Robotics and Automations in Construction:Advanced Construction and FutureTechnology

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***Abstract*--** **Research in construction automation and robotics has increased in popularity over the past few years. Although interest is high in the research and education communities, sustaining robust programs is difficult due to the diverse interests of constituents associated with the research and development process. The main goal of this paper is to convince building designers and managers to incorporate robotic systems when managing modern buildings. The premise of this paper is that there is a need to develop and maintain strong construction automation and robotics programs. This paper studies recent applications for robots and automation in the construction industry and sets opportunities and challenges through a new framework for better planning and control of construction equipment operation. One way to assist in this goal is to address the concerns of the constituencies of research and development by focusing on a process leading to implementation. The interests of the constituents of the research and development process are examined, a process leading to implementation is presented, and results from a recently completed research project are presented as an example of the process. It is concluded that a systematic approach such as the one presented will enhance the success of construction automation and robotics programs as well as lead to faster adoption of advanced technologies for field applications.**

***Index Term*--** **Robotic, Automation, Construction, Modern buildings, Industry**

I. Introduction

A competitive, market oriented and rationalized construction tomorrow requires developing of automated and robotized construction system today. This includes industrialized process originating in a mining, construction material production, prefabrication of construction components, on site construction, facility management, and rehabilitation and recycling. Today's construction projects are characterizing by short design and build period, increased demands of quality and low cost. These problems can be approached by a flexible automation using robots based on computer assisted planning, engineering and construction management. Especially in high labor cost countries, automated and robotized construction technologies can compensate increasing demand on construction projects. I consider construction robotics technology as a key to rationalization.

By automation, increased productivity could reduce high labor cost share of 40 or more percent. Automated and robotized construction process lead to a continuous working time through the year. Introduction of robotic technology would result in better working and health conditions, and advanced mechatronics know how and skills. The reduction of construction time would improve cost benefit analysis of construction project due to faster availability and return on investment of real estate. The implementation of automation and robotics technologies in construction has the potential to improve the industry in terms of productivity, safety and quality. This could be invaluable in making the industry more efficient and competitive in terms of its work processes and products. The construction industry is often fraught with problems of poor quality and safety records, time over-runs and inadequate labor, both in terms of skills and quantity. Implementing automation and robotics technologies in the construction work processes can assist in overcoming these problems as these technologies have the capability to generate higher output at a lower unit cost, with better quality products. The construction work site could be contained in a safer environment, with more efficient execution of the work, greater consistency of the outcome and higher level of control over the production process. Previous research has shown that construction sites will become more "intelligent and integrated" as materials, components, tools, equipment, and people become elements of a fully sensed and monitored environment. Automation of construction processes will augment manual labor for hazardous and labor-intensive tasks such as welding and high-steel work. Construction job sites will be wirelessly networked with sensors and communications technologies that enable technology and knowledge-enabled construction workers to perform their jobs quickly and correctly (Fiatech, 2004). Hewitt and Gambatese (2002) state that contractors utilize automated technologies on projects as a means of saving cost, reducing project durations, improving quality and consistency, and gaining other related project benefits. According to Bernold (1987), it is inevitable that intelligent machines will find their way into construction. Issues such as safety, job enrichment, high quality, vanishing craftsmanship, optimal usage of resources and preventive maintenance, are basic incentives to study the application of both system theory and cybernetics to construction operations. The introduction of these technologies will require organizational adjustments on construction site as well as in the planning and design phase. Alfares and Seireg (1996) in their study investigated the feasibility of automating the on-site construction of reinforced concrete residential buildings.

