A Research on Synchronized Multi-Site Scheduling Using 5-D Building information Modeling Technique

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ABSTRACT

The authors have been developing methods capable of deducing the Synchronized Multi-Site Scheduling using the interface matrix obtained from the relationship between preceding and following of the tasks for the construction work with a repetitive nature. In this study, several structural construction plans were estimated by carrying out simulations using the construction delivery time which are the criteria for the structural construction method plans, as objective variables. In this study, the Synchronized Multi-Site Scheduling method is in conjunction with the quantity information of the 3D model. Redefine the 3D model for using the technique of dividing and combining the 3D model utilized in the construction simulations. Various simulations are created by the 3D model is redefined with reference to the productivity data and unit price information. In concrete terms, the performance of each structural construction method plan was estimated by carrying out four process simulations for the skeleton construction work above the ground for a high rise RC office building using 1) site division 2) component division as variables.

INTRODUCTION

In project delivery method of the Design-Build of the private sector in Japan, construction planner performing construction plan without waiting for the completion of the design. In a review of specifications for building components, it is reflected in drawing at the construction plan. Therefore, there is no possibility in the Design-Build method of Japan, waiting for the completion of the design, construction planner that begin construction plan. In other words, construction planners conduct construction simulation in the early stages of design, it is verified the cost and construction schedule. Thus, there is no point in making a 4D/5D simulation using the 3D model after a construction method has been determined. On the other hand, in the early stages of design, it is difficult for construction planners to use a3D model has been created architect. In order to solve the problem, the authors developed a method to perform various simulations from a single 3D model. For the creation of various construction plans, using the Synchronized Multi-Site Scheduling software the authors developed. By using this method, design considering the construction process is possible. And, this method can be expected to contribute to practical problems such as the prevention of quality and rework in the construction stage. The 4D/5Dsimulation research in the initial stage of the design is a new theme, and there is novelty.

METHDOLOGY

In this study, the authors propose a method using a3D model architects created, construction planners to evaluate the construction methods in the early stages of design. This paper consists of two main parts. The first half of the study describes that re-defined a3D model which architects have created for the 4D/5D simulation. For re-definition of the 3D model, to operate the 3D model using a technique called Boolean operations. Part of the second is that performs the 4D/5D simulation using the 3D model that has been redefined. Construction simulation is made possible by the quantity information of the 3D model that has been redefined. In the 4D simulation shows that the verification of the cost(5D) can be from a comparison of the resource allocation which is consist of Construction machinery, temporary, and the amount of labor to be introduced.

Previous Studies: Synchronized Multi-Site Scheduling

This study is made based on ANDO(1990). A sequence of work required for a cycle of construction is divided into a number of sites which horizontally add up to one whole level, each corresponding to different stages of activities extended over several sites, and, on finishing them all in one day. In repeating the same work for the same number of days as that of site division, crew reaches the level one floor above. As for the advantages of the Synchronized Multi-Site Scheduling, stability of construction and shortening of the work term are taken up. The authors attempt to develop ANDO (1990) in this paper. The authors attempts to link between the Synchronized Multi-Site Scheduling and the quantity information of the 3D model.

Redefinitions of 3D Models

The shape of 3D models created by the BIM tool is defined by the Object Class. This approach is used effectively in the design phase. It is inconvenient to plan construction simulation; the 3D model will need to be redefined. It is necessary to create several 3D models, normally to perform several 4D/5D simulation. It is waste of time and effort, this is not realistic. For this reason, the process for dividing a single 3D model into several parts as completed forms and connecting them is necessary.

Division of Building Components

The Figure 1 above shows an example of a frame consisting of columns and beams of RC. In the case of the 3D model being made using the BIM tool, it is composed of objects; columns and beams. On the other hand, components shown in Figure 6 below are frequently utilized in the construction plan stages. These components are employed in cases where components with united column heads and beam, precast concrete with united columns and beams and cast-in-place concrete at the center of the beams are used in the construction work. Due to the fact that the models as they are cannot express the 3D model, operations of division and connection for the 3D model need to be performed.

