# FUTURE USES OF ROBOTICS AND OTHER FORMS OF AUTOMATION IN ON-SITE CONSTRUCTION APPLICATIONS

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## SUMMARY

The influencing factors which favor or hinder the development, market penetration and use of robotics and other forms of automation on construction sites were studied by the author and colleagues(1) in the United States, Canada, Japan, England, West Germany and Sweden from 1985 to 1987. Data collection was accomplished through extensive literature searches and interviews in each of country with key decision-makers, scientists, industry experts, and other pertinent persons. Although some differences exist from country to country, the following factors have a generally favorable influence: the promise of increased productivity, quality and consistency; improvements in worker safety; liability reduction; reduced operating and maintenance costs due to automation in cleaning, re-finishing and repairs; increasing worldwide competition; increasing activity in building rehabilitation and the special hazards/needs associated therewith; technological spin-offs from relevant work by military, energy and other sectors not as cost sensitive as construction. Most frequently cited impediments are: the unstructured, harsh and ever-changing construction site; conservatism in the construction industry; lack of cost-justifiability due to small use base; limitations of robot manufacturers' resources for new development; abundance of available labor in most parts of the world and in nearly all skill categories; the non-repetitive nature of the increasing building rehabilitation market. Although "the ice has definitely been broken" with about 50 different types of robotic/automation applications under development or in use in various parts of the world, it is likely to be 1995 and beyond before any significant use is made of robotics and high level automation systems on construction sites.

## KEYWORDS

Robotics, On-site Construction, Markets, Trends

## INDUSTRY OVERVIEW

In each of the countries investigated, the construction industry amounts to between 10 to 20% of the GNP, making it usually the largest single economic sector employing the largest number of manual workers. In addition, most of the building construction work is conducted directly on construction sites, an unstructured and variable environment second only to the battlefield in terms of its stringency. Despite these conditions apparently hostile to the on-site uses of robotics and automation, some significant technical developments are occurring in all countries under scrutiny. With the exception of the United States, all of the other countries studied have been experiencing a low- or no-growth construction volume during the eighties and into the nineties for some or all of these reasons: end of the post-war building/re-building boom; a stable or very low growth population; diminishing land availability for large-scale development; oil-recession; completion of most planned mega-projects; shift from new construction to maintenance/rehabilitation/restoration of existing structures and infrastructure. Despite this fact, construction robotics development is occurring in all countries, most notably in Japan. It is apparent that the factors influencing or hindering the development and use of on-site construction robots are more intricate than the "surface issues" described above.

## ECONOMIC JUSTIFICATION: A DIFFICULT YET FREQUENT DEVELOPMENT PREREQUISITE

It has been difficult to-date to develop economic justification for the use of robots to the general satisfaction of construction management. This study indicates that the most frequent reasons for developing a new construction technology are (1) to remove the worker from a hazardous or tedious task; (2) to increase the worker's productivity and/or capability; and (3) to improve the quality of construction. Although robotics and automation have much to offer in all three areas, the high initial cost for development of construction robotic systems has been the reason for a lack of economic justifiability. A fully automated construction process requires at least four items: a highly intelligent control system; sophisticated feedback sensors; an advanced mobility system; an efficient material handling system.

## Considerations for Robotics Feasibility

It has been suggested(2) that the significant variables which must be considered to develop the feasibility for the use of robotics in the construction process are (1) overall cost effectiveness; (2) hazard level reduction; (3) productivity increase; (4) quality improvement; (5) task repetitiveness and design standardization; (6) acceptance by unions and other industry groups; (7) technological feasibility. Each variable must be weighed as it applies to a particular task or unique situation. For example, in nuclear operations, the hazard level outweighs usually all other concerns. Of course, technological feasibility of any concept should be investigated at the earliest point as non-feasibility would preclude usefulness of that concept.

In most cases, the final decision to develop a robotic system will be based on economic considerations. Cost justifiability is unlikely if the use is only for a single project. It becomes easier if a unique task is considered which can be repeated with minimum variation from one job site to another. Cost justifications are therefore more successful when robotics applications involve repetitive tasks, large numbers of projects, and considerable amounts of skilled or semi-skilled manual labor.(3,4)

# ROBOT AND AUTOMATION DEVELOPMENT

## Present Programs

It is encouraging that research and development efforts in the construction robotics and automation field are progressing throughout the world, despite the generally discouraging economic climate and the change-resistant nature of the construction industry. Major efforts are under way in Japan, the United States, Israel and other countries, and are the subject of several of the presentations at this conference. Included are technologies linking the construction process with CAD/CAM, AGVs and intelligent robots, robots for high hazard tasks such as fire fighting and underwater welding, repetitive task robots for painting, cleaning or fastening, etc.

## Industry Trends and Forecasts

Current trends in the worldwide construction industry suggests that there is a climate for greater acceptance of new technology, including robotics:

o The influence of labor unions in the U. S. construction industry is waning. This allows contractors greater freedom to seek and implement innovative methods and materials.

o Large construction programs and projects are conducted increasingly by major owner/developers who operate internationally, with complete in-house or affiliated design/build capability.

o The market for construction products of all types is fully international in scope. This will become even further emphasized as the full impact of the 1992 consolidation of the European Community is felt, and as Eastern European nations develop an increasing demand for new construction of all types.

o Collaboration and cooperation among manufacturers, architects, engineers and contractors is increasing, although far from the ideal.

