THE FUTURE OF AUTOMATION AND ROBOTICS IN CONSTRUCTION ACTIVITIES

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ABSTRACT

It is the general consensus in the literature that the potential for the development and use of advanced robotics in construction is promising. It is believed that automation and robotics will put a stop to the decline in construction productivity that occurred in the last 20 years and achieve productivity increases like those experienced between 1920 and 1970. Indeed, computer technology, remote sensing, signal and control systems, artificial intelligence, and material science and engineering have advanced far enough to allow for the introduction of robotics technology into the construction industry.

How do contractors feel about that? Are they ready for this new technology? Do they think it is feasible? What areas in particular do they regard as most appropriate for this kind of application? What advantages do they see for the use of robotics in construction operations? What type of robots do they think lends itself best to internal and external construction activities? Do they conduct or support research and development activites in this field? The paper reports the findings of a survey that was carried out of the top 400 contractors in the US to investigate contractors' reactions to automation and robotics in construction operations.

1. Introduction

About 30,000 robots are being used today in the United States, European countries, and Japan. Most of these are being used in machine tool processing, welding, palletizing, painting, casting, forging, loading and unloading, and inspection. About half of these applications involve simple "pick and place" operations, and less than 10% of these use sensors for interaction with the environment.

The sizable increases in productivity and corresponding decreases in real costs of construction that occurred in the US from 1920 to 1970 were brought about primarily by mechanization of construction technology and the introduction of new types of heavy equipment between the 1920's and the 1950's. From the 1950's to the 1970's, the primary improvements were due to increases in equipment power and capacity, and in the effectiveness with which

equipment was used (1). On the other hand, despite its importance in the national economy, the construction industry has undergone an alarming decline in productivity growth over the past two decades, from a healthy 3.4% per year during 1948-1965 to a drop of -1.8% during the 1970's and 1980's (2). Research funds are now being allocated to automation and robotics research with the belief and hope that it could stop the decline in productivity observed in the last 20 years and achieve productivity increases like those experienced between 1920-1970 (3).

How do contractors feel about increased automation and robotics in their construction sites? Are they ready for this new technology? Do they think it is technically and economically feasible? What types of work in particular do they regard as most appropriate for this kind of application? What advantages do they see for the use of robotics in construction operations? What type of robots do they think lends itself best to internal and external construction activities? Do they conduct or support research and development activites in this field? This paper reports the findings of a survey that sought the answers to these questions.

2. Methodology

A survey was conducted of the top 400 Engineering News-Record contractors (4). The questionnaire was prepared to be exploratory in nature since no similar study had been done before. Based on past experience related to surveys in the construction industry, it was felt that the length of the questionnaire should be limited to only two pages in order to achieve an acceptable rate of return. That is why, only nine questions were developed to fit in two pages.

The questions contained an optional participant's profile section that included the repondent's name, title, company, address, and telephone number. Then came a company's profile section with four questions designed to identify the company's annual dollar turnover, its type of activity such as building, industrial, or engineering, the size of the company's investment in construction equipment, and whether the company undertakes in-house research or funds external research activities in robotics.

The final section of the questionnaire contained questions designed to explore the respondents' expectations regarding robotics applications in the construction industry in the future. Specifically, two questions were designed to find out what rate of increase (or decrease) was expected in robotics applications in the decade to come. One question explored what type of robots (teleoperated, programmed, or cognitive robots) would most likely be in use in the next ten years. Another question sought the respondents' opinions as to the extent to which certain factors would be affected by robotization. These factors included safety, quality of work, speed, productivity, outdoor working ability, labor management relations, competitiveness, and economy. A rating system was developed to quantify the answers to this question: "will improve considerably" was rated as 2, "will improve little" as 1, "will remain the same" as 0, and "will decline" as -1.

Finally, respondents were asked to rate major construction operations as to their suitability for robotization. These operations included excavation and earthwork, masonry, steel erection, precast components, finishings such as painting, tiles, etc., mechanical-electrical-HVAC, shop activities such as carpentry, welding, steel fabrication, etc., and materials management. Again, a rating system was developed to quantify the answers: "not suitable" was rated as 0, "moderately suitable" as 1, "suitable" as 2, and "very suitable" as 3.

