Questionnaire on Robotization in Building Work for Chartered Architects

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ABSTRACT

The Construction Robotics Committee of the Building Contractors Society has been extensively conducting construction work robotization questionnaires targeted to the construction trade – including specialized builders, construction machine manufactures and leasing companies – in order to promote the development and use of construction robots. This particular questionnaire was carried out with the primary target of architectural designers working for general contractors and architectural firms on the assumption that the awareness of architectural designers may greatly influence the success of construction work robotization.
The purpose of this paper is to report the survey results including how architectural designers recognize the current status of construction work robotization, what they want from builders and what they expect for future development.
As the promoting factors of the robotization, the construction industry has profound issues including harsh working conditions, hazardous and/or heavy labor and a lower productivity than other industries. Architectural designers therefore believe that the automation of building operation is inevitable and that the construction industry should pursue it as an industry-wide initiative.

1. INTRODUCTION

Ever since the collapse of the so-called "Bubble Economy," the Japanese economy is unprecedentedly sluggish and the construction industry is no exception. The supply and demand of construction labor is now in favor of the employer side and the shortage of skilled workers is hardly perceived. In the long run, however, the aging and shortage of the construction labor force and an improvement in productivity will be the primary concerns of the industry. As one of the solutions for these issues, the development of construction robots is largely anticipated. To date, many robots have been developed and some of them have already been put into practical use. Yet, the diffusion of robots is far from complete partly, because they do not fully reflect the opinions of people engaged in building production.

For years it has been pointed out that a requirement for the development of construction robots is to understand the opinions and demands of people engaged in the development, manufacture, sales and use of robots. With this fact in mind, the Construction Robotics Committee of the Building Contractors Society has been conducting awareness questionnaires regarding the robotization of construction work since 1988. The committee has carried out the research and analyses of specialized builders, construction machine manufacturers and leasing companies. This particular survey was designed to identify the awareness that architectural designers working for general contractors and architectural firms have regarding the robotization of construction work. This paper is a report of the research results.

2. TARGETS AND SUBJECTS

A. TARGETS

This questionnaire was conducted from December 1991 to January 1992 to determine the awareness that those people who were engaged in architectural design have in relation with the introduction of robots into construction work. In cooperation with the Design Group of the Building Contractors Society, 20 general contractors and 10 leading architectural firms of which members were working for the Group were selected as targets for the questionnaire.

Selected from each target were six respondents including three decorative designers, two structural designers and one equipment designer in the status of project leader.

B. SUBJECTS

The subjects of the questionnaire were as follows.

1) Estimation of work volume
2) Design considerations
3) Expected effects of the robotization of construction work
4) Adverse factors inhibiting the robotization of construction work
5) Perspective regarding the limitations and requirements for design work
6) Professional view of designers regarding the robotization of construction work
7) What kind of robots you, the respondents want to see developed
8) Personal experience employing robot(s)
9) The respondents' general opinion on ROBOTICS

3. RESULTS AND ANALYSIS

Out of the 120 respondents working for 20 general contractors, valid responses were returned from 101 (84.2 percent), and 42 valid responses were collected from the total 60 designers in 10 architectural firms (70.0 percent). (See Table 1.)

Table 1 Valid Responses

	Decorative designers	Structural designers	Equipment designers	Invalid responses	Total
General contractors	46/60	32/40	19/20	2	101/120
Architectural firms	19/30	14/20	8/10	1	42/ 60

Note: Returned responses/Total distributions

A. ESTIMATION OF WORK VOLUME

From the analysis of all replies, the options that the most respondents agreed were "Will decrease" for the period of one to two years later (60%), "Will increase" for the period of five years later (43%), and "Cannot estimate" for the period of 10 years later (46%) respectively. For the third target period, the second most common response, which was very close to the top answer, was "Will increase" (44%). The underlying reason for the rather pessimistic view for shorter period and the optimism for the longer period was probably the fact that the questionnaire was carried out from the end of 1991 to the beginning of 1992 when the Japanese construction industry was almost at the peak of an extremely busy period and the industry's capacity was getting close to its saturation point. (See Figure 1.)

