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Optimizing construction planning schedules by virtual prototyping enabled resource analysis

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ABSTRACT

The inherent uncertainty and complexity of construction work make construction planning a particularly difficult task for project managers due to the need to anticipate and visualize likely future events. Conventional computer-assisted technology can help but is often limited to the constructability issues involved. Virtual prototyping, however, offers an improved method through the visualization of construction activities by computer simulation — enabling a range of 'what-if' questions to be asked and their implications on the total project to be investigated.

This paper describes the use of virtual prototyping to optimize construction planning schedules by analyzing resource allocation and planning with integrated construction models, resource models, construction planning schedules and site-layout plans. A real-life case study is presented that demonstrates the use of a virtual prototyping enabled resource analysis to reallocate space, logistic on access road and arrange tower cranes to achieve a 6-day floor construction cycle.

1. Introduction

Careful planning, proper execution and established techniques are three critical factors that make construction projects successfully completed. Critical path method (CPM) and bar charts, are commonly used to enable construction projects to be done in a systematic way. This involves the project team allocating the different resources needed associated with the major method selected and decides on the appropriate sequence of assemblies. However, contractors' project planners face many uncertain and complex tasks during construction period due to e.g., design errors and mismatch of what is planned and actually needed [1]. In addition, errors and mistakes in the construction planning schedule occur frequently as its compilation depends to a large extent on the project team's limited knowledge and experience [2]. As a result, a successfully tendered building project can be very much a gamble due to the main contractor inability to predict whether the project will result in a profit or a loss in advance of construction.

For many projects, a major limitation is the lack of an effective computer-assisted technology for resource allocation and planning. Due to the complexity and the large number of factors involved, computers can be an efficient tool to help project planners. Such basic computer aids as bar charts and the critical path method are quite limited as they are unable to provide spatial construction features or resource and working space requirements [3,4]. More sophisticated methods combine the three traditional techniques of resource allocation, resource levelling and time-cost trade-off analysis. For example, Chan et al. [5], Hegazy [6], Leu and Yang [7] combine resource allocation and levelling using genetic algorithms (GAs); Li and Love [8] propose GAs for time-cost optimization problems; Hegazy and Kassab [9] combine a flowchart based simulation tool with the GA technique. Wang et al. developed a 4D Management for Construction Planning and Resource Utilization (4D-MCPRU) system which links a 3D geometrical model with resources to compute the resource requirement [10].

One of the shortcomings of the above project planning and resource allocation methods is that they did not take the real productivity rate of different machineries and manpowers into account. Virtual prototyping (VP) technology presents a great potential in this aspect. Currently, VP technology is assisting project planners to identify construction methods and prepare construction schedules [11]. If adding real productivity data, the present VP technology, can increase the objectivity of the construction planning schedule. It will allow planners to accomplish a comprehensive construction planning schedule that can effectively predict the potential constructability problems and analyze resource allocation including equipment, space and labor.

The aim of this research is to introduce VP technology into the optimization of construction planning schedule. The paper first describes the framework of integrated planning using the VP technology. Next, a case study is presented to demonstrate how the

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construction planning schedule is optimized. Future improvements to the VP technology are discussed and concluded in the final section.

2. The framework for integrated planning on VP technology

2.1. Definition of the construction model

There are two types of digital models for construction. The first type is BIMs (Building Information Models) which help evaluate performance by using information embedded in 3D models. The key function of the BIMs in the construction field is to allow project planners to view their static realistic images and check for design errors and collisions. Temporary works are a critical element in construction planning [3] and this type of model is used to develop temporary work models generated by the parametric models. Details of the temporary work model are available in Huang et al. [12].

The second type of the digit models is a detailed building component model, which is related directly to construction activities. The purpose of this model is as a design check and is also closely associated with the construction planning schedule. This type of model decomposes serial assembly models to develop a detailed construction activity. The decomposition of a product is a precondition of simulation and the assembly of parts is closely related to the simulation process. For example, assume the purpose of the simulation is to display the sequence of pouring concrete. One floor of the 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 (Fig. 1).

2.2. Definition of the resources model

Two resources models can be identified: an equipment-based model and an activity-based model.

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

Activity-based model — The activity-based model is a non-physical model linked with the productivity rate in an Excel library database. The fixing reinforcement activity is an example. The activity-base model is linked with the construction model by users when generating the VP simulation to develop one process activity in the system.

2.3. The importance of detailed simulation

It is important for the construction planning schedule to have detailed activities. A master program does not show all the detailed activities that occur in a project. The planning activities should be elaborated as more details are required. In the construction planning schedule, it is very difficult for the project planners to consider the detailed activities, resource allocation and space requirement. Project planners pay a lot attention to the master program but tend to neglect detailed activities. They understand that resource allocation is a key factor in the construction planning schedule but they lack mathematical method to analyze resource allocation. The space required by construction activities is the most difficult element for them to analyze as space is static stage *and* dynamic. Since spaces required by activities change in all three dimensions through time [13–16], the time–space may conflict between activities.

A detailed 4D planning schedule is required to compute the duration of each activity and associated space required. The activity "concreting wall" provides a good example (Fig. 2). It includes many types of activity related to time–space. Fixing reinforcement, erecting formwork and falsework, pouring, casting and dismantling formwork and falsework also require process time, space for crews to work and to temporarily store and manage the materials and equipment items needed. There are many factors to be considered in this simple activity. All of them are directly related to the construction planning schedule.

2.4. Implementation

The database of the productivity rate and the construction planning schedule is stored in Microsoft Excel format. The virtual prototyping system is implemented using Visual Basic for Applications (VBA) in the DELMIA V5 environment, and Microsoft Excel to develop the productivity database and planning schedule linking with the 3D Model. VBA is an object-oriented programming language to develop specific functions. 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 link with the productivity rate of equipment and the activity's productivity rate respectively.

2.5. Integrated construction planning schedule, site-layout planning and all construction process activities

The 3D site-layout model is developed based on the 2D site-layout planning on the 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-

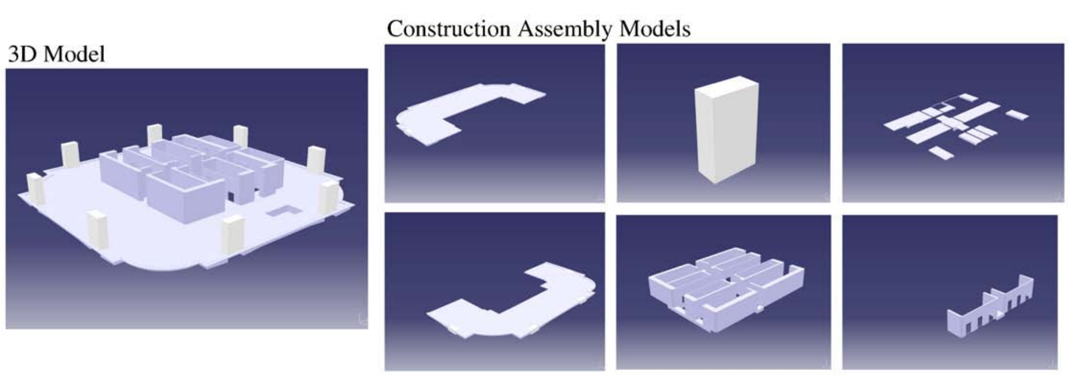

Fig. 1. Decomposition of 3D building model.