3. Results of the Survey

A rate of return of 11% was obtained. The companies that responded ranged in annual dollar turnover from $30 million to $2,800 million, with a mean of $264 million. The majority of the respondent companies (91%) undertook building construction, whereas industrial construction accounted for 63% of the answers, and engineering construction for 35%. The size of the companies' investment in equipment varied between $0 and $300 million, with a mean of $23 million.

The responses presented in Figure 1 indicate that the majority of the respondents were confident that both mechanization and robotization would spread rapidly in the construction industry. As far as the rate of robotization is concerned, however, only 38% thought that robotization would increase at a higher rate than today's. One reason why this is so may lie in the level of research activity undertaken in robotics applications specifically in the construction industry. Figure 2 indicates that robotics research in construction was indeed almost non-existant.

The construction industry has traditionally been slow in initiating and accepting innovation. It is believed that the application of robotics in construction activities will not happen overnight. It is expected to follow a phase of higher mechanization where technology leading to improved equipment will have to yield productivity improvement higher than a skilled worker. It is only thereafter that robotization will be accepted in practice (5).

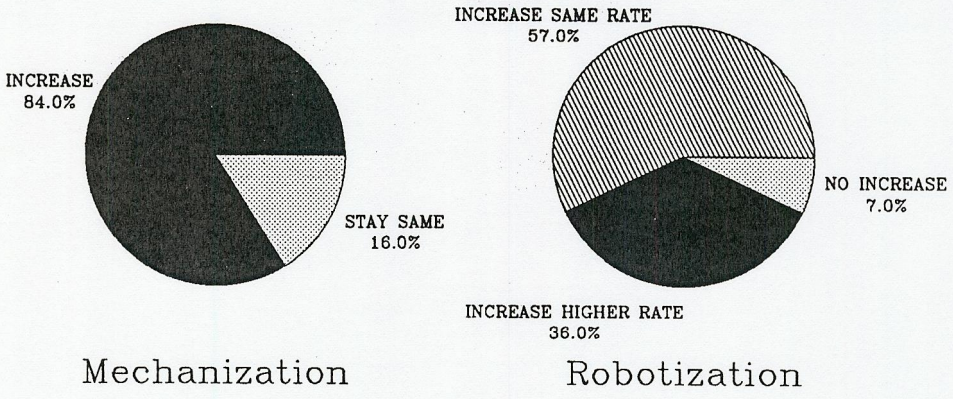

Figure 1. Respondents' expectations of the future of mechanization and robotization

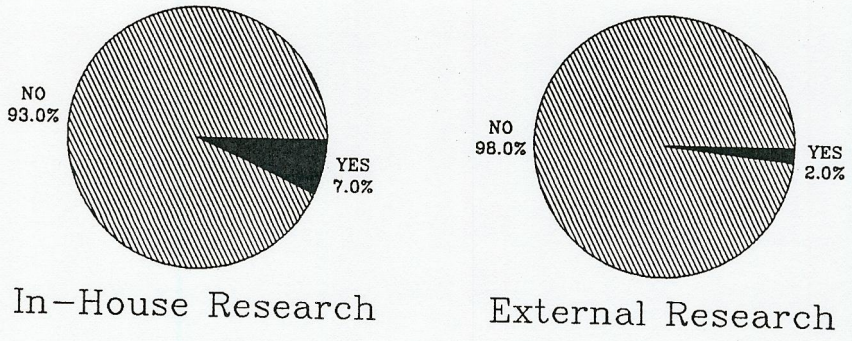

Figure 2. Respondents' in-house research activities and funding of external research

When asked what factors would be improved by increased automation/robotics, the large majority of the respondents indicated that higher productivity (95%) and speed (91%) would be achieved. 77 to 79% of the respondents indicated that there would be improvements in all the remaining factors listed in Figure 3 except for management-labor relations; only 15% of the respondents felt that management-labor relations would improve. Figure 3 is a histogram of the average ratings these factors obtained from the respondents based on the rating system defined in the previous section. It indicates that productivity, speed of production, quality of work, and site safety were rated as factors likely to be affected mostly by automation/robotics. Competitiveness, outdoor working ability, and project economy were expected to be improved but not as much. Finally, management-labor relations were expected to be worsened.

