AUTOMATED CONSTRUCTION PLANNING AND VISUALIZATION

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Abstract

There has been a lot of research on and release of commercial systems that enable evaluation and visualization of construction methods. These have enabled the selection of good construction plans. However, the process in which engineers build 3D geometry, formulate a schedule and eventually synchronize them is still a time-consuming process. Changing any aspect of the geometry or the schedule and re-linking them is also time-consuming. Therefore, the engineers may compromise on getting the best solution. This paper describes a technique to automate the generation of multiple sets of schedules, quantity takeoffs and 4D visualization from a single 3D model.

Keywords: Construction method, Construction planning, Quantity takeoff, Scheduling, Computer aided engineering, Visualization, Automation, 4D simulation

1. Introduction

Preconstruction simulation in 4D helps project participants parse the anticipated problems of their project, but the process of building a 3D model, scheduling the construction processes and linking each 3D object to activities is time-consuming. It is also difficult to rebuild and resynchronize the model as changes occur. Current 4D simulation systems have little flexibility.

In addition, in order to visualize the construction processes in the 4D environment, detailed designs and schedules are necessary. However, in the early stage of design, in which preconstruction engineers compare some different construction plans, we generally do not develop detailed designs or schedules. It looks paradoxical that we need some detailed designs and schedules in advance of comparative simulation and that we need simulation to detail the design and schedule.

I propose a new technique, with which preconstruction engineers only have to build a single simple 3D model to generate much variety of construction plans and visualize the processes in many scenarios. The key concept is separation of construction method information and building geometries. I realize pre-defined computer-interpretable construction method descriptions and implement a system to evaluate the methods to automate construction planning.

In this paper, I discuss the concept on the structural system because construction of structure tends to be the bottleneck of the whole process. High-rise buildings are my target, which include many repetitive activities.

2. Separation of construction method and building model

The difficulty of altering 4D models comes from the fact that 3D data contains construction method information. Once designers change the shapes of building elements, engineers rebuild 3D models and reassign them to the schedule. Changing the schedule forces them to reassign elements and schedule again. The solution is separating construction method information from design information, and combining them in construction planning as shown in Figure 1. If the construction method information is independent from any individual project and is pre-defined in general way, the only things preconstruction engineers have to do are model the 3D data and simulate it using pre-defined construction method information.

Separation of construction method information from building models allows us to create building models quite simple. It greatly reduces the time to enter the building models because CAD operators do not have to consider the shape of the objects. After separation of the building model and construction methods, new combinations of these data can be realized. Therefore, when changes occur, preconstruction engineers can combine the 3D building model and some other construction methods to simulate in different scenarios. The system finally attains high flexibility.

In this environment, detailed designs are not necessary. The building model does not have to have geometries. Each element is expressed in a very simple way. Simulation in the early stage of design can be achieved.

Separating the construction methods from projects can be accomplished by implementing a pre-defined construction method knowledgebase, which accordingly enables the preconstruction engineers to select some options from a large number of simulation scenarios. I call the pre-defined method descriptions “construction method templates.” We, construction engineers, have already obtained great amount of construction knowledge, and are developing new methods constantly. Feedbacks from job sites grow the knowledgebase as well.

