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Analysis of the Development and Application of Automation Technology in Building Production

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Abstract

The purpose of this research is to examine current and future trends in the use of automation technology at advanced construction sites. At the start of this study, we established basic concepts to enable a working group to share a common understanding of construction automation. Based on these concepts, research was then carried out to determine what kinds of automation technology are presently being developed by general contractors in Japan to increase the efficiency of each production process starting from the production design stage. We then carried out various analyses on the introduction of automation technology to actual construction sites. This research was conducted as part of the long-term study on robotized building production being carried out by the Subcommittee on Technology for Robotized Building Production, which belongs to the Architectural Institute of Japan's Research Committee on Building Materials and Construction Procedures.

1. INTRODUCTION

The Subcommittee on Technology for Robotized Building Production was formed in April 1987 as part of the Architectural Institute of Japan's Research Committee on Building Materials and Construction Procedures. This subcommittee was established to analyze the present state of robot development in the building construction industry, and to clarify guidelines needed for the development of robotized execution systems and construction automation (hereafter referred to as "CA"). The subcommittee also established a working group (hereafter referred to as "WG") in April 1990 to focus on the automation technology that will be needed for CA, as well as a WG to concentrate on the building technology involved in CA. This paper reports on the results of the above research.

2. SUMMARY OF ACTIVITIES

The WG has been carrying out its research and study activities according to the following procedures:

1) Confirmation of methods for CA research

The procedures and methods for doing CA research were discussed, then the WG confirmed the research agenda and prepared a schedule for the entire project.

2) Study of the common perceptions of CA

The WG tentatively established the CA concept and fields related to CA in order to ensure a common understanding of CA among members of the WG.

3) Research on current automated production technology

The WG researched the current status of automation technology in building production by general contractors in areas subject to CA. The research results were then arranged in a table according to individual classification codes.

4) Research on technology related to CA

Based on the above table, the WG conducted its research on technology related to CA in questionnaire format. The goal was to determine the current status of automation technology as it is used in the work sites of general contractors that employ advanced construction technology.

5) Analysis of research results and preparation of report

The accumulated technological research results were entered into a data base, and the work of analyzing each research item began. The frequencies of use of the technology were totalled, and the effect of the site conditions and the interrelationships between the research items were analyzed.

This paper reports on steps 3, 4, and 5 as described above.

3. CURRENT STATUS OF AUTOMATED PRODUCTION TECHNOLOGY

The WG conducted research on the current use of automation technology for building production. Automation technology in the building production process was classified into

Table 1
Automation technology classification code chart

A. Production design →	B. Construction planning →	C. Construction control →	D. Construction work →	E. Maintenance
a. Estimation	a. Project budget	a. Cost control	a. Building frame construction	a. Maintenance
b. Construction planning	b. Scheduling	b. Scheduling control	b. Finishing work	b. Inspection
c. Construction method planning	c. Construction method planning	c. Safety control	c. Electrical and mechanical installation work	c. Repair work
d. Structural planning	d. Temporary work plannning	d. Quality control	d. Others	d. Demolition work
e. Others	e. Shop drawing	e. Others		e. Others
	f. Others			

five stages: production design, construction planning, construction control, construction work, and maintenance. We further divided each stage into smaller categories, and prepared a classification code chart (see Table 1) and table showing the distribution of technologies that are currently in possession of general contractors and those that are actually in use.

The WG collected 190 responses from personnel at eight general contractors. The distribution of the answers for each classification code is shown in Table 2. The response, "construction work," was the most frequent. There were comparatively fewer types of automation technology used in the "upstream" portion of the production system. We found that automation technology tends to be concentrated in the areas most closely related to on-site execution work.

4. RESEARCH ON CA TECHNOLOGY

The objective of this research can be summarized to understand the current use of automation in the work sites of general contractors that use advanced technology.

The WG received responses from 159 architectural technicians and 117 work sites. This research was conducted in September and October 1991. Eighty percent of respondents were members of a work site. The typical work site involved in this research would be a steel frame combined structure office building with 15 above ground stories and two basement floors, a total floor area of approximately 50,000 m^2, and a construction term of about 26 months.

Table 2
Comparison of distribution for technologies in possession and in actual use.

