STUDY ON ASSEMBLY METHODS FOR LARGE-SCALE STRUCTURE USING AN INNOVATIVE AND INTELLIGENT FIELD FACTORY

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Abstract: The International IMS IF7 Project has developed a new type of the construction assembly methods for Large-scale Structure in view of the concept, an Innovative and Intelligent Field Factory for a large-scale building construction such as high-rise residences, ship building, etc. in order to improve productivity on construction site.

Much smaller investment and earlier capital collection become possible primarily because of the speed-up of construction and reduction of the injected labor force. One of the goals for developing the aforementioned construction method is to decrease the total construction period and amount of labor force to a half of those of traditional construction methods".

Keywords: Field-factory, Parallel production, Constant production, Pre-assembly, Construction-term shorten, Cost saving, Partitioning, Modularization

1. INTRODUCTION

The research project entitled “Innovative and Intelligent Field Factory”(IF7) is one of the international joint research projects under the IMS (Intelligent Manufacturing Systems) Program.

The Work-Package 1 of the IF7 Project has developed a new type of assembly method for Large-scale Structure using an Innovative and Intelligent Field Factory towards a large-scale building construction such as high-rise residences, office, ship building, or bridges in order to improve productivity on construction site.

WP1 has developed three construction methods called the Medicine Chest method, the Coffee Table method and the Big Hall method. All the three construction methods proposed can conform to construction works with various uses, forms, scales and construction terms and realize much flexibility to satisfy diverged social, users and contractors' needs. This paper focuses on describing the Coffee Table method of construction among the three.

WP3 of the IF7 Project has developed a prototype system of virtual construction site on computer where construction for a multi-storied apartment dwelling house in use of the Coffee-table construction method.

2. SOCIETY 'S AND USER' S NEEDS

A construction industry, one of the major industries in society, has an industrial obligation to supply adequate social infrastructures including buildings to satisfy the versatile social needs through its production activities. Then a construction industry is said not to be able to exist without its keen understanding of society least to mention that large sum of social investment is necessary for construction. Due to its historical role as provider of public infrastructure, the market principle has not been well implemented in a strict sense however. It is not because the construction industry ignored the principle, but because the government regulation has required a controlled development for the common public benefit.

The recent trend shows more of de-regulation necessary as the society becomes matured. The authors therefore think more of the market principle prevails in our industry, and that the construction production system will become closer to that of the manufacturing industry, where the market principle drove them more of automation to produce the products of high quality that more people are accessible to.

3. NEW PRODUCTION SYSTEM

3.1 Contractor's Needs

The construction companies must, needless to say perhaps, use the construction resources effectively, supply buildings of good quality quickly, safely and cheaply, and help realize the sustainable development of the society with un-precedent concern on environment load. Such resources as construction material, workers, temporary workers, machineries and equipments, time available, and financial resources must be orderly managed at every construction site they are engaged in to achieve the afore-mentioned business targets.

3.2 Final Goal of a Production System

The goal of a production system development is ultimately for realization of less capital investment necessary, quicker return of investment, and larger profit making by the system's shortening construction period and reduction of needed labor force.

Our setup of the target for the system development is properly phrased by putting the following question; " Does this system decrease the construction speed and amounts of labor to a half of those of traditional construction methods ".

This rather drastic set-up is done because such an extreme goal cannot be achieved by simple extrapolation of the existing technology today, but rather requires an essential paradigm shift in construction production system.

	Ratio (%)		Coffee Table Methods	Ratio (%)	
Labor's Cost	40	L/(L+M) 61		12	L/(L+M) 55
Material's Cost	35	–		3	–
Machine's Cost	15	M/(L+M) 39		10	M/(L+M) 45
Expenses	10	–		5	–
Total'	100	100		50	100

3.3 Methodology for its realization

The methodology we apply that the goal value can be realized in construction is shown in Table 1 and Figure 1.