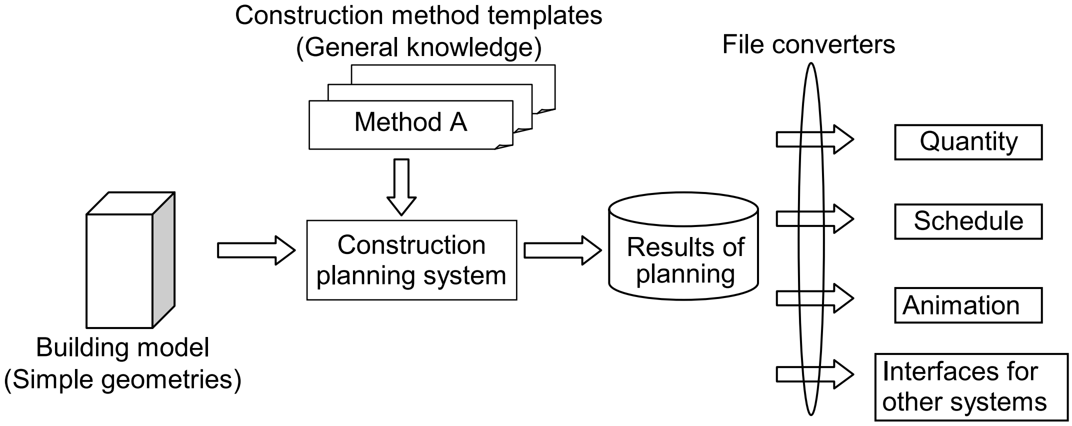


Figure 1: The outline of the construction planning system

3. Building model

Building models in this paper means simple 3D data of buildings. Models should not hold instructions on how to build but directions on what to build. It is true that construction method is a part of design. Without any tentative method, it is impossible to make decisions on material, size of elements and even façade of the building. However, in this paper, attributes such as shapes, materials and the types of joints are eliminated from the building model. It is the construction method that defines these attributes. What a building model consists of is a set of spatial areas to fill later with the embodied building elements. I propose that the areas should be expressed in cuboids (that is, rectangular prisms). Each cuboid consists of the location vector of its center and three perpendicular direction vectors. The type of element such as column, beam and wall is optional for more precise judgment. This type of geometry is easy to build by using any 3D-CAD systems.

4. Construction method templates

Construction method templates are written in XML for computer programs to read and interpret easily. They are also considered to be instruction manuals for human engineers because engineers can follow the descriptions to finally complete construction plans.

4.1 Definition of building components

4.1.1 Rules for building elements

This part of construction method template defines how to decompose building elements (Figure 2 (a)).

Building elements (in cuboids) are decomposed when a construction method is applied. Each construction method has different sets of building components. A conventional steel structure, for example, has square-columns and H-shaped beams. The "Reinforced Concrete with Steel Tube" method, on the other hand, uses round-shaped RC columns cast in thin steel cylinders, H-shaped steel beams and characteristic hybrid panel zones. The types and positions of joints also differ. The conventional steel columns are decomposed every two or three stories,

```
(a) Rules for building elements

Rule(
    Condition(
        Type = Column
    )
    Process(
        Command = Set attribute
        Attribute = Section
        Value = Box
    )
)

Rule(
    Condition(
        Type = Column
        Floor = 2n
    )
    Process(
        Command = Decompose above the floor
        Height = 1.0 m
    )
)

(b) Rules for components

Rule(
    Condition(
        Combination = Contains column elements
    )
    Process(
        Command = Set name
        Name = Column
    )
    Process(
        Command = Set attribute
        Attribute = Column stage
        Value = 2
    )
)
```

The original file is written in XML.

Figure 2: Decomposition and attribution

and their joints are approximately 1 meter above the floor slabs.

The rule is essentially the same as the if-then clause. The condition part mainly refers to the type of elements and their locations. The system evaluates the conditions for every building element and, if true, calls the designated commands. The commands are decomposition, setting attribution, etc.

4.1.2 Rules for components

A group of cuboids which are still connected each other at their intersections is called a component. Components are considered to be units of manufacturing or preassembling. The attributes such as the bolt counts, the welding length, and the concrete volume are added to the components (Figure 2 (b)). Attributes of these types are used as the workload of activities to calculate the duration.

Attributes are not only workloads but also any types of information. Components sometimes require certain kinds of equipment, such as columns stages for connecting girders and columns. Some engineers may have an interest in CO_2 emission as well as how many trucks they need to place concrete. All the attributes described here are summarized in the quantity takeoff.

4.2 Definition of schedule

The schedule of a construction method describes individual activities and their sequences.

4.2.1 Activities

Each activity has a name, a target component, some production rates, and some resources (Figure 3).

A type of component has one activity or more and an activity is assigned to only one component type. For example, erection and welding are assigned to a type of "column."