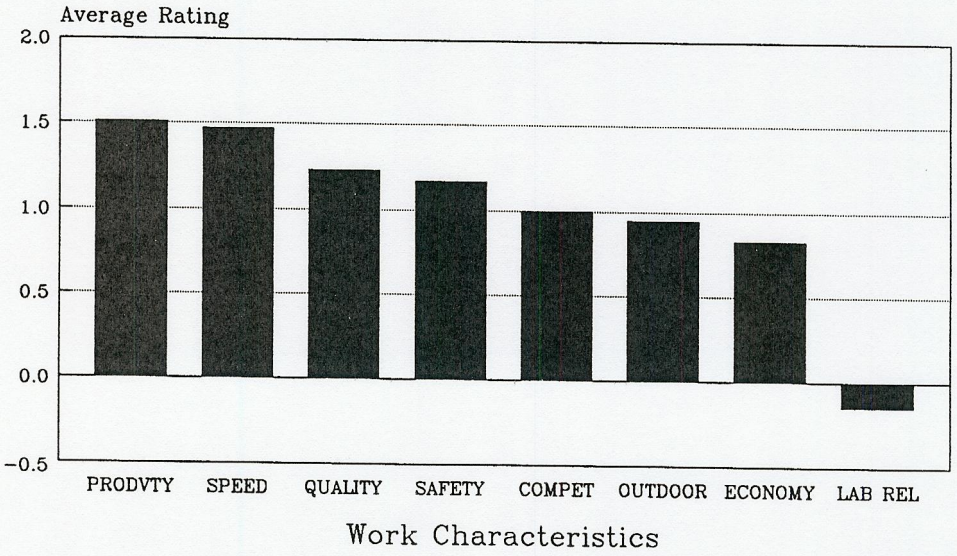

Figure 3. Work characteristics affected by automation/robotics

Figure 4 shows in what construction operations, automation/robotization was expected to be most suitable based on the rating system defined in the previous section. It indicates that materials management and shop activities were rated on the average close to the "suitable" category. None of the activities received ratings above the "suitable" category. All the remaining activities, including earthwork, precast components, masonry, mechanical and electrical installation, and finishings rated between the "not suitable" and the "suitable" categories with steel erection very close to the "not suitable" category. These findings suggest that the respondents have a guarded opinion on the future of automation and robotics in the construction industry.