Table 1 shows that, to make construction expenses 1/2, we must reduce 70% of the amount of labor, even in a case that the leasing cost of machines and carriage cost of material can be reduced by 20%.

In addition, Figure 1 shows that, to make the construction term 1/2, we must adopt a large-scale modules method and parallel production processing.

Table 1.Methodology of cost saving

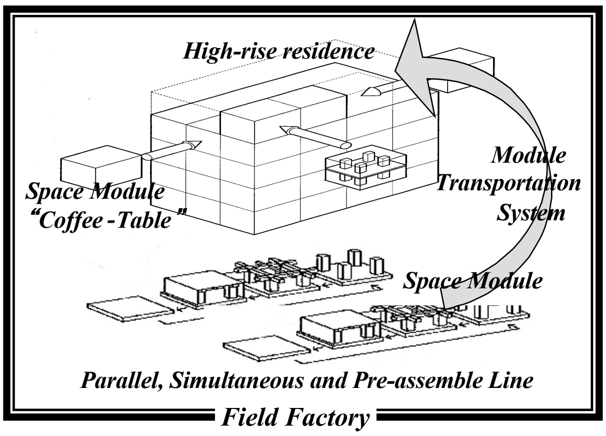
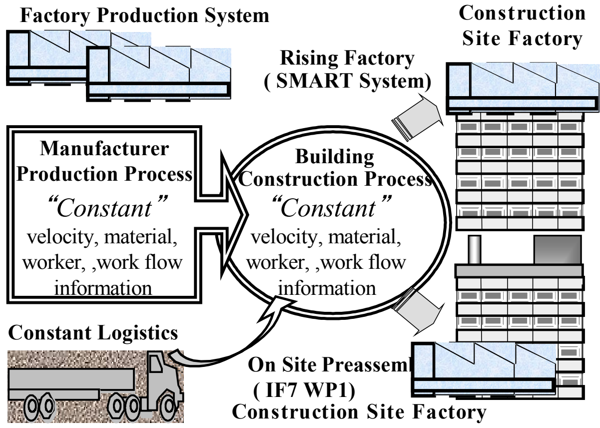


Figure 1. Methodology of time shortening

4 . CONCEPT OF COFFEE TABLE

4.1 Parallel Production System

The methodology of development is to apply a version of module production system, which is in fact



the main production technology in force by the automobile and shipbuilding industry. Its application for construction production is shown in Figure2.

The key words for this technology can be depicted as parallel and simultaneous production, pre-assembly, and large module products.

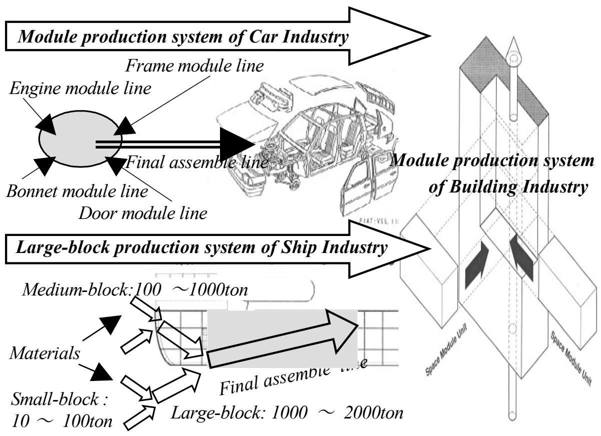


Figure 2. Production System employed by Automobile and Shipping industries

4.2 Constant Production Process on site

Much work is congested on the production site by the current system. Moreover, its construction period is determined by a sub-work of the slowest speed. On the other hand, construction term can be, in theory, shortened in infinite degree by the parallel and simultaneous production method.

The authors confirmed that it is fully a possible system to increase the construction speed, one floor per day, and decided that the concept of parallel and simultaneous production system is introduced and designed into construction planning. In addition, "constancy" is found to be a key word in the detailed design for the production process shown in Figure3.

For example, a constant machine device, a constant line speed, a constant skill and supply of labor, a constant work contents, a constant process, a constant part and a constant information etc.