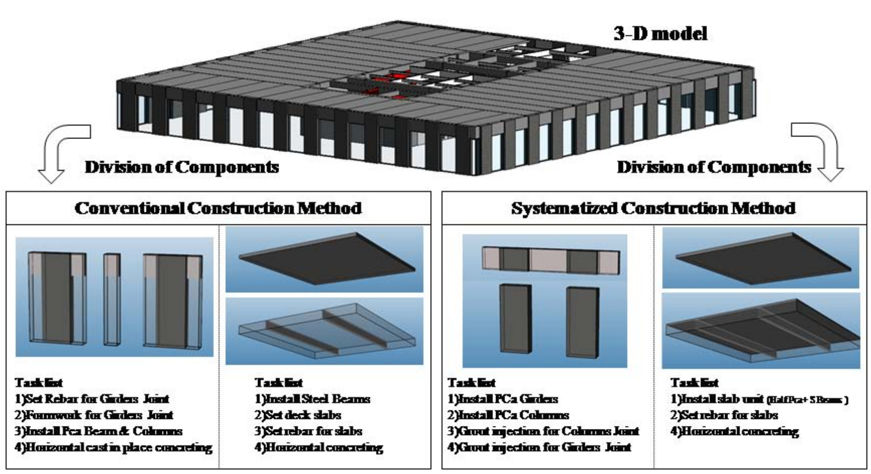


Figure 1. Division of Building Components

Site Division

With regard to the site division, the required quantities of the 3Dmodel are computed by freely creating the sites the construction planners decide on as well as by dividing the 3D model in the complete shape.

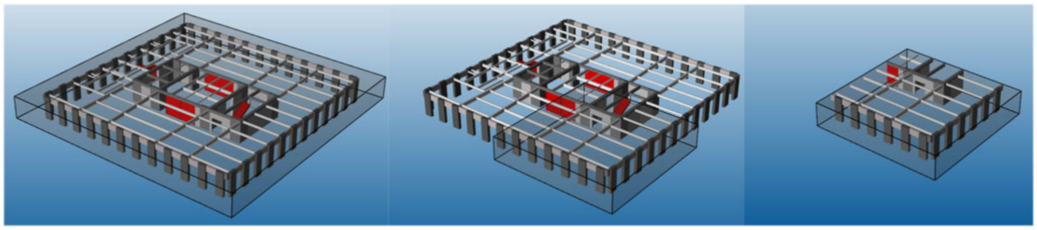


Figure 2. Site Division

Boolean Operation: (Operation Method for Division and Connection)

Aforementioned division and connection of components and sites for the 3D model are performed using the Boolean Operation as explained below.

Disconnection of 3D Model

This is an operation, required for dividing components, which consists of procedures to separate a cross sectional shape formed double by creating interference points and interference lines through interfering the 3D model with cut surfaces.

Set Operation

The set operation of sum is performed in accordance with the procedures creating interference points and interference lines obtained from the interference calculation, removing unnecessary parts and connecting the separated cross sectional shapes for the 3D model. These methods can calculate the quantities of parts where the objects obtained from dividing the components overlap with the joint parts of the objects as well as of the connected objects. Furthermore, in the case of the site division, the quantities required by construction planners to use for the construction simulation in the site can be calculated. At the stage of the construction simulation, simulations are carried out by preparing several choices for the division of parts obtained from single 3D models. However, when the part division used in actual construction work is decided as the simulation result, it is also possible to create a new 3D model and to change it for a former one.

Building for Simulation and Precondition

The simulation is performed for the skeleton construction work above the ground carried out on each reference floor of an RC office building with 25 floors.

Therefore, neither the underground work nor the foundation work is subject to the simulation. The reinforced concrete wall that is a center core is not investigated on the assumption that it is constructed regardless of the work on the reference floor because of the self climbing method. Parameters used in the simulation are the site division and the construction method. The Figure 3 compares 4-site dividing with 3-site dividing. The construction processes are sequentially finished while moving to the divided sites in the time unit of a day. With regard to the construction method, the conventional construction method and the systematized construction method are compared with each other. A 3-site division and a 4-site division as well as a conventional construction method and a systematized construction method are prepared, so four 4D/5D simulation models are verified. Based on the 3D model, the construction planning is carried out using the Synchronized Multi-Site Scheduling. The table1,2 shows the specification of the Construction process planning.