	A. Production design		B. Construction planning		C. Construction control		D. Construction work		E. Maintenance	
a	Estimation		Project budget		Cost control		Building frame construction		Maintenance	
	5.8%	1.0%	2.1%	4.9%	2.1%	6.6%	18.9%	18.0%	5.8%	0.3%
b	Construction planning		Scheduling		Scheduling control		Finishing work		Inspection	
	0.5%	0%	2.1%	1.3%	3.7%	4.3%	7.9%	9.8%	3.7%	0.3%
c	Construction method planning		Construction method planning		Safety control		Electrical and mechanical installation work		Repair work	
	3.2%	2.3%	2.6%	1.6%	7.4%	14.4%	0%	4.6%	2.6%	1.0%
d	Structural planning		Temporary work planning		Quality control		Others		Demolition work	
	1.1%	1.6%	2.6%	3.9%	8.9%	8.5%	1.6%	0.7%	4.2%	0.7%
e	Others		Shop drawing		Others				Others	
	10.5%	4.9%	7.9%	10.8%	2.6%	1.6%			0.5%	0%
f			Others							
			2.1%	1.6%						
Total	10.5%	4.9%	19.5%	24.3%	24.7%	35.4%	28.4%	33.1%	16.8%	2.3%

Notes: Left value: Percentage of technologies in possession.
Right value: Percentage of technologies in actual use.

5. TOTALLING OF RESEARCH RESULTS

Research results for a total of 259 cases of applied technology were gathered from 117 work sites. The work sites were separated into groups according to their total floor areas. The number of applied technologies used per work site for each group was as shown in Table 3. The results show that as the scale of construction increases, more advanced technologies are applied.

Next, the applied technologies listed in the 259 responses were grouped according to the technology classification codes shown in Table 1. Since some technologies cover two or more classification codes, the table shows a total of 305 cases of technologies. We prepared a distribution for the 305 cases, as shown in Table 2.

When the applied technologies were observed according to technology classification codes, the most frequent application of technology on site was "building frame construction" in construction work, followed by "safety control" in construction control, "shop drawing" in construction planning, and "finishing work" in construction work.

6. ANALYSIS OF RESULTS CONCERNING APPLIED TECHNOLOGIES

The WG analyzed construction technology where automation was actually employed at the work site. The following five items were considered for each type of technology.

6.1. Analysis of applied technologies according to their stage of development

Of the applied technologies mentioned in the answers, established technologies (those with long records of actual use) constituted about 63% of all applied technologies listed, so only 37% were new technologies. In the trial stages, new technologies made up only 10% of all applied technologies.

In relation to the technology classification codes, most of these technologies belong to "construction planning," "construction control," and "construction work." A large proportion of technology still in the trial stages, such as the use of robots and automated machinery, belonged to the category of "construction work." Well established technologies were mainly found in the areas of "construction planning" and "construction control" (see Figure 1).

Table 3
Relationships between applied technology and floor area

Total floor area	Number of applied technologies	Number of work sites	Number of applied technologies per work site
5,000 m^2 or less	18	14	1.29
10,000 m^2 or less	14	10	1.40
20,000 m^2 or less	23	19	1.21
50,000 m^2 or less	75	32	2.34
100,000 m^2 or less	70	24	2.92
Over 100,000 m^2	59	18	3.28
Total	259	117	(Average) 2.21

6.2. Analysis of applied technologies according their rates of application

We checked the percentage of work done by using each applicable technology, relative to the total work volume or entire work term. Technologies with application rates over 90% were mentioned in about 40% of all responses (the largest single category), and technologies for which the application rates were low were mentioned in fewer responses. These results suggest that many of the technologies have a high application rate.

Observation of the applied technologies in relation to the technology classification codes showed that the application rates were high for technologies in the area of "construction control," while those for "construction work" technologies were low. (See figure 2)

6.3. Analysis of applied technologies relative to the reasons for their adoption

When we checked the reasons for the adoption of technologies, three were especially notable: the labor shortage, a shortage of on-site supervisors, and technological interest. Together, these reasons constituted over 60% of all answers (see Figure 3).