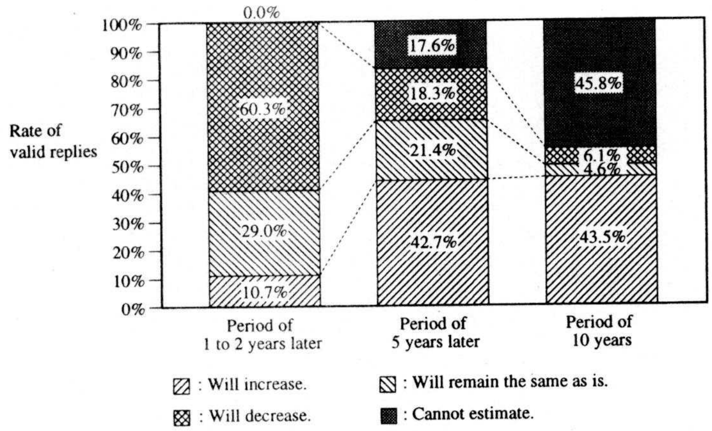
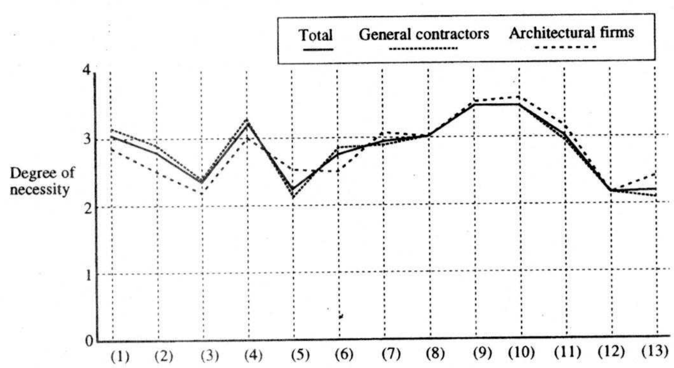


Figure 1 Estimation of Work Volume

In general, affirmative replies increased in number as the target period was farther from the present time; 11 percent said "Will increase" for the period of one to two years later, 43 percent for the period of five years later, and 44 percent for the period of 10 years later. At the same time, those who answered "Cannot estimate" increased in number as the target period stretched into the future.

B. DESIGN CONSIDERATIONS

To determine the degree of necessity of each design consideration, all responses were analyzed as shown in Figure 2 by the organization type (general contractor or architectural firm) that respondents belonged to.



(1) To make plans and designs which focus on the ease and efficiency of building work
(2) To conduct design review with construction engineers
(3) To avoid employing special finish and connection designs
(4) To actively employ labor-saving systems and industrialized construction methods (including unitification)
(5) To design according to the specific conditions of each site not by standard details
(6) To try to employ standardized and/or simplified design and structural planning
(7) To respect the individual characteristics of designer(s) (providing distinctive design)
(8) To eliminate design changes after the commencement of work
(9) To give priority to reliability and quality
(10) To pay particular attention to the balance of owner's demands and construction cost
(11) To employ advanced, innovative design
(12) To respect your own style of designing and pursue perfection
(13) To pursue overall completeness and never compromise in details

Figure 2 Degree of Necessity of Each Design Consideration

To calculate the degree of necessity, four points were given to each reply of "Absolutely necessary," three points for "Necessary," two points for "Rather unnecessary," one point for "Unnecessary" and zero for "Don't know." The total scores were calculated by multiplying the number of responses by each score. A very significant difference was not found between the two types of organizations. On the whole, (10) "To pay particular attention to the balance of owner's demands and construction cost" and (9) "To give priority to reliability and quality" were the top two considerations scoring 3.57 and 3.56 respectively. Following were (4) "To actively employ labor-saving systems and industrialized construction methods" with the score of 3.3 and (1) "To make plans and designs which focus on the ease and efficiency of building work" with the score 3.1. Table 2 summarizes the top three considerations with most "Absolutely necessary" or "Unnecessary" replies (including "Rather unnecessary") for each design work (decorative, structural and equipment).