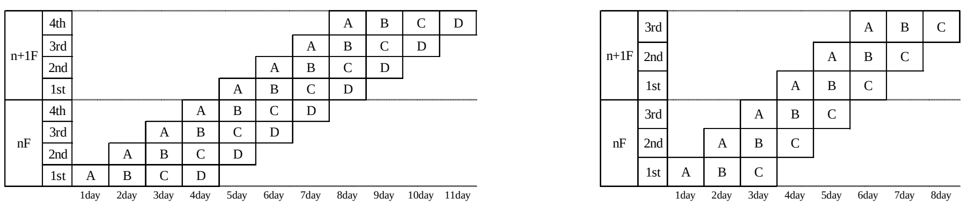


Figure 3. compares 4-site dividing with 3-site dividing

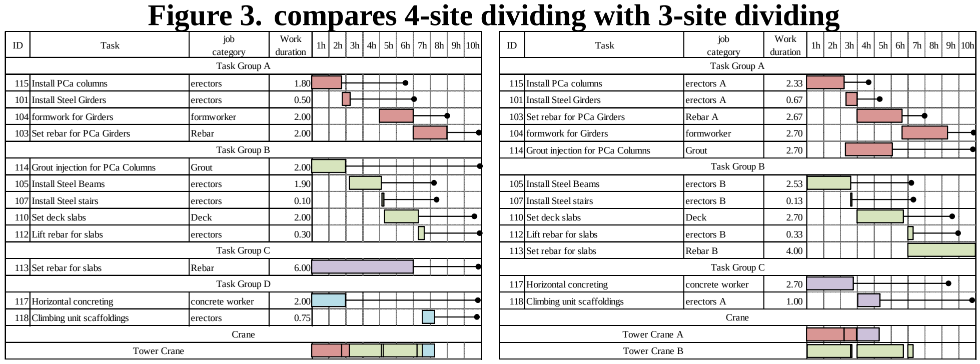


Figure 4.The multi activity chart of simulation No.1 and No.2

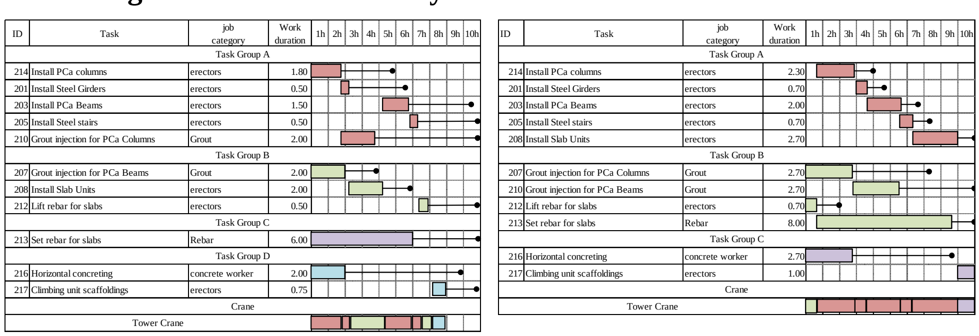


Figure 5.The multi activity chart of simulation No.3 and No.4

Table 1. Specifications of Simulation no.1and no.2

ID	Task (compornent & activity)	job category	work duration (hour)			Task Group		Preceding activity
			1-Site Division	4-Site Division	3-Site Division	4-Site Division	3-Site Division	1-Site Division
101	Install Steel Girders	erectors	2.00	0.50	0.67	A	A	115, 116
102	Install Steel Girders	Tower Crane	2.00	0.50	0.67	A	A	115, 116
103	Set rebar for PCa Girders	Rebar	8.00	2.00	2.67	A	A	101, 102, 115, 116
104	formwork for Girders	formworker	8.00	2.00	2.67	A	A	103
105	Install Steel Beams	erectors	7.60	1.90	2.53	B	B	101, 102
106	Install Steel Beams	Tower Crane	7.60	1.90	2.53	B	B	101, 102
107	Install Steel stairs	erectors	0.40	0.10	0.13	B	B	105
108	Install Steel stairs	Tower Crane	0.40	0.10	0.13	B	B	106
109	Set deck slabs	Tower Crane	8.00	2.00	2.67	B	B	104, 105, 107, 108
110	Set deck slabs	Deck	8.00	2.00	2.67	B	B	104, 105, 107, 108
111	Lift rebar for slabs	Tower Crane	1.00	0.25	0.33	B	B	109, 110
112	Lift rebar for slabs	erectors	1.00	0.25	0.33	B	B	109, 110
113	Set rebar for slabs	Rebar	24.00	6.00	8.00	C	B	111, 112
114	Grout injection for PCa Columns	Grout	8.00	2.00	2.67	B	A	115, 116
115	Install Precast Concrete columns	erectors	7.00	1.75	2.33	A	A	
116	Install Precast Concrete columns	Tower Crane	7.00	1.75	2.33	A	A	
117	Horizontal concreting	concrete	8.00	2.00	2.67	D	C	113
118	Climbing unit scaffoldings	erectors	3.00	0.75	1.00	D	C	117

Table 2. Specifications of Simulation no.3and no.4

ID	Task (compornent & activity)	job category	work duration (hour)			Task Group		Preceding activity
			1-Site Division	4-Site Division	3-Site Division	4-Site Division	3-Site Division	1-Site Division
201	Install Steel Girders	erectors	2.00	0.5	0.67	A	A	214,215
202	Install Steel Girders	Tower Crane	2.00	0.5	0.67	A	A	214,215
203	Install Precast Concrete Beams	erectors	6.00	1.5	2.00	A	A	201,202
204	Install Precast Concrete Beams	Tower Crane	6.00	1.5	2.00	A	A	201,202
205	Install Steel stairs	erectors	2.00	0.5	0.67	A	A	203,204
206	Install Steel stairs	Tower Crane	2.00	0.5	0.67	A	A	203,204
207	Grout injection for PCa Beams	Grout	8.00	2	2.67	B	B	203,204
