Implementation of an Automated Building Construction System

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1. Introduction

The Automated Building Construction System (ABCS) uses the top story framework as the frame for the execution space; this frame is equipped with automatic transport and climbing equipment; and the building is automatically assembled within this space. The system will permit builders to construct high-quality buildings according to stable schedules unaffected by wind or rain. When one story is completed, the builder uses the reaction force of the completed building frame to raise the working space, then constructs the next story. The builder completes the entire building by repeating these operations for each story.

The basic idea for this system was proposed in 1983. Subsequent research and development concentrated all the company's technologies. The system's practical value was confirmed in 1993, with its use in an actual construction project executed in Tokyo.

This report describes 1) the background to the development of the ABCS system, 2) purpose of the system, 3) course of events from the research to the development stages, 4) details of the system, 5) results of the trial execution, and 6) its future prospects.

2. Background of R&D

2.1 Problems in Japanese Construction Industry

The way that buildings are constructed in Japan must be radically transformed if we are to deal successfully with recent changes in economic conditions and with environmental and population problems.

The principal problems affecting the Japanese building construction industry are listed as the following:

1. Slowing down of construction investment
2. Labor shortage due to a lack of young workers entering the industry and aging of skilled workers
3. Widening gaps in labor productivity between construction and manufacturing industries
4. Substandard work conditions and high rate of worked-related injuries
5. Demand for protection of the global environment
Of these, the most serious are the problems related to the working population and productivity.

(1) **Working Population**

Figure 1 presents a forecast of Japan's productive population. People are considered productive between the ages of 15 and 64. The productive population will peak in 1995, then begin to fall. It is forecast that the proportion of elderly persons will rise as the productive population declines. Fewer young people are now entering the construction industry, and the average age of construction workers is five years above that of workers in the manufacturing industries. It is predicted that this trend will continue, and that the situation will even worse.

(2) **Labor Productivity**

Figure 2 presents a comparison between the Japanese building construction and manufacturing industries in terms of the rise in labor productivity during the past 10 years. Productivity in the building construction industry has risen only about 1/3 that of manufacturing. The widening of this gap between these two industries discourages investment in construction and deters young people from joining the industry. These two trends seem to be preventing the industry from fulfilling its social obligations.

2.2 **Innovation of Production Technology**

The building construction industry is taking various measures to overcome these problems. Figure 3 represents in schematic form, an overview of past research and development in the area of production technology by the construction industry. It is organized along three axes: information technology, industrialization technology, and mechanization - automation technology.

Back in the 1960s, the building construction industry began to adopt the information technology, industrialization technology, and mechanization and automation technology originally developed and used for production purposes by manufacturers. By a process of trial and error, the construction industry has made every effort to adapt to this technology to the production of buildings. Around 1990, we began to link these technologies organically to create new construction systems.

3. **Purpose of the Developed System**

At the Obayashi Corporation, our goal has been the creation of a new building production system to increase productivity and provide our employees with improved working environments. We call this the Obayashi Strategic Integrated Construction System (O-SICS) Built around a database which organizes common project information and the Integrated Project Control System responsible for the administration of the overall project, this system executes planning and design, production design and execution planning, and on-site production work more smoothly and efficiently. In the past, these tasks were divided among specialists and the sharing of task information was difficult. Our goal is to realize this system by taking advantage of all available information, communication, and automation technologies. Figure 4 shows the basic conceptual framework of this system.

The Automated Building Construction System (ABCS), which is a part of O-SICS, is a subsystem intended to automate on-site building production.
4. Details of R&D

Many of Japan’s leading general contractors establish design and engineering departments and technological research departments, and conduct sales and marketing activities incorporating the combined efforts of these specialized corporate divisions. These general contractors invest between 10 and 20 billion yen, or about 1% of their total sales in technological research and development. We have implemented the development of ABCS as part of Obayashi’s research and development efforts.

The basic idea for the ABCS system was created in 1983 by Mr. Teraoku, who was then the manager in charge of factory automation in the area of manufacturing in the Central Engineering Department. Using a model to prove the validity of his idea and by preparing a video outlining the operation of the system, he aggressively sold his proposal to top management.

The team consists of specialized technicians from the technological research institute, machinery department, and the information system center working with technical experts from the company’s design and execution departments. And, to deal with more specialized technical problems concerning machinery and information processing, we ask other companies to take part in joint research projects. (Refer to Figure 5)

Then, in 1985, an in-house research and development group was formally organized. While working further to finalize the basic ABCS concept, the group carried out feasibility studies. In so doing, they identified research and development issues concerning the required technological innovations. To achieve important elements such as the climbing mechanism and welding robots, the company cooperated with a construction machinery manufacturer to conduct joint research and began basic experiments, performance confirmation tests, and other research and development work necessary for the development of a working system.

Beginning in April 1992, we began actual system design and development on the premise that it would be applied to a real project. The project began in 1993. The research and development group performed on-site execution. (Refer to Figure 6)

5. Outline of ABCS

5.1 Project Outline

Photograph 1 shows the completed building that was constructed using ABCS. This building is a new company dormitory for single employees, one of a series of construction projects planned to commemorate the one-hundredth anniversary of the Obayashi Corporation. This building is a 10-story steel frame structure with a total floor space of approximately 10,000m² located on a site with a building area of roughly 650m². We were able to complete the structural work of the building in four months from March to July of 1993.