Table 2 Top Three with Most "Necessary" or "Unnecessary" Replies

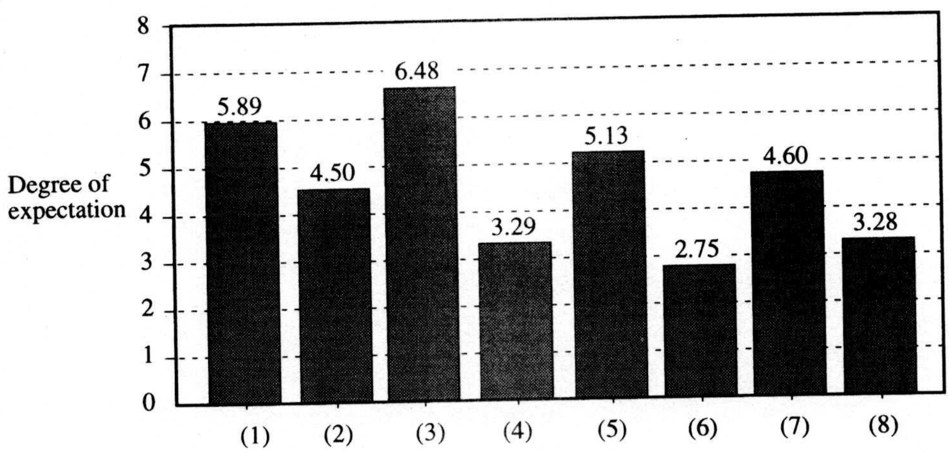
	Absolutely necessary		
Design work	No. 1	No. 2	No. 3
Decorative design	To give priority to reliability and quality	To pay particular attention to the balance of owner's demands and construction cost	To employ advanced, innovative design
Structural design	To pay particular attention to the balance of owner's demands and construction cost	To give priority to reliability and quality	To eliminate design changes after the commencement of work
Equipment design	To pay particular attention to the balance of owner's demands and construction cost	To give priority to reliability and quality	To actively employ labor-saving systems and industrialized construction methods (including unitification)

	Unnecessary and Rather Unnecessary		
Design work	No. 1	No. 2	No. 3
Decorative design	To avoid employing special finish and connection designs	To design according to the specific conditions of each site not by standard details	To respect your own style of designing and pursue perfection
Structural design	To eliminate design changes after the commencement of work	To pursue overall completeness and never compromise in details	To design according to the specific conditions of each site not by standard details
Equipment design	To employ advanced, innovative design	To respect your own style of designing and pursue perfection	To design according to the specific conditions of each site not by standard details

As shown in the table, no significant difference can be seen among the three design works as they all gave the highest scores to "To pay particular attention to the balance of owner's demands and construction cost" and "To give priority to reliability and quality." However, "To pursue overall completeness and never compromise in details" and "To respect the individual characteristics of designer(s) (providing distinctive design)" were given higher scores by decorative designers than by the other two types of designers. It therefore can be interpreted that decorative designers tend to give priority to the pursuit of added value and originality.

C. EXPECTED EFFECTS OF THE ROBOTIZATION OF CONSTRUCTION WORK

As to the robotization of construction work, the respondents were asked to rank eight expected effects in order of importance. For those ranked at first, eight points were given, seven points for the second-place effect, six for the third-ranked and so on. Figure 3 shows the calculated results on expectations for each effect.



(1) Necessary to reduce hazardous jobs
(2) Can be an effective means to shorten the term of construction work
(3) Essential to deal with the shortage of labor force
(4) Will reduce construction cost
(5) Necessary to meet demands for higher quality and accuracy of architecture and achieve consistent quality and accuracy
(6) Robots can do jobs impossible for human workers and thus the degree of freedom in designing will increase
(7) Can reduce work loads and fatigue of craftsmen (skilled workers)
(8) Effective for maintenance work such as window wiping, cleaning and inspection

Figure 3 Expected Effects of the Robotization of Construction Work

Here we choose the top three effects and discuss the reasons for their especially high scores. Behind the 6.48 points scored by "Essential to deal with the shortage of labor force" was the fact that labor shortage was very likely to become a great concern of the construction industry partly because of the industry's negative image. The answer of "Necessary to reduce hazardous jobs (5.89)" indicated robots were highly expected to replace human workers for hazardous and high altitude jobs so as to reduce as many labor accidents as possible. The third highest score of 5.13 given to "Necessary to meet demands for higher quality and accuracy of architecture and achieve consistent quality and accuracy" may be explained by the possibility that robots would be an effective means to secure consistent high quality and improved accuracy of construction work.

On the other hand, the three expected effects with the lowest scores were "Robots can do jobs impossible for human workers and thus the degree of freedom in designing will increase" (2.75), "Effective for maintenance work such as window wiping, cleaning and inspection" (3.28) and "Will reduce construction cost" (3.29). Robot technology was still at an immature stage and the survey results indicated that designers did not expect much of robots' working capabilities.

