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FEASIBILITY AND POTENTIAL IMPLEMENTATION OF ROBOTS IN CANADIAN BUILDING CONSTRUCTION

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ABSTRACT

This paper considers the feasibility and potential implementation of robots in Canadian building construction. The characteristics of the canadian construction industry are described and factors such as labour costs, productivity, and safety which have a direct bearing on the feasibility of robots utilization are examined. The potential for automation is investigated and motivation factors are analyzed. The main characteristics of construction robots are described and future trends on robotic developments are outlined. The paper also presents the early findings of a research programme including a local survey conducted in the Montreal area on the impact of robotization in construction and identifies the present difficulties and future challenges in this field. The research is currently undertaken at the Centre for Building Studies for automation through robotization of the construction processes.

1. INTRODUCTION

The construction industry is the single largest industry in most developed and developing countries. In Canada, it is the largest of the four main industries (Construction, Agriculture, Mining, and Forestry). According to a recent major study commissioned by the Construction Industry Development Council (1), construction accounts for well over half of Canada's capital investment program, and employs 4% of the total work force. The value of construction work performed currently exceeds $70 billion, over two thirds of it in building construction. The industry represents 16% of the nation's GNP and has a potential of climbing up to 20%.

It has been shown in a previous article (2) that despite this remarkable share of the industry, a number of studies conducted independently in Canada, the U.S., and Japan have indicated a decline in productivity of this vital industry. These studies have also indicated the shyrocketing cost of labor. Such combination of lower productivity and higher labor costs have contributed to a promising potential for automation. These labor costs and productivity trends are depicted in the early work of Warszawski (3) and Hasegawa (4).

It should be mentioned, however, that it was not until recently, when construction automation through robotics has received considerable attention not only in the form of published engineering textbooks, periodicals, and conference proceedings, but also through engineering and professional news (5), government reports (6), and graduate research at the M.Sc. (7) and Ph.D. (8) levels. Such clear lag of advancements and implementation of robotics in the construction process has been atributed to many factors, mainly stemming from the basic unique nature of construction projects.

This paper presents a state of the art on the current research and applications of robots in construction generally and in building construction particularly. The characteristics of the canadian construction industry are described and factors such as labor cost, productivity, and safety which have a direct bearing on the feasibility of robots utilization are examined. The potential for automation is investigated and motivation factors are analyzed. The paper also presents the early findings of a current research programme including a local survey conducted in the Montreal area on the impact of robotization in construction and identifies the present difficulties and future challenges in this field. The research is currently undertaken at the Centre for Building Studies for automation through robotization of building construction processes.

2. CANADIAN BUILDING CONSTRUCTION

As mentioned earlier the value of construction work performed currently exceeds $70 billion, equivalent to $2,900 of construction work per capita, per year. Approximately, two thirds of this construction volume are in the building sector, of which the residential constitute one half (Table 1). The industry represents 16% of the nation's GNP and has a potential of climbing up to 20%, simply because Canada is still a developing nation (Fig. 1).

3. MOTIVATION AND FEASIBILITY

Despite the apparent differences between the construction and manufacturing industries, the following motivation factors were identified in an earlier study (9) to be common for automation through robotization in the two industries:

1. Reduced labour skyrocketing cost;
2. Improved quality;
3. Free humans from tedious, boring, repetitive tasks;
4. Elimination of dangerous jobs;
5. Increased productivity;
6. Material savings; and
7. Flexibility.

Factors 1,4,5 and 7 being more influential in the construction industry were later analyzed in a consequent study (2). The findings are summarized below together with the additional elements which have a direct bearing on the feasibility. The elements examined are: labor costs, productivity trends, and safety related costs.