While the climate for change may be present, there are still many developments needed before construction robots will become commonplace. Most studies reviewed and opinions gathered during this investigation indicate that on-site robots will not make any significant entrance into the construction trade before the end of the century. The needed extensions of robotic technology are still in the research stage. Only a few true on-site construction robots have been developed - the rest are only "pre-robot" devices, semi-automatic, or fully automated forms of construction equipment. Most significantly, the companies who are the potential prime users of this robotic equipment have so far with few exceptions elected not to invest the large sums of money needed for its development. Even in Japan, the M4 level intelligent robots are not expected to be developed until the mid-1990s, and deployment will probably not occur until after the new millennium. However, various construction site sensors and computer controlled equipment which will extend the capability of today's equipment operators should find increasing use within the next ten years.

During a recent meeting(5) of 50 technical experts from business, industry, universities, and government, a Delphi method forecast was used to predict the rate of diffusion of new technology in construction and the attendant economic benefit over the next 10 years. Included were the following estimates:

For site preparation: By 1990, 5% of new construction equipment will be equipped with semi-automatic control, and 5% of all digging, grading and ditching equipment will be controlled by data from a computer data base. By 1995, the first figure cited above will rise to 50%.

For site management and on-site construction: By 1995, 5% of all commercial construction sites will be using position-measuring sensors and control systems for navigation, material handling and inventory tracking. Residential sites will lag commercial sites by 15 years in the use of such sensors and control systems.

For data bases in construction applications: By 1995, 5% of all commercial construction sites will use "as built" data bases for on-site part fabrication and have measurement sensors directly feeding a computer data base. Residential sites will lag commercial sites by 15 years in the use of such data bases.

In addition to the above predictions of technology diffusion, the relative economic importance to the construction industry of various other current technologies was developed. These technologies were considered most important:

1. Computer aided design (CAD) systems
2. Computerized inventory control and material scheduling
3. Computer assisted surveying and measurement
4. Semi-automated control of machinery for ditching, grading, lifting, positioning and material handling
5. Computer control of spraying equipment for painting, fire proofing, plaster, concrete, etc.
6. Computer control of cut-off equipment for boards, panels, and masonry

## Future Forms of Automation

It is well recognized that the unstructured, constantly changing environment of the construction site is one of the primary reasons that robotics and automation have been slow to develop. It has been suggested(6) that construction technology has improved in an evolutionary fashion, and not necessarily in the same revolutionary manner as technology in other industries. It is logical to expect this evolutionary trend to continue. Barring minor breakthroughs in specific areas, the basic evolutionary progress will focus on automating and/or robotizing those tasks which can be clearly defined and systems-engineered. This evolution will take two paths: (1) integration into existing tasks; (2) total redesign of traditional methods to adapt them to robotics and automation.

The integration of robotics and automation into existing processes is at least in part dependent upon the uniqueness or repetitiveness of the process. The higher functional levels, such as construction company organization and project plan, are unique for each project. As the functional level moves down to a particular activity (e.g., the foundation plan layout) and a particular process (e.g., form work and reinforcement bar placement), the task requirements become less unique and more repetitive. Finally, at the lower functional levels, the individual work tasks and motions become highly repetitive. It is towards the bottom of this overall structure where uniqueness disappears and the processes and tasks become more repetitive that the greatest opportunities exist for the earliest uses of robotics and automation. While robots and automation are being introduced slowly into existing, traditional processes, much research and development is in progress to redesign the traditional methods to make them better suited to robotics and automation.[7] This will result eventually in more robotic and automated factory production of elements and components, with the site becoming increasingly a staging area and final assembly point. Some tasks, such as reinforcement bar bending, should continue to grow in use on-site and off-site as CAD/CAM processes are applied to greater degrees in the manufacture of all types of special building components.

Several special needs will also create opportunities for robotic and automated technology development. The high and continually increasing levels of spending in infrastructure repairs and building rehabilitation have created special needs for such devices as remotely controlled or automated inspection vehicles, automated tunnelling and boring machines, remotely operated asbestos removal equipment, nondestructive on-site testing equipment with sophisticated sensors, etc. Concurrently, it appears likely that specialty contractors will begin to emerge who perform jobs using the aforementioned highly specialized rigs, moving from job site to job site to perform their particular tasks very efficiently and cost-effectively.

Finally, one exception may exist to the general finding that although the potential for robotics and automation in the construction industry is great, little impact will be felt until the beginning of the next millennium. The fact that the Japanese domestic construction market has not been growing is a major factor causing the Japanese construction companies to enter the international market with increasing effort and aggressiveness. This trend, together with the early involvement of several Japanese construction firms in developing robotic and automation applications, may serve to accelerate the use of robots and automated equipment in other geographic areas.

## CONCLUSIONS

A. Except as developed and used by large Japanese construction companies, current penetration and use of true on-site construction robots throughout the worldwide construction industry is practically nil.

B. Between now and 1995, the penetration of robots and automation into construction will continue to be evolutionary, aimed at applications where it is most easily engineered, economically justifiable, or meets a particular overriding need, such as overcoming a serious hazard.

C. Between now and 1995, on-site construction technology improvements will continue to be primarily in the form of semi-automatic equipment, tele-operated devices, and improved mechanical devices to extend the capability of the worker.

D. For the countries covered in the study, most local construction markets have leveled-off into a low- or no-growth mode. This will place highly competitive pressures on construction companies domestically as well as internationally, and act as a motivator to adapt the latest cost-effective technical innovations to construction projects.

E. Funding of research and development for the construction industry world-wide is increasing. With the exception of Japan, R&D spending levels as a percentage of total business volume will remain insignificant when compared to other major industries. In addition, many pertinent R&D efforts remain in basic research, laboratory and prototype development stages. Commercial implementation remains seven to ten years away for most current efforts.

F. The continuing growth in the rehabilitation of existing buildings and in the infrastructure repair markets will be significant. New materials, methods and automated equipment will be developed to meet this growing demand.

REFERENCES

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