We adopted the system that a parts-production factory is set off-line from the construction process, and in this factory, the parts are pre-assembled to manufacture a large module.

Figure3. “Constancy” is a key word

For the “Smart System” developed by Shimizu Corporation shown in Figure 3, as an example, it was a key word in the design of the production process to realize “constancy” throughout the process. The Smart System employed a raising assembly plant that proceeds simultaneously to the progress of the other construction work.

We developed also the other kind of system that the pre-assembly plant of parts is installed on the ground at site, in consideration of adopting the parallel and simultaneous production system.

4.3 Principle for Partitioning

When a building is partitioned into module units, an examination must be made from both of the structural and production viewpoints. The modular coordination theory (MC) is applied for that purpose to make the part division attain universality.

The principles for partitioning are as follows.

The principles for partitioning

(1). Demountable
(2). Stability of module
(3). Transportability
(4). Standard size for partitioning
(5). Maximum weight for manual handling
(6). Structural stability, etc

And division faces is located at the center position of the girder and at the leg position of the column by theoretical and the rational reason.

Because the appearance of the module looks like a coffee table, it is called "Coffee Table".

The parts expansion obtained from a building plan, through larger modules to elements are shown in Figure 4 and Figure 5.

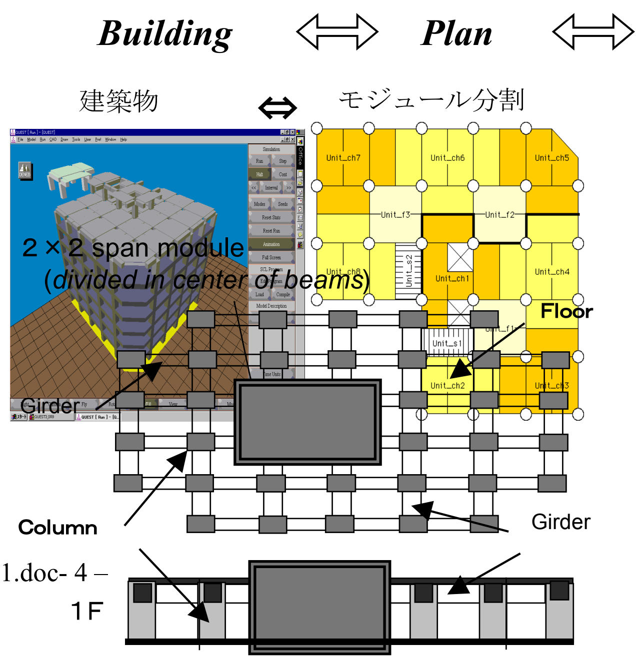


Figure.5 The flow of module

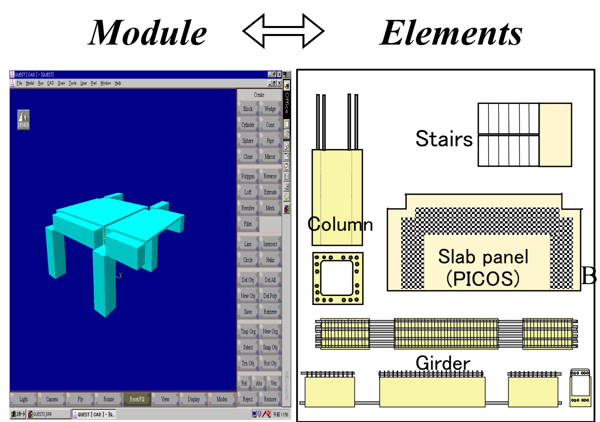
Figure4. Partition of building

4.4 Trial design for pre-assembly process

As for the introduction of robots to the construction site, some difficulties are pointed out for actual implementation, such as less repetitive work, much manual operation, heavier modules for transportation and assembly, rough ground at site, and by-leg mobility etc.

As for these difficulties, the Coffee Table method solves them nicely, as it employs large modules, automatic assembly of parts at a site factory, large-scale module transportation and a constant production process. Those are shown in the table 2.