3.1 Labour Costs

This is the single most important and decisive factor. As Joseph Engelverger (10), President of Unimation Inc. - the largest U.S. robot manufacturer - has put it: "The prime issue justifying a robot is labor displacement. Industrialists are mildly interested in shielding workers from hazardous working conditions, but the key motivator is the saving of labour cost by supplanting a human worker with a robot". A number of studies and surveys, carried out in the manufacturing industry, strongly support this view (11). In fact, the results of a recent survey conducted among general contractors and construction equipments suppliers in Montreal area (2) also supports this view. The participants were asked to rank the following factors in order of importance as prime motivating factors for the use of automated equip-

TABLE 1 - Total Value of Construction Work Purchased and its Percentage Distribution Canada, 1983-1987

TYPE OF CONSTRUCTION	1983		1984		1985		1986		1987	
	Value	Percent of total	Value	Percent of total	Value	Percent of total	Value	Percent of total	Value	Percent of total
	$ 000,000		$ 000,000		$ 000,000		$ 000,000		$ 000,000	
Construction - Total	**55,948**	**100.0**	**56,574**	**100.0**	**67,983**	**100.0**	**70,406**	**100.0**	**72,348**	**100.0**
Building Construction	**30,753**	**55.0**	**31,411**	**55.5**	**41,459**	**61.0**	**47,002**	**66.8**	**48,690**	**67.3**
Residential	16,851	30.1	16,647	29.4	24,145	35.0	28,636	40.7	29,281	40.5
Industrial	2,450	4.4	2,708	4.8	3,470	5.1	3,129	4.4	2,996	4.1
Commercial	6,482	11.6	7,129	12.6	8,697	12.8	9,865	14.0	10,744	14.9
Institutional	3,065	5.5	2,924	5.2	3,119	4.6	3,488	5.0	3,697	5.1
Other Building	1,905	3.4	2,003	3.5	2,028	3.0	1,883	2.7	1,972	2.7
Engineering - Total	**25,195**	**45.0**	**25,163**	**44.5**	**26,524**	**39.0**	**23,404**	**33.2**	**23,658**	**32.7**
Marine	426	0.8	474	0.8	379	0.6	387	0.6	473	0.6
Road, Highway & Airport Runways	4,326	7.7	4,276	7.6	5,179	7.6	5,029	7.1	5,216	7.2
Waterworks and sewage systems	2,229	4.0	2,170	3.8	2,481	3.6	2,258	3.2	2,488	3.4
Dams and irrigation	291	0.5	272	0.5	283	0.4	272	0.4	273	0.4
Electric power construction	4,397	7.9	3,664	6.5	3,314	4.9	3,649	5.2	3,963	5.5
Railway, telephone & telegraph construction	2,469	4.4	2,724	4.8	2,787	4.1	2,627	3.7	2,903	4.0
Gas and oil facilities	8,128	14.5	8,552	15.1	9,207	13.5	6,638	9.4	5,683	7.9
Other Engineering construction	2,929	5.2	3,031	5.4	2,894	4.3	2,544	3.6	2,658	3.7

Source: Construction in Canada, Statistics Canada, publication no. 64-201, 1988-1987, p.12

ment: reduce labor costs, reduce capital costs, improve quality of work, decrease time of activities, relieve workers of tedious and/or dangerous jobs, and remedy high labor turnover problems. Labor cost was ranked by the majority of respondents as the prime motivation factor for automation (see Fig. 2). The average cost of construction labor in the province of Quebec is $30.00/h, including an overhead or markup of 15% and fringe benefits which amounts to one third of the wage, distributed as shown in Table 2.

Table 2
Distribution of Fringe Benefits

COMPONENT	SHARE
Unemployment Insurance	2.30%
Construction office fee	0.50%
Retirement plan	1.90%
Workmen compensation premium (CSST)*	9.99%
Medical insurance	4.99%
Social benefits (average)	10.00%
TOTAL	32.9 %

* Quebec Construction Safety Board

3.2 Productivity Trends

This is certainly the most important factor next to the reduction of labor cost. In fact, the two factors are directly linked in any economic analysis or feasibility study performed to justify the implementation of robots (3,7,11 and 12). Actually increased output (productivity) and decreased costs are two sides of the same coin. On construction projects where the buyer (owner) commits himself to a project before it is produced, unlike the case in the manufacturing industry, this factor becomes naturally more important. In this respect, it is tied to motivation factor No. 4 considered in Fig. 2: "decrease time of activities". It is important to note that this factor was ranked next to the reduction of labour cost as the prime motivation factor for automation in construction. This has been expected before carrying out the survey because delivering the project on scheduled time has been frequently encountered to receive top priority on a number of construction projects.

The robotization's positive impact on productivity has been vividly illustrated by Hasegawa (4), comparing productivity trends of the automated manufacturing industry and the traditional construction industry (Fig. 3). Similar productivity trends in Canada (Fig. 4) are less revealing, probably because of the less intensity of automation in its manufacturing industring in comparison with Japan. In the U.S. the manufacturing industry has experienced productivity increases due to robotization ranging from 50% to 400% for specific applications (11).