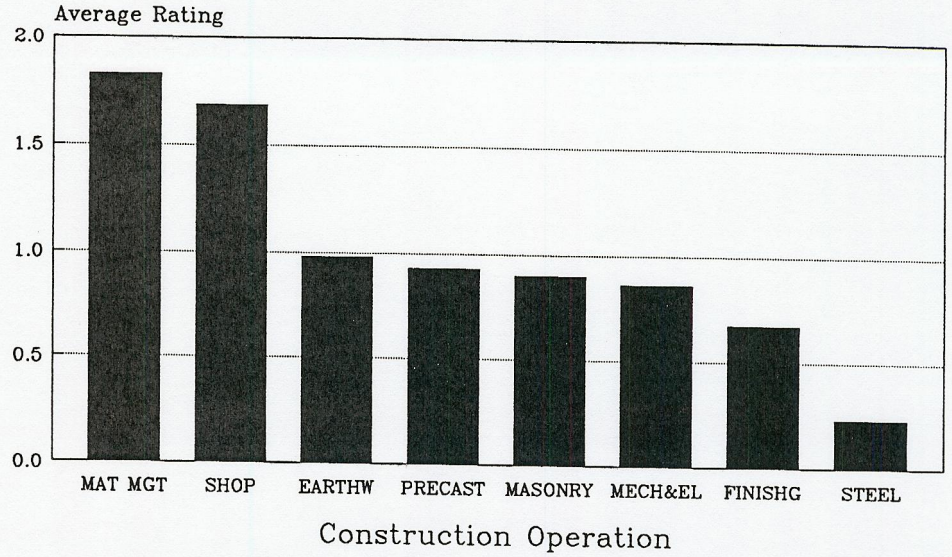

Figure 4. Construction operations likely to be affected by automation/robotics

When asked about their vision of the type of robot that will dominate in construction activities in the next decade, the majority of the respondents predicted teleoperated (74%) and programmed (64%) robots would be most prominent, whereas cognitive robots (10%) would not be very popular (Figure 5). Again, the response suggests a guarded and cautious view of the extent to which robotics will be developed in the future for use in construction.

The answers of the respondents were statistically analyzed to identify if any marked tendencies were apparent in predominantly large companies vs smaller companies, in companies with large investments vs smaller investments in construction equipment, and finally, in building construction companies vs engineering and industrial construction companies. The writers expected that relatively larger companies could afford experimentation with advanced robotics better than smaller companies, and that the answers would reflect this bias. It was also expected that

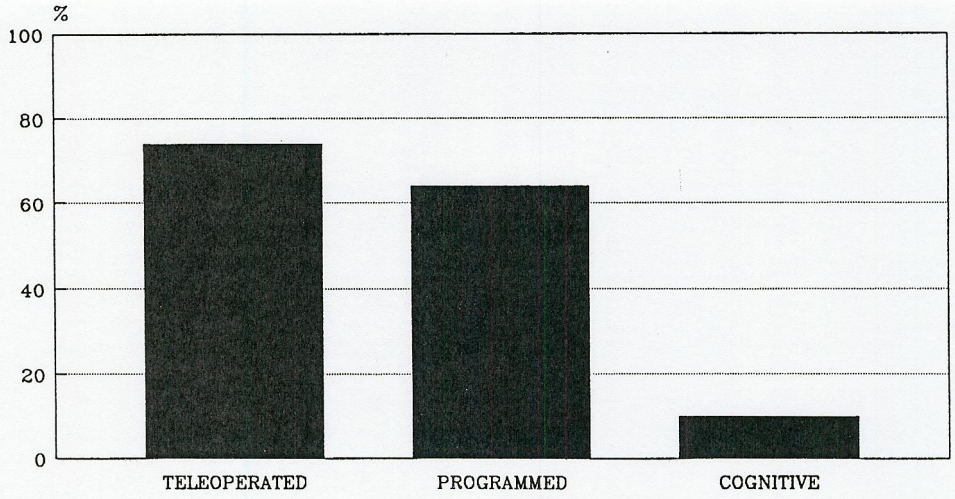

Figure 5. Expected types of machines in the next decade

companies with sizable investments in construction equipment would feel the need for higher machine productivity and therefore be more receptive to further mechanization and eventually robotization of their activities. The mean ratings of the respondents' expectations of the effects of automation/robotics on the work characteristics studied in this survey, are presented in Table 1 arranged by annual dollar turnover, size of investment in construction equipment, and type of construction undertaken. Table 2 presents the mean ratings of the respondents' expectations of the suitability of automation/robotics in different types of construction operations, also arranged by turnover, investment in equipmwent, and type of construction.