Activities depend on construction methods, and the workloads of the activities

```
Activity(
    Activity name = Install girders
    Target component = Girder

    Production rate(
        Minutes = 10 minutes
        Workload unit = piece
        Resource = Ironworker team
    )
    Production rate(
        Minutes = 15 minutes
        Workload unit = piece
        Resource = Crane
    )
    Resource(
        Name = Ironworker team
        Amount = 1
    )
    Resource(
        Name = Crane
        Amount = 1
    )
)

Activity(
    Activity name = Weld girders
    Target component = Girder

    Production rate(
        Minutes = 5 minutes
        Workload unit = Length of welding
        Resource = Welder
    )
    Resources(
        Name = Welder
        Amount = 10
    )
)

Sequence(
    Successor(
        Activity = Weld girders
        Floor = all
    )
    Predecessors(
        Activity = Install girders
        Floor offset = 0
        Type = SS+30%
    )
    Predecessor(
        Activity = Weld columns
        Floor offset = -1
        Type = FS
    )
)
```

Figure 3: Definition of activities

are calculated in accordance with the attributes of building components. The schedule definition in the templates is a prototype, which does not contain the duration. To calculate the duration of an activity, the system sums up the attributes and multiplies production rates to obtain the biggest number from alternative durations. Installing girders, for example, has two production rates; 15 minutes apiece for a tower crane, and 10 minutes apiece for an ironworkers' team. If there are one crane and one team, the duration will be calculated with crane's rate, but with two cranes and one team, the team rate will be used.

An activity also has one resource or more. These resources are categorized into temporary equipment, machinery, and labor. These types of resources are displayed along with the bar chart in the end.

4.2.2 Sequences of activities

Activities have predecessor-successor relationship, which has four options; Finish-to-Start, Start-to-Start, Start-to-Finish, and Finish-to-Finish. Lags can be added optionally and thereby statements such as "SS+30%" is acceptable.

The most important thing here is that activities do not have the location information as described in the former section. Activities are automatically generated for all the floors. Therefore, parametrical description of floors is necessary. For example, "Weld columns" of the *n*th floor is performed after "erect columns" of the *n*th floor and "install beams" of the *n*+1th floor. If the project has multiple zones, they are also referred in parametrical numbers.

5. Implementation of the system

To illustrate the concept, I have implemented a prototype system. I used Java to implement the main construction planning system and used MS-Excel, MS-Project and a general VRML viewer to display the results.

The main system reads and normalizes a set of cuboids, which can be translated from 3D-CAD data, then interprets a construction method template to decompose the cuboids, add some attributes, and finally produces a quantity takeoff, a schedule, and visualization of the processes over time (Figure 4).

Table 1 shows the features of two sample construction methods, and the input and output images are shown in Figures 5 and 6. Figure 5 is entering a building model using a 3D-CAD and Figure 6 shows some results of simulation for these methods. The planned

