Automation in Construction 37 (2014) 68–80

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Integrating building information models with construction process simulations for project scheduling support

Wei-Chih Wang [a,*], Shao-Wei Weng [a], Shih-Hsu Wang [b], Cheng-Yi Chen [a]

[a] Department of Civil Engineering, National Chiao Tung University, 1001, University Road, Hsin-Chu, Taiwan
[b] Department of Civil Engineering, R.O.C Military Academy, Taiwan

ARTICLE INFO

Article history:
Accepted 17 October 2013
Available online 12 November 2013

Keywords:
Building information modeling
Operations simulation
Quantity takeoffs
Stroboscope
Scheduling

ABSTRACT

Many construction practitioners and researchers have developed four-dimensional (4D) models by linking the three-dimensional (3D) components of a building information model (BIM) with the network activities of a project schedule. In such a 4D model, the BIM provides limited information, except for the 3D components. To enhance the benefits of using BIM in 4D applications, this study proposes an interface system that uses the BIMs ability with regard to quantity takeoffs of required materials (such as steel, forms, and concrete) to support site-level operations simulation, ultimately leading to the generation of a project schedule. Our proposed system includes mechanisms that collect, store, and transfer information among various software packages. Facilitated by the BIM's quantity takeoffs, the operations simulation is able to consider uncertain durations of work tasks, which allows it to consider the competing needs for resources among multiple work tasks, and to evaluate various resource allocation strategies in order to create a suitable construction plan. Finally, the resulting project schedule is also linked to the BIM 3D components, thus producing an improved BIM-based 4D model.

1. Introduction

As a construction project grows increasingly complex and involves numerous building elements, two-dimensional (2D) drawings are often unable to adequately express design ideas or resolve the conflicting problems that interfere with the construction. Three-dimensional (3D) computer-aided design provides a solution that resolves these problems [1]. A number of researchers, though, have indicated that a four-dimensional (4D) model, which integrates 3D building components with time as the fourth dimension, can further facilitate construction management by discovering inappropriate schedule sequences, evaluating issues of constructability, and identifying potential time–space conflicts [1–7].

Recently, building information model (BIM), which is a 3D framework that can digitize a great amount of building information, has received much attention in the field of construction project management [7–11]. In particular, combining a BIM-based 3D model and a project schedule (which represents the fourth dimension of time) into a 4D model has been highlighted as one of the great merits of using BIM [10].

Currently, to develop a BIM-based 4D model of a construction project, several steps must be performed [2,6,11]. First, a BIM-based 3D model using commercial software (such as Bentley MicroStation or Autodesk Revit) and a project schedule (using MS Project or Primavera software) are developed separately. Second, a schedule simulator (such as SmartPlant Review or Navisworks) is utilized to link the 3D components with the related scheduling activities. Third, the resulting 4D model displays the construction sequence by showing consecutive 3D components as a progression over the time-span of the project.

However, the current 4D models are limited in that they do not effectively employ the BIM information to support construction scheduling [12,13]. That is, their BIM model mainly provides information regarding the 3D components, and thus offers little advantage over other 3D models used in 4D applications.

To improve the BIM's effectiveness in 4D applications, this work develops an interface system that applies the BIM's quantity takeoffs of a reinforced concrete (RC) structure to facilitate a site-level operations simulation, and consequently, to generate a construction schedule. Unlike current 4D models in which the schedule is developed separately, the proposed system generates a construction schedule according to the results of a BIM-facilitated operations simulation, and the resulting schedule is then linked to the BIM-based 3D components for 4D animation.

2. Review of current studies

This section reviews current studies of 4D and 3D models that address issues regarding the simulation of construction operations. It is worth noting that in most 4D models, the term "simulation" is similar to "visualization" or "animation," because it graphically views scheduling activities forwards or backwards temporally during any period of

* Corresponding author. Tel.: +886 3 5712121x54952; fax: +886 3 5716257.
E-mail addresses: weichih@mail.nctu.edu.tw (W.-C. Wang), m09716005@chu.edu.tw (S.-W. Weng), wss.cv91g@nctu.edu.tw (S.-H. Wang), 494310021@s94.tku.edu.tw (C.-Y. Chen).

0926-5805/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.autcon.2013.10.009

time, thus supporting the project participants (e.g., owners, designers, and contractors) in more effectively understanding the sequences of construction work [2,6,14]. On the other hand, the term "operations simulation," as used in the present study, is related to the performance of site-level construction processes, which are cyclic in nature, for several iterations, and is concerned with the competing needs for resources [15,16].

2.1. 4D models

According to Sheppard [3], although the development of 4D models began in 1973, it was not until 1984 that the first construction simulation software (Construction Systems Associates' PM-version) was introduced in the market. The major merit of such 4D models is the visual enhancements they provide. In addition to the 3D geometric data, BIM, which is capable of storing and computing large amounts of data, has been incorporated into the development of 4D models [4,7,8]. Moreover, the availability of commercial 4D management software, such as Bentley's Navigator and Intergraph's SmartPlant Review have made 4D applications increasingly popular [14].