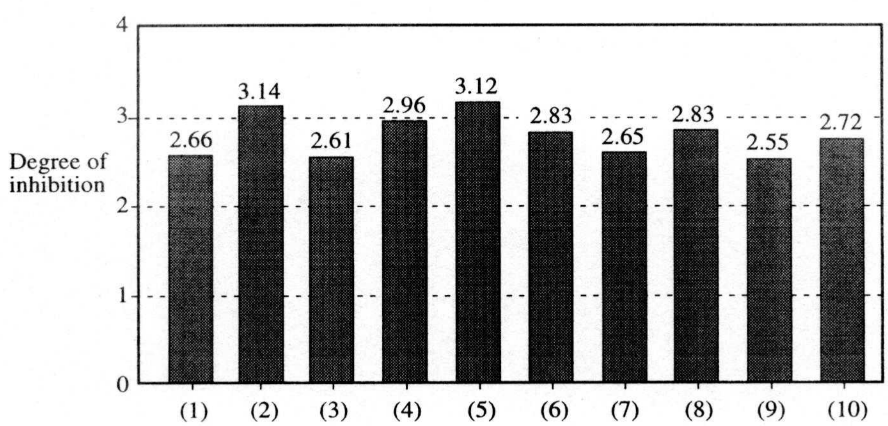
D. ADVERSE FACTORS INHIBITING THE ROBOTIZATION OF CONSTRUCTION WORK

Figure 4 shows the calculated results for the degree of inhibition of each factor; four points were given to each response of "Very possible," three points for "Possible," two points for "Rather possible" and one point for "Impossible."

The reason for the highest score 3.14 given to "Design and specifications differ from site to site" is that the construction industry custom-makes individual buildings of different designs and specifications. Reflected in the second highest score 3.12 of "Many different types of jobs are required and very few jobs are repetitive" was the fact that many and various types of workers come to site one after another for their respective jobs and a high level of skills is required at the site. In addition to these two, "Prefabrication and material standardization are not well developed" (2.96), "Many types of materials are used and new products are continuously being introduced" (2.83) and "Labor-saving won't necessarily lead to cost reduction" (2.83) were listed as major factors inhibiting the robotization of construction work. From these results, we can infer that there are other inhibiting factors specific to the production systems of the construction industry. To effectively use robots throughout the construction industry, it would be necessary to change the overall framework of production which would entail the analysis and improvement of job contents and the standardization from design to construction work.

As shown in the chart, there was no big difference in the scores of the 10 factors. In other words, they were all considered to be major inhibiting factors.

(1) Many conditions such as ground and soil conditions differ from site to site.

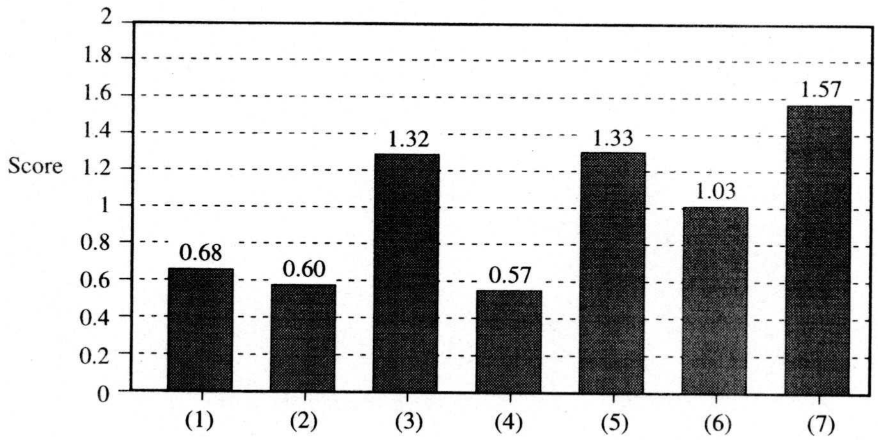


(2) Design and specifications differ from site to site.
(3) Information exchange is insufficient between the design and building work sections.
(4) Prefabrication and material standardization are not well developed.
(5) Many different types of jobs are required and very few jobs are repetitive.
(6) Many types of materials are used and new products are continuously being introduced.
(7) The contents of jobs are often unclear and changeable and rely much on the decision-making of workers at site.
(8) Labor-saving won't necessarily lead to cost reduction.
(9) Insufficient supply of information on the types and performance of developed robots
(10) The level of robot technology is quite low (they have accuracy and operation speed defects).