Table 1. Mean ratings for different types of operations arranged by annual dollar turnover, size of investment in equipment, and type of construction undertaken

TYPE OF OPERATION	ANNUAL TURNOVER		INVESTMENT IN EQUIPMENT		TYPE OF CONSTRUCTION	
	>$150m	<$150m	>$1.5m	<$1.5m	Bldg	CE+Ind
Earthwork	0.88	1.00	1.05	1.00	0.97	0.96
Masonry	0.88	0.90	0.94	0.86	0.89	0.68
Steel Erect	0.25	0.15	0.22	0.26	0.24	0.17
Precast Com	0.76	1.19	0.68	1.19	0.97	1.00
Finishings	0.94	0.55	0.72	0.68	0.65	0.76
Mech & Elec	1.20	0.68	0.81	1.00	0.91	1.04
Shop Activ	2.00	1.52	1.74	1.71	1.70	1.69
Matls Mgmt	1.56	1.30	1.47	1.38	1.36	1.38
Sample Size	18	21	20	21	37	26

Table 2. Mean ratings for work characteristics arranged by annual dollar turnover, size of investment in equipment, and type of construction undertaken

WORK CHARACTERIST	ANNUAL TURNOVER >$150m	ANNUAL TURNOVER <$150m	INVESTMENT IN EQUIPMENT >$1.5m	INVESTMENT IN EQUIPMENT <$1.5m	TYPE OF CONSTRUCTION Bldg	TYPE OF CONSTRUCTION CE+Ind
Safety	1.18	1.05	1.00	1.25	1.14	1.19
Quality	1.11	1.38	1.25	1.24	1.27	1.27
Speed	1.39	1.57	1.45	1.48	1.46	1.54
Productivity	1.53	1.52	1.42	1.60	1.54	1.58
Outdoor Abil	0.88	0.95	1.00	0.89	0.94	1.00
Lab-Mgmt Rel	-0.11	-0.20	-0.26	0.05	-0.06	-0.08
Competitive	0.89	1.05	0.95	1.05	1.06	1.04
Economy	0.67	0.89	0.74	0.90	0.83	0.88
Sample Size	18	21	20	21	37	26

Statistical analysis indicates that there are no statistically significant differences between the mean ratings of smaller vs larger companies, companies with larger vs smaller investments in equipment, and building vs engineering/industrial construction companies. Although one can observe trends, one should treat the results with caution.

4. Conclusion

The potential for the development and use of advanced robotics in the construction industry is promising. The necessary conditions for the deployment of such systems have been in place for the last 20 years. Indeed, computer technology, remote sensing, signal and control systems, artificial intelligence, and material science and engineering have advanced far enough to allow for the introduction of robotics technology into the construction industry (6).

An exploratory survey that was carried out of the top 400 contractors in the US to investigate contractors' reactions to automation and robotics in construction operations indicates that further mechanization of existing operations within the existing work processes is expected in the next decade but that robotization in the same period will continue to increase at the same rate as today's. The sort of robotization respondents envisage is more of the teleoperated and somewhat the programmed type; contractors do not see cognitive robots as having an impact in the next decade. The improved robots and automated practices are expected by the respondents to increase productivity, speed of construction, quality of the finished product, and safety; further automation is expected to improve materials management and further robotization is expected to occur in shop activities. Contractors have a cautious attitude toward further automation and robotics in the other construction operations.

Shop activities mostly display batch manufacturing characteristics where the work object is mobile through the production facility and work tools are stationary. In traditional construction operations, on the other hand, the work object is stationary but constantly changing as work is undertaken with tools that are mobile. Several changes are necessary in order to implement the use of robots in construction operations other than shop activities (7): the design process and the structuring of the construction site must be changed to accomodate robots; new technical expertise to manage, maintain, and operate robotic equipment must be developed; the present labor force must be restructured including retraining certain classes of laborers; construction contractor attitude regarding advanced technologies must be changed toward the positive; and all individuals associated with construction must be educated on the potential benefits of robotizing the construction jobsite.

As far as the differences among the various subsamples are concerned, analyses indicate that there are no different responses that are statistically significant between large vs small companies, companies with large vs small investmants in construction equipment, and building vs engineering/industrial construction contractors. The low rate of response to the survey, the generally conservative view of the future of automation and robotics, the low priority attached to research and development in robotics, and the lack of trends among the subsamples indicate that the construction industry may not yet be aware of the potential benefits that such improvements may yield or that there is informed and genuine doubt regarding the possibilities of implementing such technologies in traditional construction activities.

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