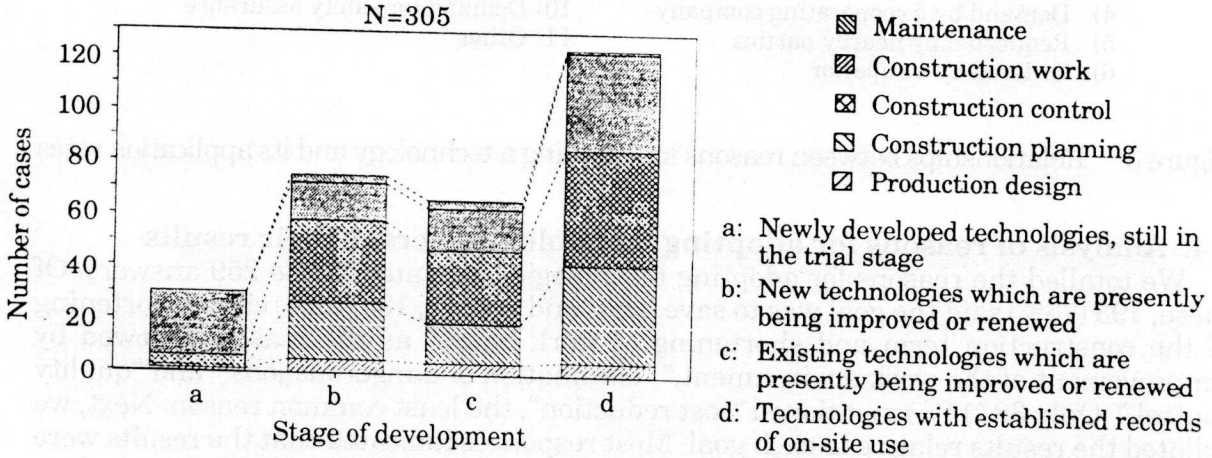


Figure 1. Relationships between development stages and classification codes

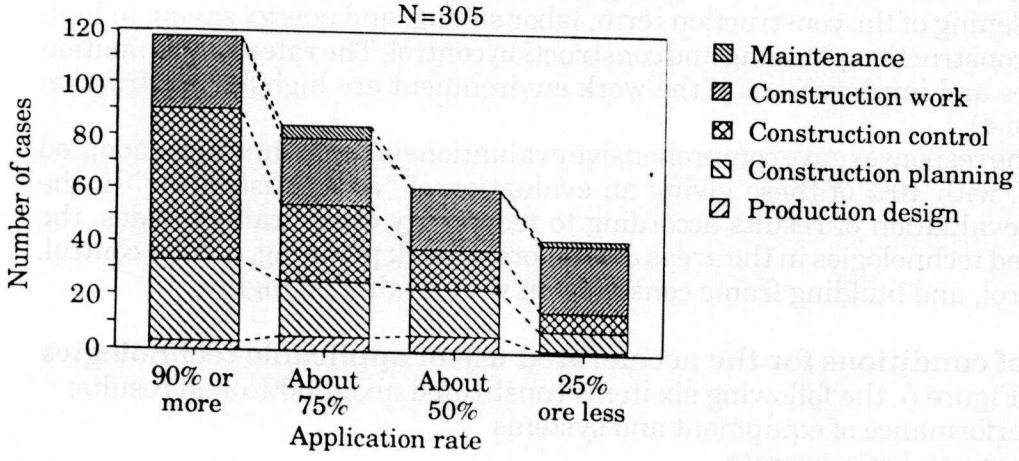


Figure 2. Relationships between application rates and classification codes

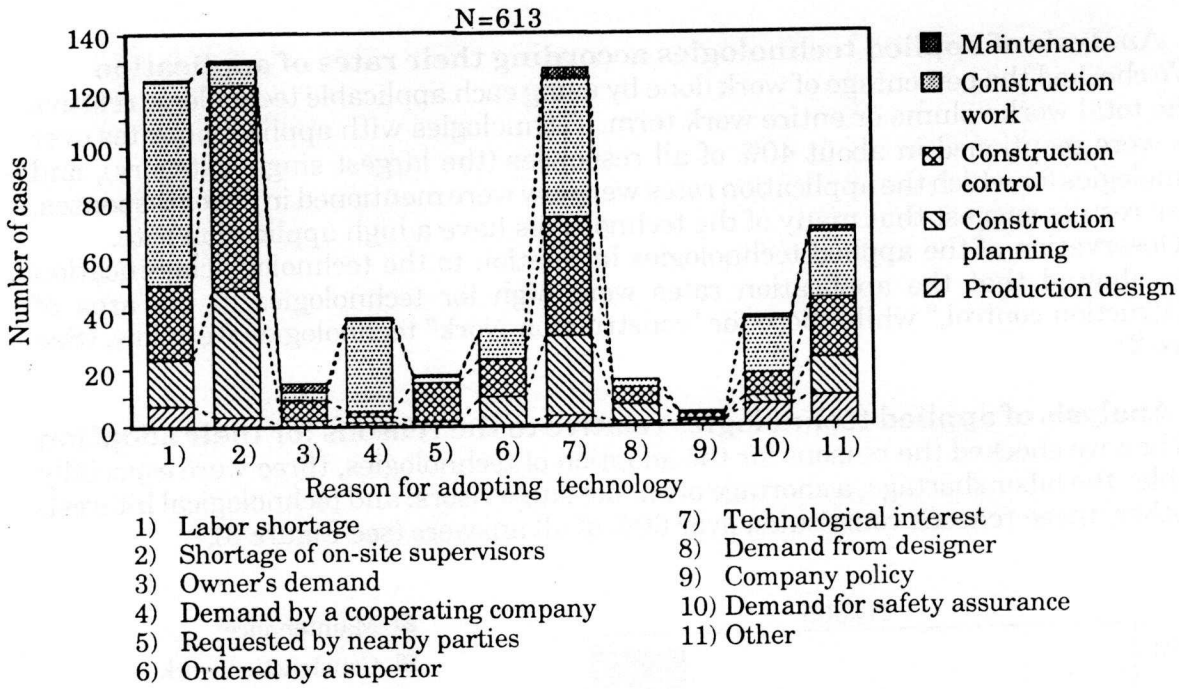


Figure 3. Relationships between reasons for adopting a technology and its application rates

6.4. Analysis of reasons for adopting technologies versus their results

We totalled the reasons for adopting technologies as stated in the 259 answers. Of these, 193 (75%) said the goal was to save labor and energy; 134 (52%) cited "shortening of the construction term and shortening of work hours" as the reason, followed by "improvement of the work environment," "elimination of dangerous jobs," and "quality control." Only 38 (15%) mentioned "cost reduction", the least common reason. Next, we collated the results relative to each goal. Most responses indicated that the results were almost as expected. However, those who said that their reason for adopting the technology was to reduce costs gave the lowest evaluations, indicating how difficult it is for automation to contribute to cost reduction.

Consideration of the reasons for adopting technology for each classification code indicates a shortening of the construction term, labor saving, and energy saving in high percentages for construction planning and construction control. The rates for elimination of dangerous jobs and improvement of the work environment are high for construction work (see Figure 4).

Over 90% of the responses gave comprehensive evaluations of the technologies adopted of "satisfactory", with 10% of these giving an evaluation of "very satisfactory." In the comprehensive evaluation of results according to technology classifications codes, the results for applied technologies in the areas of temporary work planning, quality control, scheduling control, and building frame construction were evaluated highly.

6.5. Analysis of conditions for the accelerated use of applicable technologies

As shown in Figure 5, the following six items constituted about 60% of all results:

1. Improving performance of equipment and systems
2. Making systems easier to operate
3. Providing sufficient time for prior study before use