Figure 4 Adverse Factors Inhibiting the Robotization of Construction Work

E. PERSPECTIVE REGARDING THE LIMITATIONS AND REQUIREMENTS FOR DESIGN WORK

As to the limitation and requirements of design work when achieving the robotization of construction work, two points were given to the response "Acceptable," one point for "Depending on conditions," minus one point for "Not acceptable" and zero for "Don't know." The results of our calculations are shown in Figure 5.



(1) The limitation and standardization of materials and design adversely affect the individuality and originality of buildings.
(2) Drawings and specifications will become more complicated and too detailed.
(3) As it will be necessary to settle design at earlier stages of building production, the planning process will become of greater importance.
(4) It may lead to a cost increase within a short to medium period.
(5) Designers must have expertise on construction robots and understand their performance and functions (construction work capabilities).
(6) The division and specialization of the design process will continue.
(7) Computers will be more extensively used in design work.

Figure 5 Acceptability of Design Limitations and Requirements

It can be understood from the questionnaire that many respondents affirmatively replied to "Computers will be more extensively used in design work," "Designers must have expertise on construction robots and understand their performance and functions (construction work capabilities)" and "As it will be necessary to settle design at earlier stages of building production, planning process will become of greater importance." On the other hand, the overall attitude of respondents was negative to "It may lead to cost increase within a short to medium period," "Drawings and specifications will become more complicated and too detailed" and "The limitation and standardization of materials and design adversely affect the individuality and originality of buildings." In other words, designers may accept construction robots as long as construction costs would not increase and the degree of design freedom would not deteriorate.

F. PROFESSIONAL VIEW OF DESIGNERS REGARDING THE ROBOTIZATION OF CONSTRUCTION WORK

As for design with the robotization of construction work as a precondition, the majority of respondents (74%) of both general contractors and architectural firms conditionally answered that robotization was an acceptable precondition depending on the type of building, cost requirements and so forth.

In particular, structural designers (25%) and equipment designers (26%) of general contractors replied that they would positively consider the introduction of robots into construction work. Probably because they were afraid of limitations on the degree of design freedom, decorative designers of both general contractors and architectural firms were not very positive about robotization (10%). (See Figure 6.)

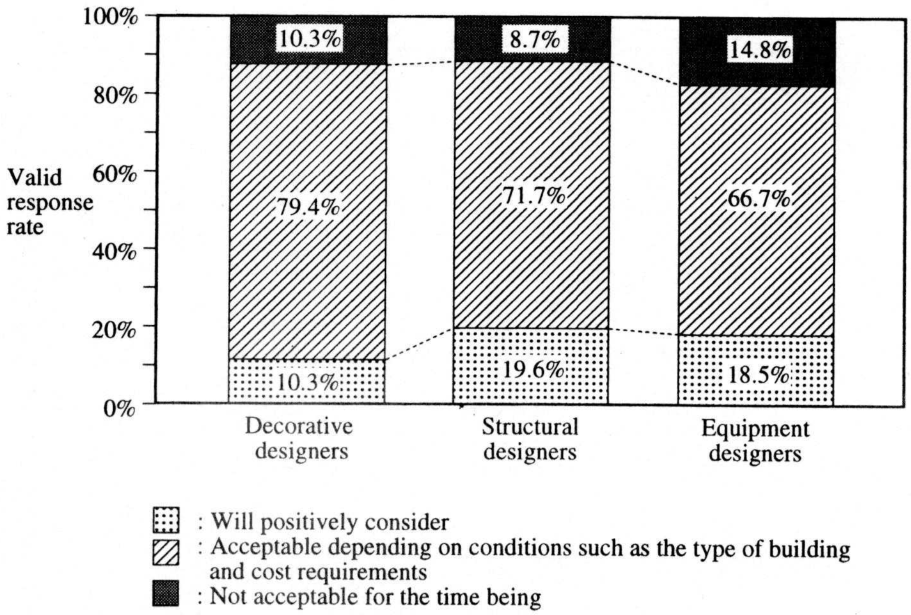


Figure 6 Design with the Robotization of Construction Work as Precondition

G. WHAT KIND OF ROBOTS THE RESPONDENTS WANT TO SEE DEVELOPED

Many specific designs of robots were suggested to cover a wide scope of construction work, including steelwork erection, disposition of formwork, exterior paint spraying, installation of ceiling fixtures, building frame setting and finish/equipment work. Also, respondents selected compact packaging, multi-functions and capability for performing hazardous jobs in place of human workers as requirements for robots. Found in numerous replies were some designer-specific requirements, including robots capable of tracing very minute details or measuring the precision of steelworks.