208	Install Slab Units	erectors	8.00	2	2.67	B	A	205,206
209	Install Slab Units	Tower Crane	8.00	2	2.67	B	A	205,206
210	Grout injection for PCa Columns	Grout	2.00	0.5	0.67	A	B	214,215
211	Lift rebar for slabs	Tower Crane	2.00	0.5	0.67	B	B	208,209
212	Lift rebar for slabs	erectors	2.00	0.5	0.67	A	B	208,209
213	Set rebar for slabs	Rebar	24.00	6	8.00	C	B	211,212
214	Install Precast Concrete columns	erectors	7.00	1.75	2.33	A	A	
215	Install Precast Concrete columns	Tower Crane	7.00	1.75	2.33	A	A	
216	Horizontal concreting	concrete	8.00	2	2.67	D	C	210,213
217	Climbing unit scaffoldings	erectors	3.00	0.75	1.00	D	C	210,216

4D/5D SIMULATION

1) No.1: 4-Site Division by Conventional Construction Method

The multi activity chart of simulation model No.1 is indicated in Figure 4. In the case of the simulation for this model, since the total hours used for working in each category does not exceed 10 hours, the number of the crew is not increased. Because of the working hours used for a tower crane being less than 10 hours, this simulation model is established by installing one tower crane. The simulation results in103days for the delivery time, 2900 for the total number of workers.

2) No.2: 3-Site Division by Conventional Construction Method

The multi activity chart of the 4-D simulation model No.2 is indicated in Figure 4. When carrying out the simulation for this model, the total hours used for working in the categories regarding an erector, tower crane and rebar exceed 10 hours. Therefore, in order to reduce the working hours, one more crew is added for each of the works for erector and rebar and the number of workers in each crew is increased. This simulation model is effected by installing two tower cranes. This simulation results in 99days for the delivery time, 3300 for the total number of workers.

3) No.3: 4-Site Division by Systematized Construction Method

The multi activity chart of the 4-D simulation model No.3 is indicated in Figure 5. In the case of the simulation for this model, the total working hours for each category does not exceed 10 hours, so the number of the crew is not increased. Because of less than 10 hours for the tower crane work, the simulation model is effected by installing one crane. This simulation results in 103days for the delivery time, 1900 for the total number of workers. The total number of workers decreases as compared with No.1.