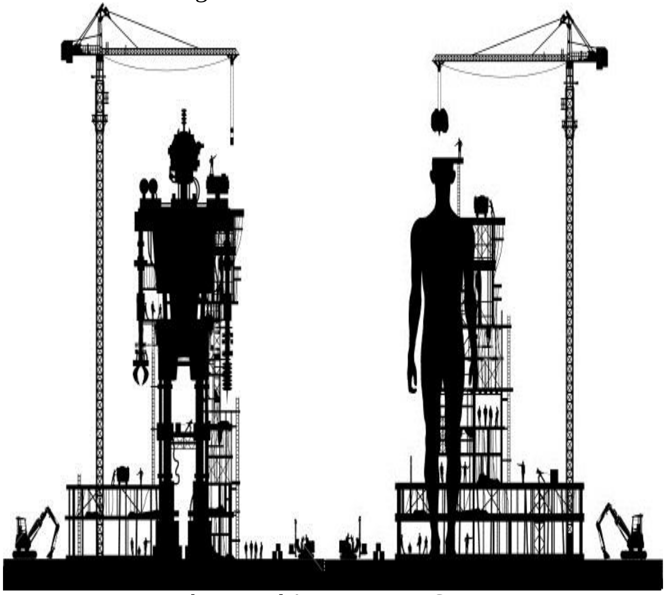

Fig. 1. Robotics and Automation in Construction

The basic construction tasks were identified, analyzed and modified with a view towards potential for automation. The research outlines a computer-aided construction system approach specially suited for integrating design and implementation by on-site robots. Slaughter (1997) in her research analyzed selected attributes of 85 existing construction automation and robotics technologies to examine certain trends in the development of construction technologies and the attributes which can influence their use. Since the introduction of the term "construction robot" some 20 years ago, more than 550 systems for the automation, unmanned operation and robotization of construction works have been developed and tried in Japan (Obayashi, 1999). According to IAARC (2004), in North America, pure industry-based work is far less evident than in Japan but many universities are increasingly working in collaboration with Japanese construction companies. In Europe and other parts of the world, work is on a smaller scale and is usually focused on specific areas of construction.
However, automation and robotics implementation in the construction industry is not as numerous as research suggested as the inherent barriers within the industry and technology itself, such as costs, organizational structure, available technology and work culture, inhibits real application on site. By identifying these barriers and investigating ways in which they could be overcome, progress can be made to better understand and facilitate greater use of these technologies in the construction industry.

II. DEFINITION OF CONSTRUCTION, AUTOMATION AND ROBOTICS

Automation is a process performed by using programmable or computer-controlled machines. Mechanization is introducing the use of machines to the production process, but automation goes one step further in that the process is not only supported by machines but these machines work within the framework of a program or control system that regulates their behavior.

Fig. 2. Automation and Robotics

Robotics is the field of knowledge and techniques that permit the construction of robots. Robots are not merely machines controlled by simple computer programs; they must be able to sense and react to the environment. Webster's Dictionary (1998) defines a robot as "an automatic device that performs functions normally ascribed to humans or a machine in the form of a human." The Robot Institute of America gives a more technological definition, that is, "a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks." A robot is therefore, a multifunctional manipulator programmed to perform various tasks normally ascribed to humans.

Construction Automation is the use of mechanical and electronic means in construction to achieve automatic operation or control to reduce potential exposure, time or effort while maintaining or improving quality (Hewitt and Gambatese, 2002).
Construction Robots are ingenious machines and use intelligent control but varies in sophistication. Generally they are designed to increase speed and improve accuracy of construction field operations (Stein, Gotts and Lahidji, 2002). The Japanese has a liberal interpretation of the term construction robots. Their definition includes advanced automation and remote control devices used on the construction site or prefabricated shop (Seward, 1992).
Three separate issues have emerged from studying the definitions, namely the difference in the sophistication of technology application between mechanization, automation and robotics. At one end of the spectrum is *Mechanization*, which involves the use of equipping a process with machinery. The machinery used may range from the simplest to the highly sophisticated and innovative machines, and the aim here is to make the process easier,

with the tasks accomplished in a shorter time frame, cheaper cost and of a higher quality.

The machinery used may be so technologically advanced that it would render the whole process automatic. In this case, the ***mechanization process*** has become an ***automation process***, where it goes one step further and the process is not only supported by machines but these machines can work in accordance with a program that regulates the behavior of the machine. The automation process is where, such as in manufacturing, the products move along the assembly and the automation technology or machinery used remains more or less stationary. Automation is easier to incorporate in a sense because each product is identical and the process is repetitive.

This may apply to prefabrication of materials off-site in the construction industry or production of drawings during the design stage. For on-site application, an example of this would be assembly of prefabricated buildings. One of the most sophisticated and advanced application would be that of **robotics**, where task-specific, dedicated robots executing discrete tasks on simplified building technology is used. Further research especially in Japan has explored the possibility of using intelligent or advanced robots that can execute complex, ill-structured tasks.

Both the term automation and robotics have been widely accepted throughout the construction industry and usually refer to automation, unmanned operation and robotization of construction works.