It is required to deliver Coffee Table modules to final assembly area with JIT (Just In Time) for the needs of the construction schedule. The coffee table method can, therefore, construct a building in super-short term by quick automated assembly of modules at the on-site factory aside.



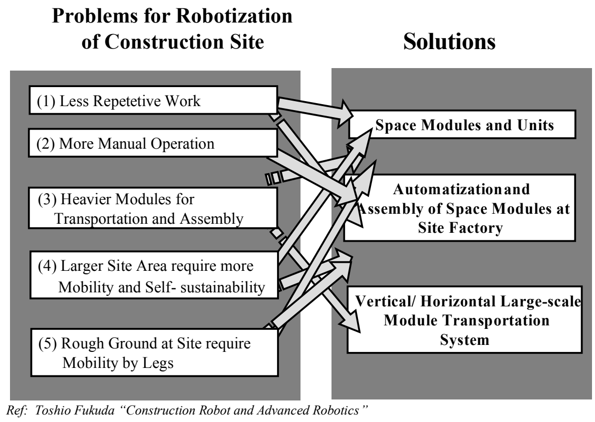


Table2. Implementation difficulties of site robots

For realization of the construction speed, two days per a floor, the manufacturing schedule plan for transferring, setting, assembling of each element and adjusting time of module production at the site factory must be designed.

It is required to deliver Coffee Table modules to final assembly area with JIT (Just In Time) for the needs of the construction schedule. The coffee table method can, therefore, construct a building in super-short term by quick automated assembly of modules at the on-site factory aside.

4.5 Evaluation of Process

The new production system in result induced much more different methods for design of production process from the traditional type construction methods. These are shown at Table 3.

Comparison of Traditional Method and Coffee Table Method

	Rate of Robotization
Final Line System **(The industrialized Construction Method)** 1. Sequential Production Method 2. Repetitive Assembling of Large volume of Multiple Kind 3. Interplay of Multiple Labor and Machine	１０～２０％
Pre Assembly Line System **(Coffee Table Method)** 1. Parallel Processing Production Method 2. Repetitive Assembling of Space Modules 3. Work of Simplified Function at Fixed Location	４０～８０％

Table 3. Different Methods

5. PROCESS SIMULATION FOR PRE-ASSEMBLY USING A MODEL

The manufacturing process of assembly for coffee tables at the field-factory is simulated.

5.1 The floating table

The factory is installed on site, and the floating table is arranged shown in Figure6. and Photo 1.

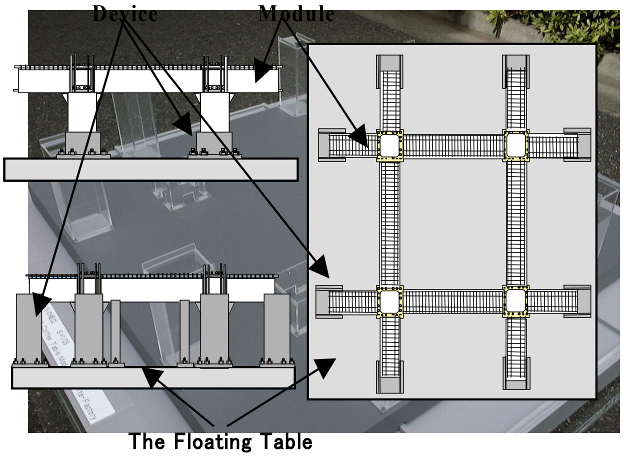


Figure.6. Floating Table

Photo.1 Floating Table

A module is manufactured on the floating table, and is carried to a final assembly place of the building site. This sequence of modular assembly at the site factory intends to reduce the number of workers at site and increase their productivity by designing the process to get more repetitive work with use of a single functioning automation machine. This process arrangement shortens a construction period drastically via modular assembly at the floating table.