3.3 Safety Related Costs

Accident rate is much higher in the construction industry as compared to the manufacturing industry. A comparison between the accident rates in the two industries in the U.S., U.K., and Canada has been reported in an earlier study (2). Compared with manufacturing, the U.S. construction has seven times as many fatalities per worker and twice as many disability injuries. In the U.K., construction in general has experienced about four times the fatalities experienced in manufacturing; and for some specialized trades, such as steel erection, the figure jumps to fourty. In Canada, construction is the third most dangerous industry after the forestry and mining with 10% of the total work force experience time-loss injuries. In Quebec, one worker in 13 has an accident, 1 in 33 comes out with total disability and 1 in 10,000 dies at work. In addition construction accidents not only result in injuries, loss of human lives, and direct costs, but it also has an indirect negative impact on productivity, delays and work disruptions and quality of affected works.

There is no doubt that safety and accidents have related costs. Easy to recognize are the Workmen Compensation premiums paid by contractors, the costs of a prevention officer and a first aid station. But these elements represent only a portion of the total costs associated with safety and accidents. Indirect costs must be added as they represent the largest portion of the total cost.

In a recent study (13) conducted in the province of Quebec, the various elements of safety related costs have been indentified and estimated. These cost elements are presented in a Cost Matrix form to illustrate their type (Table 3). The matrix summarizes Quebec construction safety and accident costs for 1986 where the construction volume reached 13.068 billion \$. The results indicate that safety related costs amount to 4.8% of the total value of construction works.

Table 3
Prevention and Accidents Costs in Quebec 1986

	PREVENTION	ACCIDENTS	TOTALS
CSST PROGRAMS COST	INSURED (PREVENTION/INSPECTION COSTS) 18.0 M\$	DIRECT (COMPENSATION COSTS) 93.6 M \$	TOTAL CSST COST FOR CONSTRUCTION (FROM ASSESSMENTS) 111.6 M \$
EMPLOYERS' COST	NON-INSURED COMPLIANCE COSTS (COST MODEL) 133.3 M\$	INDIRECT (MULTIPLIER OF DIRECT COSTS) 374.4 M\$	TOTAL EMPLOYERS' COST FOR SAFETY AND ACCIDENTS 507.7 M\$
TOTALS COSTS	TOTAL COSTS OF PREVENTION 151.3 M\$	TOTAL COST OF ACCIDENTS 468M \$	COSTS OF SAFETY AND ACCIDENT IN QUEBEC 619.3 M\$

4. CONSTRUCTION ROBOTS

Construction robots are still at the development stage and their use is rather limited. The potential implementation of robotics have recently received considerable attention in general construction (14 to 19) and building construction (2 to 4). Other studies have focused on, the social implications (11) and the economic feasibility (8,12) of the robotization of construction activities.

Robots in current use are industrial robots, used mainly in the manufacturing industry. These robots are with a fixed base. Such robots cannot be directly used in construction. Typically a construction robot needs to have a mobile base rather than fixed, and therefore is required to interact with the surrounding environment (i.e. intelligent robot). Also construction robots need to be tough to withstand the harsh and hositle environments normally associated with construction projects. Current studies (6, 20) indicate that in the future, robots performing simple industrial tasks such as painting and spot welding will either have a stable or a declining share in the overall population, while those performing difficult and more sensitive tasks such as assembly will increase their share considerably. Also the share of non manufacturing robots is increasing. Such trends constitute a step forwared towards the development of construction robots.

As for the utilization of robots in building construction, Warszwaski (3,12) divided the building construction process into 10 basic activities and, based on the analysis of these activities, found that all construction operations (except for site works and mechanical systems) can be performed using four basic types of robots: assembly, general purpose, floor finishing, and exterior wall robots. Different approaches have been proposed by others (4).

At the Centre for Building Studies, a research program have been undertaken to investigate the robotization of building construction processes. In addition to the economic and social implication of automation, the potential implementation of robotics is being considered on three fronts:

1) automation of construction equipment including flexibility to meet the chaning environment and market conditions. In this respect, equipment shall be capable of altering functions. Such automated equipment (robot) could be equiped with muti-manipulators, and multi-adaptable effectors. This front constitute a natural development and progress at the equipment level.