III. Robotics and Automation Technologies in Construction

Special robots and automation technology have the potential to increase productivity by performing tasks efficiently and improving working conditions through applications that limit the exposure of humans to safety hazards. Construction is a diverse industry characterized by almost unique circumstances for each project and a dynamic unstructured environment, with safety hazards, temporary activities and changing weather conditions, which all together hold back greater automation. This explains why there are few industrial robots to be found in the construction sector. However, recent years have seen an increase in the development of special robot and automated machines that carry out complex sequences of operations in the construction sector with certain impact. Examples of these special robots include wall (façade) climbing robots for inspection and maintenance, concrete power floating machines, concrete floor surface finishing robots, construction steel frame welding robots, wall panels' bricklaying robots, robotic excavators and automated cranes for the assembly of modular construction elements.

Fig. 3. Façade climbing robots for inspection and maintenance

Other advances in the automation in construction have been reported on the software side where IT applications have been developed, to increase the safety standards of the construction site, to assist in better planning and execution of projects, to automate the buildings' design process, to visualize the community projects using immersive 3D VR techniques and to monitor and control the parts and materials flow (through tags and RFID) of the entire construction process.

Research activities in the field of robotics and automation in the construction industry are divided according to applications into two large groups: civil infrastructure and house building. Typical civil infrastructure applications are the automation of road, tunnel, and bridge construction; earthwork; etc. In the field of house construction, main applications include building skeleton erection and assembly, concrete compaction, interior finishing process, etc. Classification according to applications is consistent with other possible classifications, which divide R&D activities according to the development of new equipment and processes (robots, automatic systems, IT application, etc.) or the adaptation of existing machinery to transform them into robotic systems.

II. Materials and Methods

Developments of construction robots are technologically difficult because of the nature of the construction work processes itself. The cheapest option is usually to adapt these technologies from other industries, but the obvious differences between work processes across the industries form a crucial barrier. To work in construction, the robots need to be robust, flexible, with high mobility and versatility. Stein, Gotts and Lahidji (2000) listed the different attributes of the construction robots as compared to those in other industries. Construction robots must move about the site because buildings are stationary and of a large size, and these robots require engines, batteries, or motors and drive for mobility. Constructions robots are also faced with changing sites and must be reprogrammed with each new condition; and therefore require digital control with manipulators using coordinate systems to direct threedimensional motion. Playback control found in most industrial robots does not suffice for construction applications. Construction robots also have to handle large loads of variable sizes, function under adverse weather conditions and are constantly exposed to dust and dirt on site, creating different demands as compared to conventional industrial robots. To overcome this, there is a need to look at how construction tasks are performed to encourage repetition, and the construction sites need to be re-configured to provide a more structured and controlled operating environment.

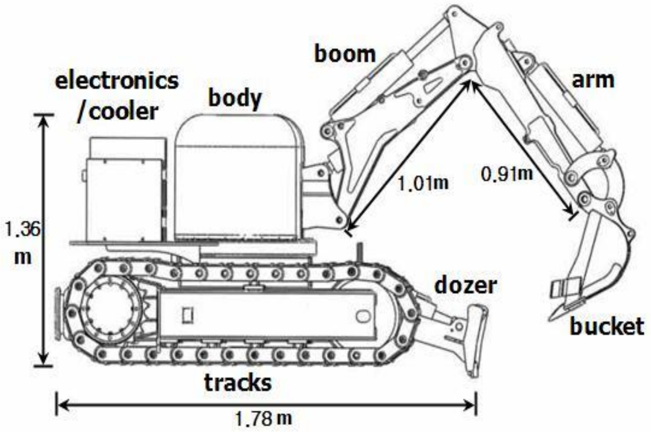

Fig. 4. Coal Mining Robot Design

IV. INTEGRATION OF ROBOTIC BEAM ASSEMBLY SYSTEM

System integration takes a role of combining the entire systems including the robotic bolting device, the robotic mobile mechanism, and the bolting control system. In this study, the system integration is homed in the control station which is placed on the cabin. Inside the cabin, the operator remotely controls the robotic systems, manages the whole automation process, and performs troubleshooting when the system malfunctions. With the monitoring device equipped in the control station, the user interface contains following features:

- States of the robot including the current operation, position information of each device, alarms, and etc.
- Sensory information from sensor network including camera image.
- Automatic manipulation and bolting function.