Elements of columns, girders, and slab panels are assembled on the floating table. The floating table is therefore a temporary device to attain accuracy of the height of the column and the girder and the position such as the horizontal and vertical ones.

5.2 The assemble process of the column.

The bottom part of a column is inserted into the device fixed on the floating table. Then, the columns are assembled vertically by using the adjustment bolt. Photograph 2 shows the assemble process of the column on the floating table.

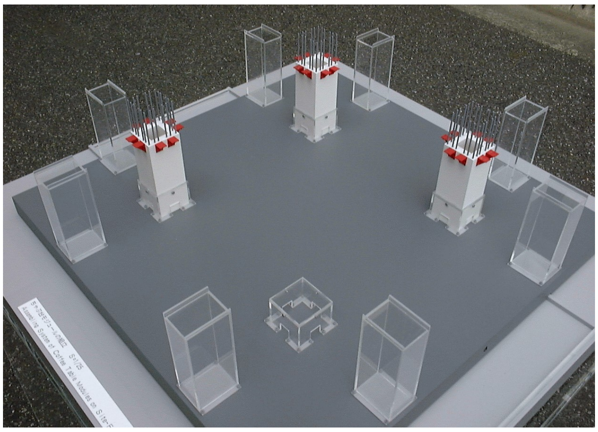
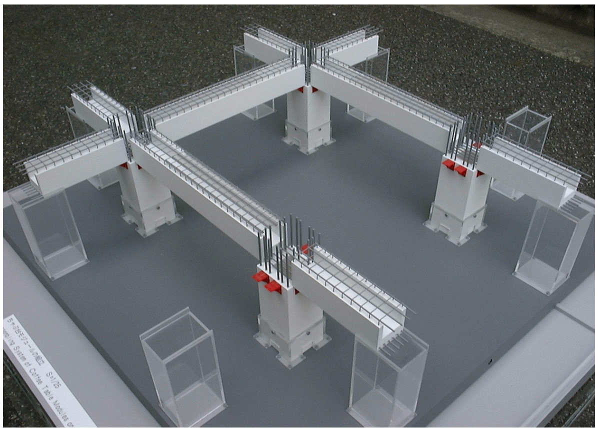


Photo. 2 Column assemblies



Next, angle-peaces are installed, and a column and a girder are fixed temporarily by this angle-peace.

The column is assembled within 2.5minute, and all the columns of a module are assembled in 10 minutes.

Because it is not on critical pass, adjusting work after assembly of the column is done on a parallel with the assembly work of the next girder.

5.3 The assemble process of a girder

A girder is put on the column and the temporary pillar device. After this process, the columns and the girder are fixed temporarily with temporary angle-peace.

One girder is assembled in 5 minutes, and this process finishes in 10 minutes. The girders must secure the vertical direction of four end parts and a horizontal direction and the precision of the rotation. This process is shown in Photo 3.

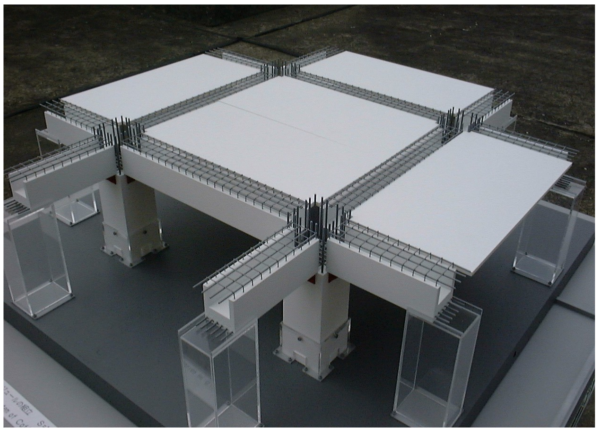


Photo. 3 Girder assemblies

5.4 Slab-panel setting process

A slab-panel is manufactured two panels at one grid size. Therefore, the slab-panels of the same dimension are necessary with six panels for a module. After this process is finished, all the elements are connected as shown in Photo 4.

