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Development of a BIM-based structural framework optimization and simulation system for building construction☆

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ABSTRACT

Building construction has become increasingly complicated and extensive. Building information modeling (BIM), which is a technology that allows for the consistent management of information, is regarded as a necessary tool for managing the process of building construction from beginning to end. However, the information provided by BIM is rarely applied to on-site construction planning and scheduling. In this paper, we describe a BIM-based structural framework optimization and simulation system for managing construction planning and scheduling. Moreover we conduct a dynamic visualization of the construction process according to the optimized schedules by applying a predefined calculation formula and logic along with 3D geometry data and process data to determine the amount of work required for major construction processes. In addition, if more than two different construction schedules are fed into the system, it is able to compare construction schedules using its comparison simulation function.

1. Introduction

Many cities around the world have constructed high-rise office buildings as part of the competitive efforts among nations to boast of skyscrapers with landmark heights. However, there are uncertainties associated with such building projects, primarily due to their enormous scale and complexity. In particular, the structural framework for the building is implemented in such a way that reinforcing bars and forming and concrete works are repeated for every floor. Therefore, unless work schedules are optimized at the initial construction phase, the overall construction schedule is hampered. In order to minimize uncertainties in structural frameworks, it is necessary to predict project risks initially and solve them using information technology.

Recently, there has been a movement to adopt the building information modeling (BIM) method, which combines information technology with architecture and construction. Building construction has become increasingly complicated and extensive [1]. BIM, a technology that allows for the consistent management of information, is regarded as a requisite tool for managing the entire lifecycle of a building, from the initial conceptual design to its maintenance. However, the absence of standard formats between architecture and design platforms has been regarded as a factor that has made it difficult to implement BIM-based projects. The International Alliance for Interoperability (IAI) has developed industry foundation classes (IFCs), which are standardized data sets to enable the identification of data compatibility between application tools [2]. IFCs have been utilized as a standard format for exchanging and sharing BIM data. The recent research in the area of BIM can be classified into two categories: the four-dimensional (4D) simulation approach [11–13], which dynamically visualizes 3D building models following a time axis based on the input of designers, and the interoperability approach [4–10], which exchanges BIM data between applications. However, BIM information is rarely applied to on-site construction planning and scheduling.

In this paper, we describe a BIM-based structural framework optimization and simulation system that we developed to manage scheduling for important frameworking processes. First, we created a 3D geometry for the building based on a work breakdown system (WBS). Then, we fed geometry data that were extracted from the 3D geometry together with process data into the system. To link quantity data with process data, we defined such resource data as human resources, equipment, and materials, and we highlighted the construction method data, such as reinforcing bars and forming and concrete works. Thereafter, we used those

☆ For demonstration of the system in the manuscript, we posted on YouTube (http://www.youtube.com/watch?v=IBjxb3L60Ug). The 3D building model in this video is a high-rise building with 151 stories height under construction at Incheon City of Korea.

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construction method data to create detailed items for process data. Finally, we created a construction schedule by inputting calculation formula and calculation logic into the system to determine the workload required for each crucial process, and we performed dynamic visualization depending on the optimized schedule acquired from a 4D simulation function. If the structure of the process data, the properties of the resource data, etc., are changed, the construction schedule is automatically changed and a new simulation result can be obtained. Moreover, the system can compare more than two different construction schedules through a comparison simulation to help a user predict project results easily and accurately.

2. Literature review

BIM identifies building elements (walls, slabs, windows, doors, and stairs) by their attributes (functions, structures, usage, and others) using parametric technology, and it reflects any changes in the building elements immediately into the building configuration information by recognizing the relations between those attributes. Therefore, the characteristics of building elements and their relational information can be obtained by simulation using model data, which makes it possible to make rapid decisions during a construction project. In addition, BIM not only provides predictable information with regard to quantity, cost, schedules, and materials but also makes it possible to perform data analysis depending on structure and environment [3]. Research on utilizing information technology in the construction industry is separated into two categories: compatibility experiments using a neutral format such as IFCs and 4D simulation using dynamic visualization for 3D geometry.