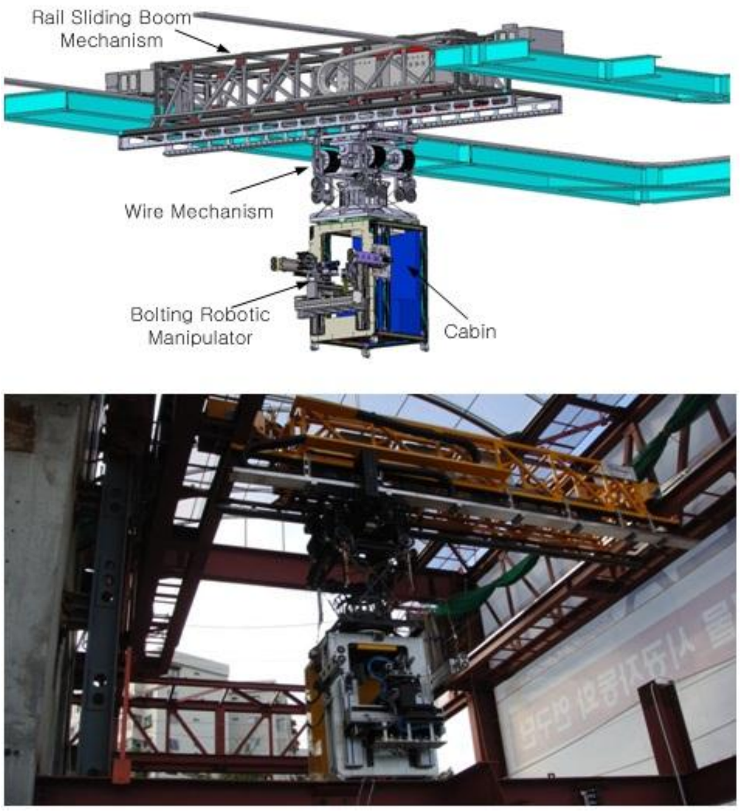

Fig. 5. Integration of robotic automation system for steel beam assembly

V. ROBOTIC MOBILE MECHANISM (RAIL SLIDING BOOM MECHANISM)

In order to implement the robotic automation system for steel beam assembly, a mobile mechanism to transport the robotic bolting device to a target position is required. In this research, we developed a rail sliding boom mechanism and a scissors-jack type mobile manipulator.

Fig. 6 shows the rail sliding boom mechanism. This mechanism consists of a boom part and driving parts. Since the boom part has the function of variable length, it is able to turn around the corner, where the distance between the inside rail and the outside rail is larger than the straight section. Two driving parts are located at both ends of the boom body, and slide on the rail structure placed on the CF to transport the mobile mechanism and the robotic bolting device. Also, they are connected to the boom body with passive hinges and can be independently controlled to increase the mobility specially on the corner driving.

Fig. 6. Rail sliding boom mechanism

VI. CULTURE / HUMAN FACTOR

The different work cultures between countries also play an important role as barriers to implementation. In some countries there are institutional barriers as well as active workers unions that look upon these technologies as a way to replace the workers. In Japan, concern about the aging construction workforce, upgrading of their academic background and the tendency for young workers to stay away from the industry has pushed forward the technologies (Obayashi, 1999). Construction robots can take considerable time to set-up and need to be constantly monitored by skilled workers. Therefore, for robots to become more commonplace on the work site a new breed of workers is needed; who has a strong academic background with special training in areas of robotics engineering and control.

VII. THE FUTURE OF ROBOTICS AND AUTOMATION IN CONSTRUCTION

The automation in construction has moved through several historical periods, according the ISARC trends (Ueno, 1998): a) cradle (1984-85), b) growing (1986-89), and c) developing (1990-98). However, even at the time of preparing this document one can assert that the consolidated has not been achieved yet. This may happen in the near future, but it is difficult to imagine that the houses will be built in the future like today's cars. However, as illustrated in the examples above the automation in construction is increasing and many of the developed prototypes will see their way to real application. Some factors are very important and will affect the way to real implementation in the near future. These factors are summarized as follow:

- Change of attitude in the construction companies, the machinery industry, the research centres and the government R&D officials, in order to develop new high tech commercial products and pass the phase of prototypes.
- Implementation of new IT and telecommunications technologies is already changing the work process in all the social segments, including the construction people. Today's form of work is unimaginable only a few years ago.
- Globalization of the market and consequently adaptation of the commercial structure in today's construction sector introduces a very high level of competitiveness, which urges companies to adopt more automated and efficient means.