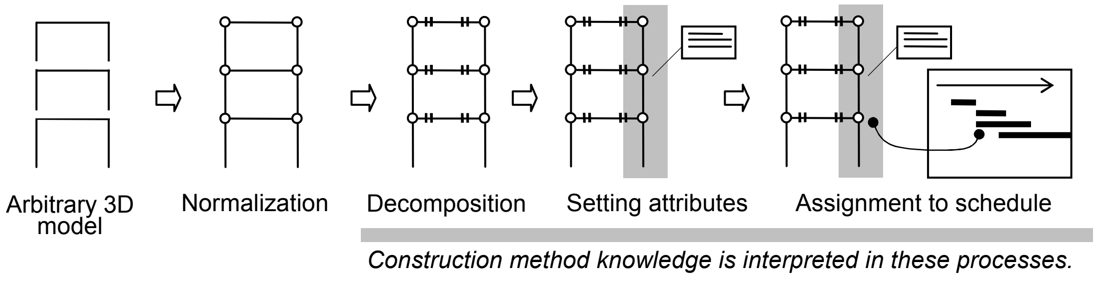


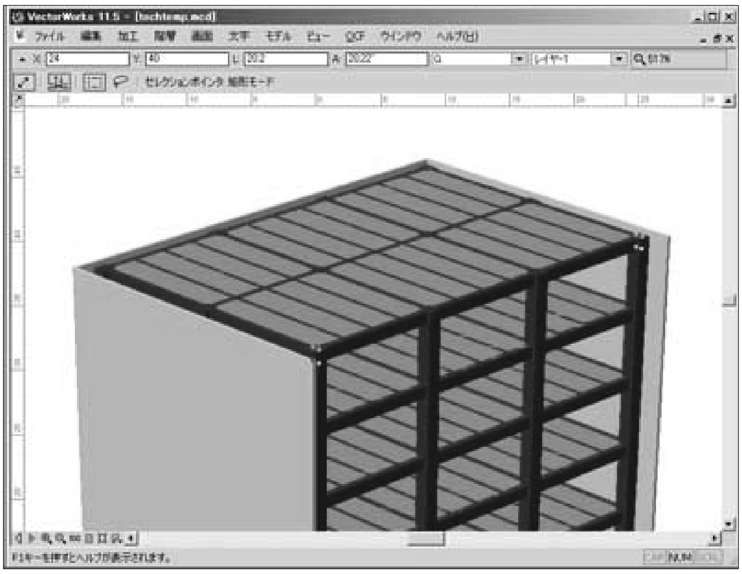
Figure 4: Simulation processes

structures differ according to the construction method templates. The quantity takeoff, which is on spreadsheets, has default unit prices. It is easy for estimators to modify the unit prices to calculate the total cost. The schedule, displayed on a project management system, shows the amount of resources as well.

As for the turnaround time of the system, it takes one to two hours to enter a building model of some stories (in case of a building with about 3000 normalized elements), and approximately 1 minute to process the building model and a construction method template and to finally produce the a quantity takeoff, a schedule and 4D visualization (pre-processes and post-processes included), while human engineers have to spend much more time for paperwork for half a day to two days. If the engineers perform many more construction methods, it multiplies time reduction effect.

Table 1: Features of two construction methods

		Method A (a type of steel)	Method B (a hybrid structure)
Structure	Column	Box-shaped steel	RC formed by steel tube
	Girder	H-shaped steel	H-shaped steel
Elements and Joints	Column	2-story long Welding at 1m above the floor Joints on random floors	Decomposed on every floor and on every bottom face of girders
	Girder	Non-bracket joint Welding	Bracket joint Bolting
Activities		1 Cast floor concrete 2 Erect columns of the current working floor 3 Install the girders only of the next floor 4 Deck, rebar work 5 Cast the next floor concrete	1 Cast floor concrete 2 Set the steel forms (columns) 3 Install the panel zones 4 Install the girders 5 Deck, rebar work 6 Cast the next floor concrete

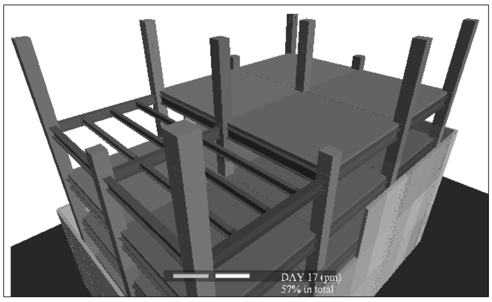


The front wall is temporarily removed for display.

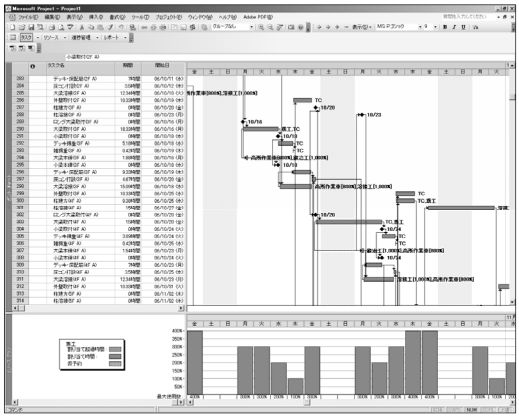
Figure 5: Building model input using 3D-CAD

6. Conclusions

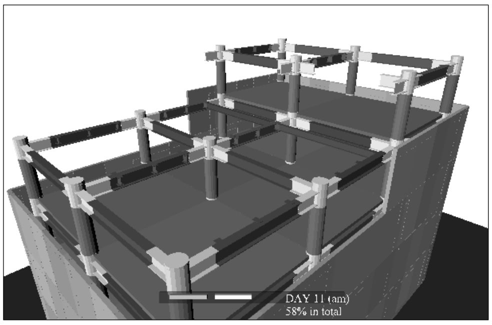
I have proposed a new concept to simulate construction processes by separating the construction method and the design information. I have also implemented a system to illustrate how this idea works. This technique helps automation of preconstruction planning and visualization of construction processes in the very early stage of design without making much effort to maintain building models. Project participants can make decisions on their directions judging from the total cost and time of their project including both of design and construction processes.



Result of method A



Bar chart schedule



Result of method B

Quantity takeoff and estimation

Figure 6: Results of simulation

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