2) partial automation of the construction process through prefabrication of the building components in a similar way to the manufacturing industry. In this case, the present industrial robots can be utilized in a factory environment to produce the various elements needed for building construction. This calls for a large scale standardization in the building industry in a similar way to that introduced in Japan as described in (7), where, for example, 60% of all Japense homes use standardized steel frame produced by robots. On this front, more research effort is needed for the development of modular building systems and standardized building components. This is viewed as a natural development for the present prefabricated building construction.

3) On-site automation, which could be partial or full. Partial auto-

mation in this respect calls for the replacement of the present workshops on construction sites by automated ones. As such, production of concrete batch plants, preparation of reinforcing bars, fabrication of masonry blocks and precast elements, preparation of pipe elements and joints, and carpentry works can all be performed by robots in an automated process. In this case, current manufacturing robot technology can be employed with limited changes. Full automation, however, require robotization of the entire construction process off and on-site. This would integrate the different types of automations discussed in this section. The main challenge here is the development of mobile assembly robots and mobile finishing robots, for exterior and interior works.

Despite the promising potential for robotization in construction described earlier in this paper, there are practically no construction robots used at any commercial level in North America. The use of robots is currently limited to hazardous jobs including decommissioning of nuclear power plants, construction and maintenance work for deep water offshore facilities, and tunnel excavation and lining.

5. SUMMARY AND CONCLUDING REMARKS

The characteristics of the Canadian Construction Industry has been described and factors such as labor costs, productivity trends, and safety related costs which have a direct bearing feasibility analyses have been examined. The results of a local survey conducted in the Montreal area on the impact of robotization are presented togther with the early finding of this research program.

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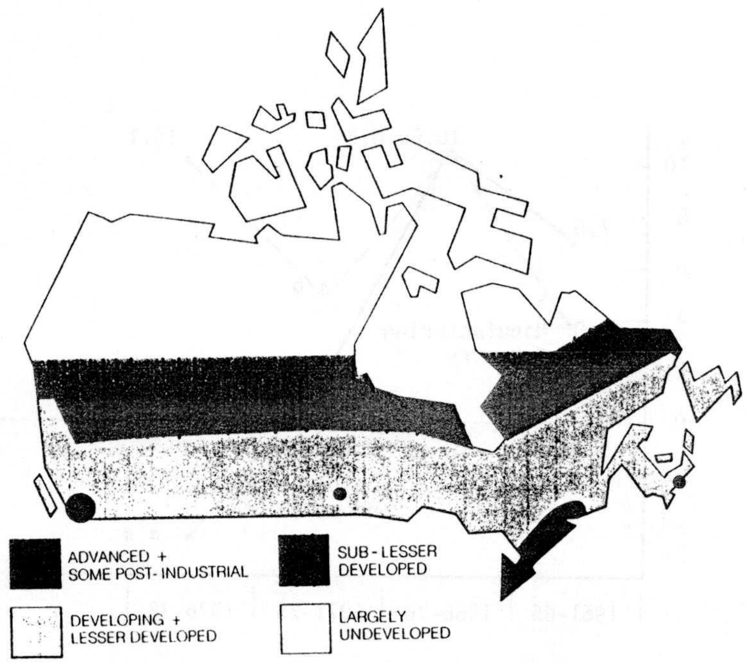

FIG. 1 Canada Still a Developing Nation - Ref. (1)

