resource can be analyzed. Most building construction projects rely on tower crane to perform lifting and hoisting activities [13]. Tower crane is the most critical factor of the construction planning and scheduling. Through 3D visualization and simulation on tower crane, the planner understands the planning in details and is able to predict the planning mistakes [14]. The following sections will describe how resource allocation analyzed by using a case study.

4. Case study

4.1 Introduction

The case study was about two residence buildings project in Hong Kong. At the time of our research, the foundation of the two building was already completed. The site layout planning had been done. During construction, the project managers encountered a critical problem while planning the construction typical cycle. They would like to have a visualization, digit and mathematical method to measure the constructability of construction planning and scheduling. They
provided us a preliminary construction planning and scheduling of typical floor construction which was a time slot – planning and scheduling on a 6-day cycle.

The building used the prefabricated concrete facades that were supported by in-situ concrete walls and lift core and half of in-situ slab. The two buildings were named No. 1 and No. 2 respectively. The project managers divided the buildings into two working bays in the middle. The bays of building No.1 were namely 1A and 1B. The bays of building No. 2 were namely 2A and 2B. The construction cycle of each bay was one day behind one another so as to fully utilize the tower crane.

A set of steel formwork panels was applied on all the concrete walls and concrete slab. Project managers planned to construct the two buildings at the same time but only one set of steel formwork was used. Two tower cranes were installed in the construction site for lifting the formwork panels, prefabricated concrete façade, reinforcement bars and concrete buckets. One Tower crane (T1) was installed between Bay 1A and Bay 1B while the other tower crane (T2) was installed in the middle of Bay 2A and Bay 2B (Figure 4). The two tower cranes were of different capacities. The maximum radius of T1 was long enough to reach Bay 2B whereas the maximum radius of T2 can only reach the temporary storage space. There were two ways to lifting the steel formwork. One was directly lifting the formwork from bay 1A to bay 2A by using T1. The second one was lifting the formwork from Bay 1A to the temporary storage space between the two buildings by T1 and then the formwork was lifted by T2 to Bay 2B. For pouring concrete, both Bay 1A and Bay 1B used the tower crane while a placing boom was used in Bay 2A and Bay 2B.

Figure 4. The location of the two tower crane and the four bays.
Project planners encountered a critical problem on the construction planning and scheduling. All preliminary planning duration of the activities were not computed by mathematical method. They wanted to use the real productivity rate data to verify the construction planning and scheduling especially for the cranes as they were the critical elements on the whole construction planning and scheduling.

### 4.2 Preparation of construction model and resource model

A BIM of temporary work was developed based on the design drawings prepared by nominated subcontractor and that of building component was built based on the process activities to decompose the suitable assembly models. The equipment of two tower cranes and the placing boom were built to the equipment-based Model. Their capacities were based on their capacity catalogues to build. The activity-based Model was prepared from previous projects.

### 4.3 Start from preliminary construction planning and scheduling

In this case, the main construction method was to use of one set of steel formwork for two buildings to reduce the cost of steel formwork. However, there was not enough space for storing the steel formwork. The schedule of the project was represented with simple time slot document. We generated a template of construction planning and scheduling in VP-Excel format for inputting the time slot planning data (Figure 5). The planning and scheduling was imported into the VP system. It can allow the users to link the process activities with their related Construction Models and Resource Models (Figure 6).

### 4.4 Build site layout environment

The project planners had finished the site layout planning before we joined. We based on their 2D site layout planning to build the 3D site layout environment such as the location of two different types of tower cranes, site office, storage area, passenger and material hoists and access road. The 3D site layout could provide a virtual construction site for VP system to analyze the assignment of tower cranes.
Optimizing Construction Planning and Scheduling through Combined Virtual Prototyping Technology and Building Information Models

Figure 5. Construction planning and scheduling for VP-Excel Format.

Figure 6. Assignment of the tower crane to lift the façade in one process activity.
4.5 Analysis the resource allocation

By integrating the preliminary construction planning and scheduling, site layout planning, construction models and resource models, the simulation of the construction process was developed to analyze the resource allocation. All productivity data of the activities were obtained from various previous projects. The data was thus objective. We would apply the tower crane into these activities. The data included the duration of delivery material as the material must be delivered to the site before the installation of this material to prevent delays to other work. There were different types of productivity rate related to the tower crane (Table 1). The user defined activities which are linked with tower cranes in order to analyze the accuracy of the construction planning and scheduling.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Tower Crane</th>
</tr>
</thead>
<tbody>
<tr>
<td>The capacity of transit mixers</td>
<td>Yes</td>
</tr>
<tr>
<td>The speed of pouring by using tower crane</td>
<td>Yes</td>
</tr>
<tr>
<td>The lifting time of rebar</td>
<td>Yes</td>
</tr>
<tr>
<td>The lifting time of steel formwork from the building to temporary storage platform</td>
<td>Yes</td>
</tr>
<tr>
<td>The lifting time of steel formwork from 1B to 2B</td>
<td>Yes</td>
</tr>
<tr>
<td>The rising time of the working platform</td>
<td>Yes</td>
</tr>
<tr>
<td>The lifting time of rising and installation of facades</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The planning of the usage of the tower cranes was crucial to timely and safe achievement of the 6 day floor planning and scheduling as cranes were involved in various activities across a construction site and a large number of building components were installed by using the cranes. Firstly, based on real productivity data, the VP system checked the duration of the construction planning and scheduling used by the tower cranes and then adjusted the activity duration. Secondly, based on the preliminary construction planning and scheduling, the VP system visualized and showed the clashed activity by using tower cranes on the display and Gantt Chart respectively (Figure 7). Through these two steps, users adjusted the construction planning and scheduling to achieve no-clash activity on the planning according to the clashed activities.
5. Conclusion

It is believed that virtual prototyping will have strong potentials and will impose significant impact on the construction. In this paper, it illustrated how construction model and resource model can be prepared for the construction virtual prototyping. The purpose of using VP technology to construction simulation is to assist project planners to better understand construction planning process and predict the construction mistakes. The case study illustrated that VP system enabled the user to validate the proposed construction planning and scheduling. From the experience of the case study, access road is a key resource on construction planning and scheduling. The resource of access road should be analyzed in the VP system. This approach achieves the vision for Integrated Design Solutions (IDS) as the construction planning and scheduling integrated two new technologies that are VP technology and BIMs to minimize the planning errors and mistakes. Lastly, we are currently looking for other real projects to analyze critical more resources in order to optimize the construction planning and scheduling before building.
References


Optimizing Construction Planning and Scheduling through Combined Virtual Prototyping Technology and Building Information Models