5.2 Practical System

Figure 7 presents an outline of the ABCS system employed in the construction project. The major technological elements incorporated in this system are also given below.

I) Super Construction Factory (SCF)

The Super Construction Factory (SCF) constitutes the core of the ABCS system, and is a ‘building construction factory’ enclosed by roof and external walls. The SCF incorporates an elevation device on a shaft installed at the same location as the building’s main column. Each time the SCF completes one level, it is raised up one floor to continue construction work in the vertical direction. This process is performed repeatedly until the SCF reaches the top of the building and becomes integrated with the top floor. (See Photo 2)
(2) Transport and Assembly System
The SCF is equipped with a ceiling crane for transporting steel bars, concrete floor panels, and external wall panels, and several welding robots for joining building components. Prefabricated building components are assembled on site and welding work is performed by a fully automated process. The required building components are transported from stock yards to the construction site by fork lift, and are then hoisted to the SCF by automated cargo lifts. (See Photo 3)

(3) Administrative and Control System
The Control Room was located off site in this project. From here, overall construction work was administered and controlled, including the operation of various robots and other automated machinery, management of precision tasks, and quality control. However, plans call for the installation of the Control Room at the top of the SCF. (See Photo 4)

5.3 Sequence of Construction using ABCS
Upon completion of the foundation or below-ground work, the SCF was constructed on the first floor built using the ABCS system. Automated transport and assembly systems were then added to the SCF, and the building was constructed following the steps shown in Figure 8. When the SCF reached the top of the building, the elevation equipment and ceiling cranes were removed and the main structure of the SCF was integrated with the top floor of the building; the removed machinery and equipment to be reused in future projects.

6. Result of Implementation
(1) Effect of Reduced Cost
Figure 9 compares the ABCS system and conventional construction methods in terms of the number of man-hours required to construct buildings of different story heights. The horizontal axis represents the total man-hours and the vertical axis represents the story height. As the story height of the building increases, the ABCS method begins to progressively reduce the total man-hours required. At or above 10 stories, fewer man-hours are required to employ the ABCS method, and the gap widens as the height increases.

(2) Effect of Shortening Construction Period
Figure 10 compares the time required for body work and finishing work for buildings of various story heights for the ABCS method and the conventional construction method. The horizontal axis represents the construction period while the vertical axis represents the story height. Our analysis of data obtained from the dormitory construction project reveals that it would take almost the same amount of time to complete a 20-story building using the ABCS method as it does using the conventional method. But it also indicates that the ABCS method will reduce construction time by three months for a 30-story building and 6 months for a 40-story building.

(3) Improvement of Construction Work Environment
As photograph 5 indicates, the SCF is covered with a roof and enclosed by walls, so that the work is unaffected by wind or rainfall. The results of work noise measurements reveal that the noise level outside the SCF is below the level specified for night-time work (60db). This means work can now be performed around the clock.

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This weather-proof capability provides a construction work environment that is comfortable for the workers, while allowing it allows cooperating companies, parts manufacturers, and material suppliers to set up their delivery schedules with confidence.

(4) Comparison of Construction Cost
This system was as cost effective as the conventional construction method. Greater cost benefits will be achieved by including equipment installation work and finishing work in the building construction process now executed by the ABCS method, in addition to the structural and exterior finishing work.

7. Future Outlook in ABCS
The results of the application of the ABCS method to an actual construction project have confirmed its technical feasibility. By providing the workers with a comfortable working environment and freeing them from heavy lifting and dangerous work, the roof and automated machinery have created an attractive worker-friendly environment for construction work.

(1) Expansion of System Application Range
We have to improve the cost-benefits of this system so that it will come to be widely used and become the core technology of a new building production system. To do so, we must expand its capability to include equipment and finishing work, and reduce the cost of its production equipment.

(2) Expansion of System Framework
Moreover, in order to maximize the benefits of the ABCS method, key issues such as a preliminary examination of its applicability at the design stage and logistics inside and outside the construction site need to be addressed.

References

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Figure 1  Population prediction

Figure 2  Changes in labor productivity in construction industry and manufacturing industry

Note: Data furnished by the Economic Planning Agency and the Prime Minister's Office. Labor Productivity = Gross domestic product (1985 values) / the number of workers.
Figure 3  A developing trend of product technologies in the construction industry

Figure 4  A basic concept of new building construction system (O-SICS)
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Figure 5 Organization of R&D for automated building construction system

Figure 6 History of R&D for Automated Building Construction System

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Photo 1  A new company dormitory constructed using ABCS

Photo 2  Exterior of Super Construction Factory (SCF)

Photo 3  Steel column erection with SCF-crane

Photo 4  Control center
Figure 7  System organization of ABCS
Figure 8 Sequence of construction using ABCS

1. [Diagram 1]
2. [Diagram 2]
3. [Diagram 3]
4. [Diagram 4]
5. [Diagram 5]
6. [Diagram 6]
7. [Diagram 7]
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Start floor above ground (Building Stories)

Figure 9 Comparison of labor force required

Figure 10 Comparison in schedule

Photo 5 Interior of SCF