To achieve the consolidation period in the construction automation big efforts need to be made in different fronts:

1. **Integration**. This is one of the key issues which are necessary to be consolidated during the next years, being the main lemma "from architect's desk to site robots". For this purpose three main actions should be taken:

1.1 Feedback design of houses, taking into account the prefabrication, erection, assembly, transportation and other stages of the construction process.

1.2 Diversity of the design using the highest number of the similar standard prefabricated elements (i.e. building different houses with the same parts).

1.3 Software standardization which permit the easy and fast data exchange between architects, civil engineers, electrical engineers and computer science experts.

2. **Pre-fabrication**. Expand this technology to cover other materials other than the concrete (including composites), which shall immediately boost the productivity. Three main actions are:

2.1 Mass production using pre-fabrication in order to select the parts from a catalogue. This means that CIM concept must be introduced, including JIT production.

2.2 Standardization of the maximum number of parts through the use of grid dimensions, common joints, connections, etc.

2.3 New materials for pre-fabricated parts which make them lighter, maintaining the same mechanical features.

3. **Robots and automated machines**. The robots and highly automated machines are the key issue. Using them ensures a high level of productivity. Some of the main actions are:

3.1 Easy to use robots. Develop robust robots which are easy to control and program through friendly human machine interfaces.

3.2 Cheap robots. Develop cheap robots which cover single type of application, being not general. This will permit to increase the sales of units.

3.3 Increasing the level of automation of existing machinery. Modify the conventional construction machines (cranes, compactors, etc.) in order to convert them into robotic system.

Investment in R&D. More research and developed investment in RAC both in basic and applied research through national and international targeted programs, such as the EU research frameworks. One of the main objectives has to be targeted also at changing the culture of the operators directly involved in the construction process, through education and training. Otherwise the operators would resist the introduction of innovation.

RESULTS

The following conclusions are made:

- Robots are increasingly involved in construction operations to maintain highly accurate actions and to reduce hazardous risks achieving improved control and safety.
- Automated construction can be further developed to include: design, engineering, maintenance of existing and planned structures.
- Many research works suggest highly autonomous robotic system for the construction performance. The "Sense-and-Act" may indeed become a reality in the development of more advanced robotic systems for construction applications.
- Real-time planning is commonly employed in tasks that require the robot to contend with uncertainties and undefined environments.
- Efforts should be paid to convince professionals in building management to look into the possibility of integrating robotics and building automation together to improve the quality of services for modern intelligent buildings.
- All new ideas for Automation or robotizing on the building site have to be generated by a combination of new designs, new forms and new materials that meet the requirements for building in a metropolis. However, many problems in construction engineering cannot be fully addressed through optimization and computation.
- With intelligence activities such as generalization, analysis and decision-making for multi-objectives, there can be a better understanding of the construction engineering problem.

DISCUSSION

Initially, robots were developed for the manufacturing industry and were intended to perform routine task in a very familiar environment. Unlike such robots, those designated for work on construction sites must be mobile, maneuver in changing environments, and perform a different task at almost every step. Construction engineering is changed by the application of more industrial production, sustainable production, mass individualization, and intelligent building to improve constructability. Therefore, recent research indicates that robot technologies can; in fact; significantly improve quality and equipment control in several construction automation applications. The ability to automate construction would be useful particularly in settings where human presence is dangerous or problematic; for instance, robots could be initially sent to underwater or extraterrestrial environments, to create habitats to await later human travelers. Actually, there is plenty of room for improvement in all process elements concerning robotics and automation.

CONCLUSIONS

Changes in the work culture and environment of the construction industry in the past decade have brought to the fore innovations in construction technology and the approach in which construction work is performed.

With the implementation of automation and robotics technologies in construction, the industry could improve in terms of productivity, safety, quality and global competitiveness. The common barriers that have been identified which hinder greater automation application are, economics and cost, structure and organization of the construction industry, technology and culture or human factor. The importance of these factors towards the adoption of these technologies in construction is seen in the form of current automation and robotics technologies available and its real time application in construction. The degree of implementation and level of investments vary across the world from country to country, with the greatest concentration of robotics application in Japan. The difference can be explained through the different work cultures, government policies and incentives, and organizational point of responsibility. By taking advantage of the positive aspects to be gained in greater use of automation and robotics technologies, the construction industry may gain a competitive edge in the global market in the future as compared to other industries.

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