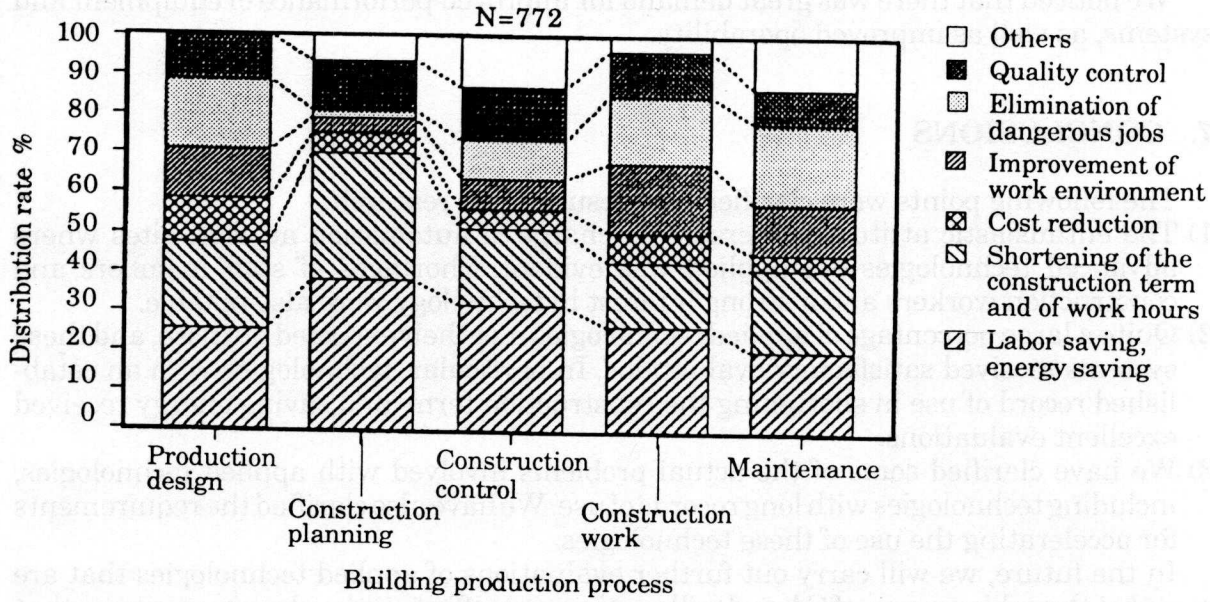
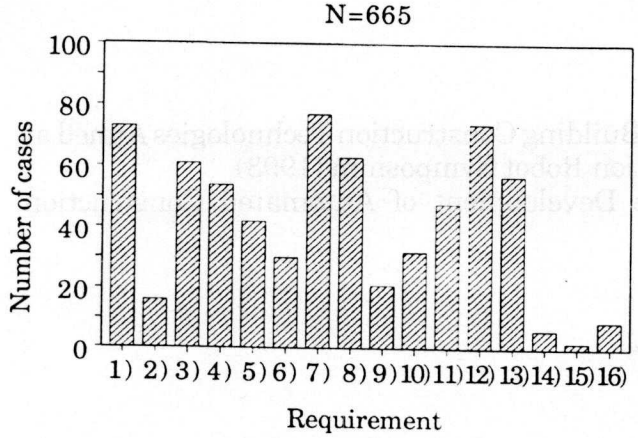


Figure 4. Distribution of the reasons for adopting technology for each classification code



1) Providing sufficient time for prior study before use
2) Improving knowledge among top executives
3) Assembling complete reference materials
4) Achieving thorough communications with specialists on introductory training, planning, operation guidance, and system maintenance.
5) Preventing excessive expenditures on preparatory work or on arrangements and preparation for production and design changes
6) Preventing excessive expenditures of time and money on inspection and repair work
7) Improving performance of equipment and systems
8) Ensuring skillful operation of equipment and systems
9) Taking measures to gain the cooperation of operators
10) Maintaining sufficient numbers of high-quality operators
11) Taking measures to minimize the time and labor needed to input data when operating the system
12) Making systems easier to operate
13) Making systems more widely applicable
14) Designing lightweight and compact system
15) Achieving cost reductions for equipment and systems
16) Other

Figure 5. Requirements for accelerating the active use of CA technology

4. Ensuring skillful operation of equipment and systems
5. Assembling complete reference materials
6. Making systems more widely applicable

We noticed that there was great demand for improved performance of equipment and systems, as well as improved operability.

7. CONCLUSIONS

The following points were clarified as a result of our research:

1) The enthusiastic attitude of persons in charge of automation at work sites where advanced technologies are applied was evident. Shortages of staff members and construction workers and a strong interest in technology were also notable.
2) Quite a large percentage of applied technologies met their expected purpose, and these systems received satisfactory evaluations. In particular, technologies with an established record of use in shortening the construction term and saving energy received excellent evaluations.
3) We have clarified some of the actual problems involved with applied technologies, including technologies with long records of use. We have also clarified the requirements for accelerating the use of these technologies.

In the future, we will carry out further evaluations of applied technologies that are aimed at the achievement of CA and will continue our efforts to develop new systems that incorporate CA technology. At the same time, we will further explore CA through concrete evaluations of overall effectiveness.

In closing, we would like to express our gratitude to the many people who contributed to the present report.

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