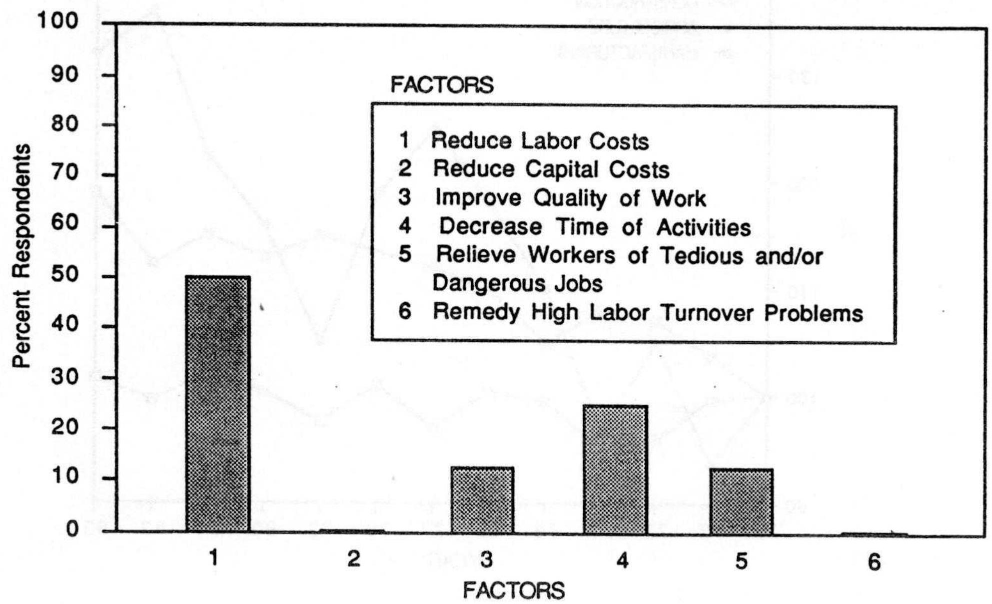

FIG. 2 Prime Motivation Factors for Automation - Ref. (2)

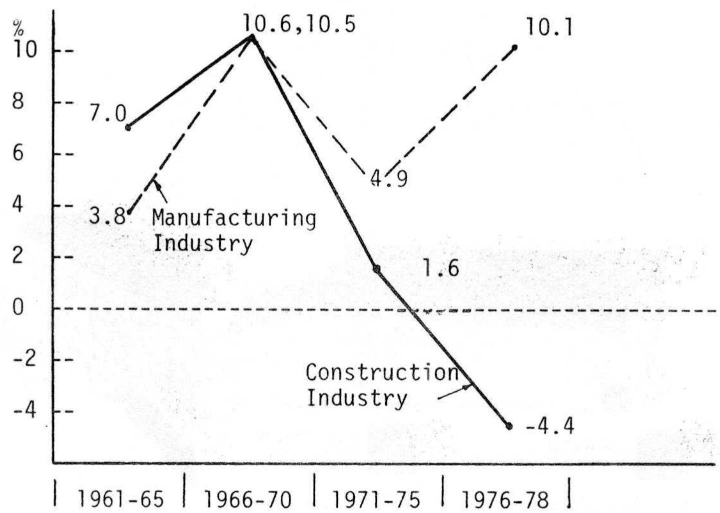

FIG. 3 Productivity Trends in Japan - Ref. (4)

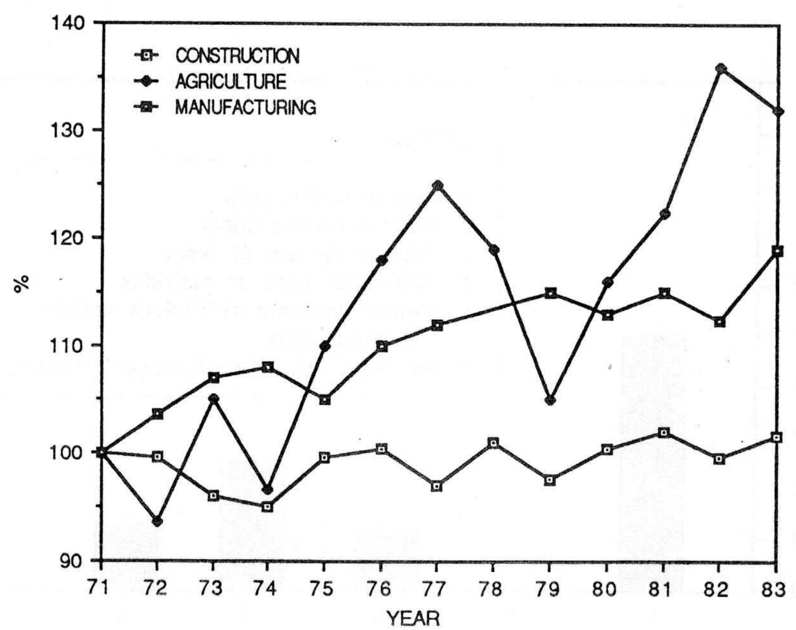

FIG. 4 Productivity Trends in Canada (Statistics Canada)