Besides the visualization of construction schedules, researchers have developed numerous 4D applications, which include the detection of construction conflicts [7], optimization of site layouts [17], analysis of workspace congestion [18], discovery of inconsistencies among scheduling activities [2], planning of resource utilization [19], monitoring of progress discrepancies [5], detection of structural safety problems [7], discovery of spatial-related hazards [20], and generation of construction schedules [21].

For example, to facilitate the monitoring of a project's progress, Golparvar-Fard et al. [5] proposed the visualization of performance metrics that represent deviations in a project's progress. This is achieved through the superimposition of a 4D as-planned model over time-lapse photographs to produce comprehensive visual images that offer new insights. In their study, the augmented photographs provide a consistent platform for representing as-planned, as-built, and progress discrepancy information that facilitates communication and reporting processes. As another example, which involves an application that supports construction safety management, Benjaoran and Bhokha [20] applied a 4D CAD model together with rule-based algorithms in order to automatically detect spatial-related hazards (working-at-height) and to visualize the required safety measures, together with the optimal construction sequence.

Furthermore, Mikulakova et al. [21] integrated a knowledge-based approach and the BIM to generate automatically construction schedules and evaluate the schedules. In their study, an Industry Foundation Classes (IFC)-based BIM provides data for building components (i.e., objects with attributes) that are modeled as constraints during the planning process. A constraint describes the situation related to an execution problem resulting from construction conditions. A case-based reasoning system was applied to acquire a suitable construction process (including a certain number of tasks) with a similar execution problem. The obtained construction processes are then ordered to generate a schedule. This schedule can be visualized in CAD environments with IFC interfaces.

2.2. 3D models with operations simulation

With the objective of reducing resource idling time and improving site productivity, operations simulations have been applied to construction modeling processes in order to investigate time conflicts in allocating the utilization of resources [15,16]. Since the time and effort required to build simulation models are known weaknesses of operations simulations, numerous studies have been proposed that use 2D graphical symbols to represent the elements of construction operations [22–24]. These models of operations simulations, which have become known as activity-cycle diagram-based models, include CYCLONE (CYCLic Operation NEtwork) [15], RESQUE [25], COOPS (Construction Objective-Oriented Process Simulation) [26], and Stroboscope (State and Resource Based Simulation of Construction Process) [24]. Stroboscope, which is adopted in the present research, is a general-purpose simulation language that can dynamically access the state of the simulation and the properties of the resources involved in construction operations [24].

With the advancements in computer technologies, the three dimensions of building components have been added to operations simulation models in order to obtain valuable insight into the details of construction operations that are difficult to represent [23,27–29]. For example, Lu et al. [12] proposed a "zoom" interface between two computer system in a Critical-Path-Method (CPM)-based 4D CAD platform called 4D-GCPSU (graphics for construction planning and resource utilization) [19,30] and an operations simulation platform called SDESA (simplified discrete event simulation approach) [31,32]. This zooming into the processes of a CPM activity for operations simulation modeling enables one to assess the impact of the activity constraints (such as resource utilization, site layout, and alternative installation sequences) upon activity durations. How information generated by BIMs can be applied to support 4D development or operations simulation is not addressed in their study.

As the preparation of inputs for simulation is time-consuming, Wu et al. [33] proposed a 3D methodology 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. This simulation is applied to overcome the limitation of pre-specified activity sequences in such a way that whenever an activity is completed, all activities that have not yet begun are checked to determine whether their resource constraints are fulfilled. From the resulting set of executable activities, one activity is chosen randomly for execution and the required resources are allocated. Monte Carlo simulation with activities selected randomly supports constraint-based simulation and is repeated several times. A suitable solution with acceptable project duration is obtained and simulation results are then imported into a standard scheduling system, such as MS Project, for further modification. Finally, an improved 4D model is obtained. 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.

König and Habenicht [34] proposed an intelligent approach to automatically assign process patterns and define activity interdependencies to provide inputs for constraint-based simulation of construction operations. They adopted a BIM-based multi-model approach that links several models, including the quantity takeoff model, to obtain required input data for construction simulation and scheduling. In addition to a bar chart representation, the resulted schedule can be visualized.

In addition, many visual reality (VR) techniques have also been proposed that support construction simulation in a manner that allows interactions with the animation to define very realistic construction operations [35–37]. For instance, considering that construction engineers must be convinced of a model's accuracy (i.e., model credibility) before they will rely upon any simulation results, Rekapalli and Martinez [35] developed a discrete-event-based VR method to test the effectiveness of user interaction capabilities in validating complicated simulation models. Considering that 3D technology is not effectively combined with the pre-processing modeling of construction simulations, Chen and Hung [37] developed a 3D augmented-reality (AR)-based model that supports define inputs to run simulations. They devised 3D modeling components that virtually represent the areas, paths, machinery, and resources of material transportation operations, and also defined rules for transforming the modeling components into the required inputs. Simulation results were retrieved automatically for 3D, not 4D, animation. Furthermore, their study is not related to BIM.