Research on the compatibility of IFCs is classified as follows: an interoperability test method in terms of IFC data structure or geometry data, a system implementation method for verifying interoperability, and a data exchange method [4–6]. These areas of research have only focused on compatibility in terms of geometry information reflecting a design schedule for targeted compatibility tests, and consequently, some attribute information was taken into consideration. In the meantime, Kiviniemi [7] highlighted certain problems that arose from a building information exchange using IFCs in terms of geometry representation. In particular, there are some complicated problems involving the conversion and mapping of an information model during data conversion from geometry data generated through different representation methods into an IFC format. These problems include the conversion between the boundary representation (B-Rep) model and the solid model. An additional process is required to address these problems [8]. More recently, some collaborations have attempted to share a 3D geometry model by extending the IFC data model [9,10]. Although this extended model is still in the conceptual phase, it has been adopted as a standard information model in many commercial building design systems for data management using IFCs.

Research on a 4D simulation has focused on the management of a construction schedule and an implementation of the dynamic simulation environment for processes. Tulke et al. [11] proposed a dynamic collaboration framework that automatically creates a construction schedule through a business process reengineering approach and dynamically simulates cost calculation in connection with the schedule. However, geometry information is applied only to visualization through 4D simulation while it is additionally connected to the system separate from the construction schedule, which shows that conventional methods cannot be avoided. In the meantime, Tulke and Hanff [12] implemented a 4D simulation system that automatically connects geometry information based on data stored in a building model with time schedules to plan a construction sequence. However, the system could not break from the existing frame, which is merely a simple connection between geometry information and the schedule. Chau et al. [13] implemented the functions necessary for managing 3D geometry models, schedules, and dynamic resources on the 4D information system platform called Graphics for Construction and Site Utilization. However, this platform did not suggest results for developing an actual system or applications; it simply provided conceptual definitions for important factors to be included in the 4D simulation.

3. Hierarchical structure of a structural framework

3.1. Overview

A building can be defined as a hierarchical structure consisting of multiple building elements and work information. A structural framework consists of several zonings. A zoning is a conceptual unit used in the organization of building structures or building plans. Depending on the size of the building, a zoning may be a single floor or a part of a floor, or it may consist of several floors. In addition, zonings can be divided into multiple subzonings. A zoning includes construction work data, and more than one building member (for example, the 100th column on the first floor) is assigned to the construction work data with work-type data such as a lift and installation for the assigned member. Work-type data include the resource attributes necessary for carrying out individual works for a target construction project. Work time and cost are calculated based on the quantity and work-type attributes of the member assigned for the construction work data. The time and cost of all the construction work data at the same sibling are added to obtain the parent construction work data for a zoning, and the time and cost are determined according to a hierarchical structure. When a user inputs the expected construction date into the system, the start time and finish time of the construction work data are determined by adding the start time to the calculated work time. The rest time of the construction work data are determined based on the hierarchical tree of the structural framework. Therefore, the schedule data for the entire construction process are determined, and these data are used to perform the 4D simulation.

Creating a structure for a structural framework, as shown in Fig. 1, begins with 3D CAD modeling of a building based on WBS. First, an IFC file is exported from the 3D CAD modeling system to obtain the input data for the geometry information and the construction structure information from the CAD system, which carried out the architectural modeling. Then, an Excel file is exported from the 3D CAD modeling system to obtain input data for quantity information. Our structural framework optimization and simulation system creates a hierarchical structure based on input data from the IFC file and the Excel file. A user creates a construction method based on the definition of large-scale work and small-scale work, and the user assigns the construction method to the building elements in the framework construction structure. The construction method generates large-scale work and small-scale work for building elements automatically, and the framework construction structure is extended. The user inputs human resources, equipment, and material resources in the extended framework construction structure; the calculation process is executed; and work time, start time, and cost are calculated. When the work time, start time, and cost of all the small-scale work are calculated, the work time and cost of construction are determined. The final calculated framework construction structure is used for 4D simulation as schedule data.