H. PERSONAL EXPERIENCES IN EMPLOYING ROBOT(S)

Affirmative answers to this question were 18 out of 143 (13%). Two thirds of experienced designers belonged to architectural firms and two thirds of experienced architectural firm designers were engaged in decorative design work. Most of their robots were used for the construction work of rather large office buildings, factories and intelligent buildings. The types of robots used are shown in Table 3.

Table 3 Types of Robots Used and Their Applications

Type of robot	Description of work	Number of construction works*
Concrete floor finisher	Floor finish	7
Fire-resistant coating sprayer	Spraying	1
Automatic window wiper	Window wiping	1
Concrete placing robot	Concrete placing	3
High altitude job vehicle	Scaffolding	1
Curtain wall installer	Installing large unit sashes	1
Welding robot	On-site welding of steelworks	3
External wall plate installer	Installing external wall ALC plates	1
External wall paint sprayer	Spraying paint on external wall	1

* multiple replies

The primary purposes of the employment of robots included "Quality control" (20.8), "Improvement of construction work capabilities" (20.8) and "Labor-saving" (20.8). A small number of respondents chose "Cost reduction" (8.3) and "Construction period reduction" (4.2). However, two thirds of all respondents who were experienced with the use of robots listed "Construction period reduction" as a profit of robotization. They found that robots made better achievements than expected. Half of the experienced designers at general contractors selected "Labor-saving" as a merit of robotization. Of all experienced designers, 17 percent said that robots were "Highly accurate." It seems that construction robots achieved a satisfactory level of quality. As demerits, 58 percent of respondents said that they had "Limited capabilities" and 17 percent answered "Cost increased."

The number of designers who were experienced with the use of construction robots was still limited. There is not enough data here to conclusively describe the overall trends of robotization, however, robotics are obviously succeeding in saving labor and reducing work terms. It was also obvious that construction robots had some limitations and represented a large expenditure, presenting issues to be solved in the future.

I. THE RESPONDENTS' GENERAL OPINION REGARDING CONSTRUCTION ROBOTICS

We analyzed designers' views over the introduction of robots into building production and the prerequisites for acceptance of construction robots. In general, most designers were positive about the robotization of construction work. Yet they can be categorized into an affirmative ("absolutely yes"), neutral ("conditionally yes") and negative ("too difficult yet") groups.

The typical opinions of the affirmative group were, "It is already necessary to start the use of robots as precautions for future labor shortage, higher quality control and safety enhancement," "It will be necessary for architectural designers to assume the robotization and automation of construction work as preconditions of design work," and "Better results may be achieved when construction work is totally deliberated from the design process." On the whole, they expected much of robotics.

The neutral group expressed various opinions including, "We should continue consideration because only a limited number of areas can be robotized," "Priority should be given to the establishment of industrialized construction method," and "It will be insignificant if any

profits are secured for owners and/or designers." More or less, they counted on the robotization of construction work.
The negative group's comments such as, "It is still an immature technology and cannot be put into practical use," and "It should not be used if it adversely affects originality or creativity," showed their belief that there were some high-standing obstacles to overcome. Generally many respondents – regardless of their organizations and design work – made comments indicating their uncertainty and dissatisfaction about the robotization such as, "It won't be accepted if the individuality or originality of buildings are impaired" and "Designers are not provided with sufficient information on robotics."

4. CONCLUSION

In our questionnaire for subcontractors, most respondents were very realistic in hoping for robots manipulated and monitored by human operators and expressing their expectation of robotics development specifically for the improvement of safety and for labor-saving.

In the survey for architectural designers, on the other hand, respondents expressed broader visions regarding the future development of construction robotics, reflecting their position at the upperstream in building production. In general, they were very positive about the robotization of construction work, pointing out the necessity for comprehensive systems covering the design and planning process with robotization as a precondition, a well-defined planning period, extensive information collection from builders, closer communication among designers, builders and robot developers, standardization and systematization of construction methods, mass production methods and consistent functionality with CAD/CAM applications. They shared a common idea that the construction industry should earnestly deal with this issue as an industry-wide project.

This survey provided us with a number of issues and obstacles that we have to discuss and overcome in order to develop and introduce robots into construction work. We at the Building Contractors Society will conduct in-depth analysis of factors inhibiting the use and diffusion of robots in the construction industry and prepare guidelines for the development of robots.

The members of the Construction Robotics Committee which conducted this survey are;
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