4) No.4: 3-Site Division by Systematized Construction Method

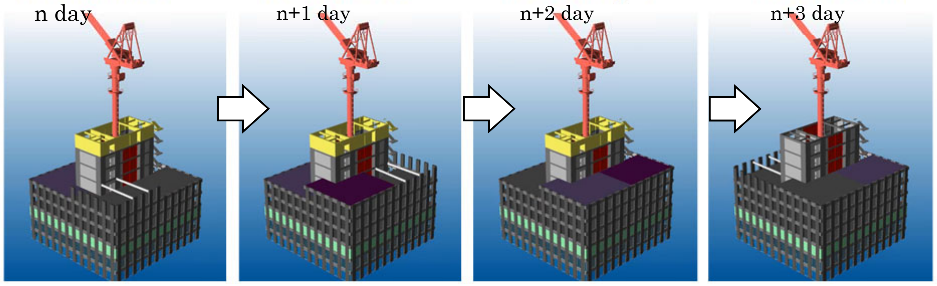
The multi activity chart of the 4-D simulation model No.4 is indicated in Figure 5.In this simulation model, which is different from that for No.2, the total working hours used for each of the three working categories, erector, tower crane and rebar, do not exceed 10 hours. As a result, this simulation model is formed by installing only one tower crane in spite of the process plan for high-speed construction implying that the execution of one floor can be completed in 3Days. This simulation results in 99days for the delivery time, 1425 for the total number of workers.

Table 3. Simulation results

	1 floor completed in 4 days The number of divisions of the location:4	1 floor completed in 3 days The number of divisions of the location:3	Team organization	
Delivery time	103days	77days	Job category	number of workers per team
Conventional Construction Method	**<u>Simulation model no.1</u>** Number of Tower Crane：1 Total number of workers：2900 number of workers per day：29	**<u>Simulation model no.2</u>** Number of Tower Crane：2 Total number of workers：3300 number of workers per day：44 *Annotation Erectors:2team Reber:1team 5wokers/1team 10workers	erectors	5
			grout	4
			deck	5
			Rebar	5/10
			Form worker	5
			concrete worker	5
Systematized Construction Method	**<u>Simulation model no.3</u>** number of Tower Crane：1 Total number of workers：1900 number of workers per day：19	**<u>Simulation model no.4</u>** number of Tower Crane：1 Total number of workers：1425 number of workers per day：19	erectors	5
			grout	4
			Rebar	5
			concrete worker	5

Summary of 4D/5D simulations

The simulation results are shown in the Table3. In the case of the 3-site Division by the conventional construction method, the simulation model is not effected without increasing the number of tower cranes and workers in order to shorten the construction period. In the case of the 4-site division, the increase in the number of workers and machines is not required. On the other hand, in the simulation using the systematized construction method, the process is able to be established without increasing tower cranes and workers in the case of 3-site division. In general, it is said that the systematized method is more expensive than the conventional construction method due to the cost required for transporting products manufactured in a factory to a construction site with a trailer. Therefore, it is clear that when planning the construction process regarding the delivery time as an evaluation axis, the process planning of simulation model No.4 is effective from the view point of the increase in the number of tower cranes and workers. As a result, it is clarified that in the case of priority being not given to the process, the process plan of simulation model No.1 satisfies the delivery time at a low cost and that



No.3 can reduce human power although it takes a higher cost than No.1.

Figure 6. 4D Animation of the simulation model no.3

CONCLUSIONS

In this paper, the following items have been made clear.

1) A 3D model created by an architect cannot be utilized as they are in the case of carrying out construction planning. Therefore, the shape of the 3D model itself needs to be redefined and new process components for construction planning are required to be created.

2) The operation for dividing and connecting the 3Dmodel performed using the Boolean operations in order to solve the aforementioned problems can be applied for components and site divisions. A method for effectively utilizing the 3D model by relating the 3D model subject to the operation to the process planning data can be indicated.

3) In case of a 4-D simulation being performed using the 3D model, a composite construction method is effective both for labor saving and for machine work saving. The site division is effective for shortening the term of work.

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