The photo. 4. Connecting process

5.5 Lifting process of the coffee-table module

A module manufactured at the field-factory is lifting by a large crane, shown in Photo 5.
The modules are supplied to the final assembling place within an interval of 30-minute.

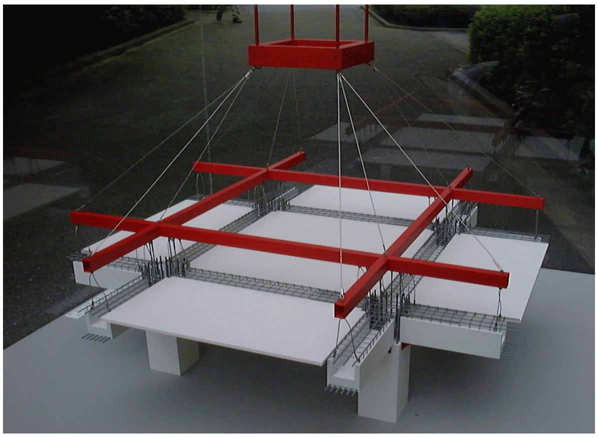


Photo 5. Module lifting process

All the modules for one floor can be assembled within a day according to this scenario. This module assembly process was confirmed intact by the numerical simulation, model simulation and trial construction.

5.6. Scheduling of the coffee-table module

A model residence is constructed by the coffee table method of construction. The schedule table of the Coffee-Table construction for this case is shown in Table4.

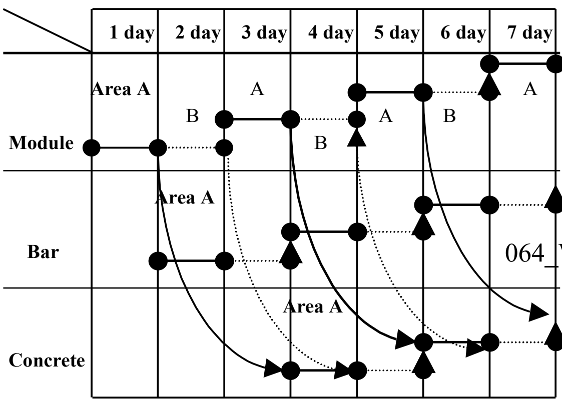


Table4. Schedule table

ACKNOWLE DGMENTS

IF7 WP1 has developed three construction methods of the Medicine Chest method, Coffee Table method, and Big Hall method.

This paper covered the Coffee Table method only. Two other construction methods will be reported in another opportunity.

IF7 WP3 has developed the prototype system of virtual construction site in computer for the Coffee-Table construction method.

The aim for the virtual construction site using QUEST, ENVISION is to develop a computer integrated construction system so called “V&R Coms” (Virtual & Reality Construction Management System) that is described elsewhere in this ISARC.

IF7 WP1 examined the possible application of the infill technology.

A "SI (Skeleton -Infill) Residence" will be reported by the end of the project.

This paper is a part of the IMS IF7 project.

REFERENCE

(1) IMS-Joint International Research Program. Domestic Research and Development Program. (IF7).
“Study on Innovative and Intelligent Field Factory – Repots of Research Findings (summary edition)
Match 2000

(2) Takehito Tezuka. Hiroo Takada. “Robot Oriented Modular Construction System. Parts1: Construction System ”. 9th ISARC 1992 Tokyo

(3) Hiroshi. Kurita. Hiroo. Takada, “Robot Oriented Modular Construction System Part2: Design & Logistics” ISARC 1993 Houston.

(4) Takashi Kunugi, Hiroo Takada. ”Parts Oriented Production System” IABSE 15th. Kobe 1998

(5) Kamikawa, Hiroo Takada “International Conference on Flexible Machine Automation” ICMA2000

(6) T. Iwase. Hiroo Takada., “Development of virtual and Real-field construction management system in innovative intelligent factory.” ISARC. 1999.

. Study on Innovative and Intelligent Field Factory