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Robotics in construction — a state of the art review

R. D. Wing

Dr B. L. Atkin, P. Atkinson, C. E. Bridgewater and J. Ibañez-Guzmán, *Construction Robotics Research Group, University of Reading*

The most compelling conclusion drawn by Dr Wing is that robots should not be designed to mimic human tasks. This warning is borne out in other work[21] where it is argued that instead of designing robots to accomplish tasks performed around humans, construction details should be designed with automation and robots in mind. Buildings should, therefore, incorporate robot-oriented design concepts.[21] Furthermore, industrial robotic manipulators should not be adapted to automate traditional construction processes.

38. Robotic manipulators and construction plant and equipment have evolved from different design concepts and have different objectives.[23] The former have their origins in the machine tool industry where component stiffness is an all-important property in obtaining accuracy and .epeatability. The low payload : weight ratio of these devices is much too low for construction plant, such as cranes, which are generally rugged, but not particularly stiff. In construction, the payload : weight ratio is an important factor, as plant and equipment needs to be transportable and manoeuvrable. Industrial robotic manipulators are concerned primarily with position control, whereas construction plant and equipment is more concerned with force control. Understanding the fundamental differences between the design of robotic manipulators and the design of construction plant and equipment can lead to improvements in both types of technology.[23]

39. In construction processes, two thirds of the production time is taken up by some kind of assembly operation.[22] It seems reasonable to expect, therefore, that efficiency of construction might be increased if components were designed for assembly. This implies that connections must be simple and conform to a standard that is coupled with the target robot's structure and performance characteristics.

40. Dr Wing also pointed to the need for further work in the field of human factors, particularly those concerned with developments in man-machine interfaces. Indeed, work has already begun. A useful example is to be found in the development of an ergonomic control system for a large construction pipe manipulator.[24] A joint venture between the University of Texas at Austin, Dupont–Grove and the National Science Foundation has produced a multifunction manipulator based on a modified telescopic crane. The manipulator, which is controlled by the ergonomic control system, incorporates a pair of master–slave control levers to manipulate pipes of varying diameters. Optical position encoders are used to relay control movement to an industrial microcomputer. The system can also be used to train operators. Further examples in the development of

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man–machine interfaces include studies of the operation and control of excavators.[25,26] The aim is to understand more about the mechanics of excavation processes so that operation and control might be improved.

41. A literature survey of automation and construction robotics conducted by the Construction Robotics Research Group at the University of Reading[27] indicates that research efforts are being concentrated in five areas: the enhancement and optimization of existing construction plant and equipment; the application of artificial intelligence techniques to construction planning and scheduling; the simulation of construction processes; the application of robot-oriented design concepts; the development of task specific robots. It is the view of the Reading group that construction robotics is at the same stage now that computer science was in the late 1960s. At that time, expectations had risen to the point where many people believed that soon most things would be computerized. However, as history records, hardware improvements took longer to materialize than had been predicted. In a similar way, the real measure of the problems that have to be solved in the field of robotics in general, and construction robotics in particular, are only now becoming clear. There is some way to go before a second generation of construction robots will emerge.

Dr Ing. I. Vávra, *Technical University, Prague*

If robotics is to be introduced successfully into the construction industry there is a strong argument for proposing a robotics technology that will be able to cope with all production processes used in this area. It will be necessary to solve all the interactions (Fig. 8) that prevail between robot, human being and building

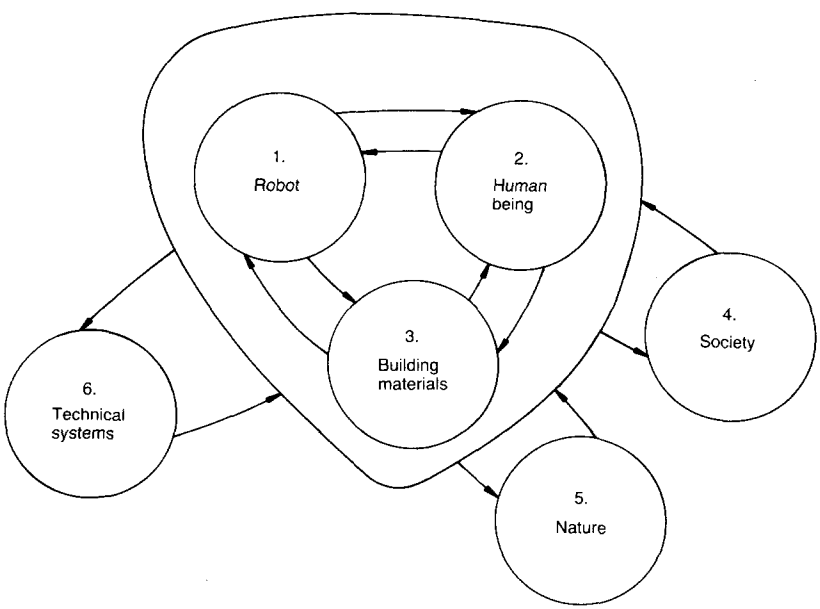

Fig. 8. Construction process using robotics and relationship with other factors

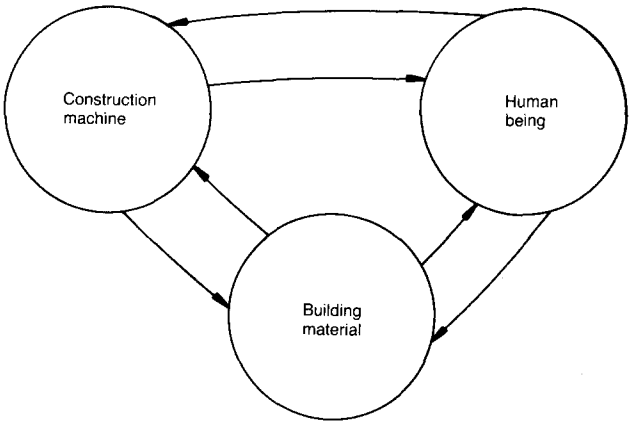

Fig. 9. Mechanical construction process

materials. Three fundamental systems determine the course of construction processes: society, nature and technical systems.

43. The mechanization of construction processes involved interaction among all these factors[28] (Fig. 9). That led to the establishment of measures for human safety in connection with construction material. With the application of robots, those interactions will be removed, which will lead to a decrease in the overall level of accidents. Up to now the technologies have been developed in such a way as to be manageable by humans. However, with the use of robotization, this approach can be removed, and construction and the pace of activities have to be planned so as to comply with the robots used.

44. It will be useful to solve the interaction between human being and robot in the following areas

(*a*) the preparation, doing and inspection of work done
(*b*) safety measures in connection with the common relation robot–human being.

These measures will be connected with

(*a*) the development of CAD/CAM systems
(*b*) the development of systems for data and commands, communication device, sensing device, blocking device, and systems for testing the robot before and during the work; all these devices and systems have to work reliably in severe conditions.

45. For the interaction between robot and processed material the suitability of construction materials for use in connection with robotic work and the safety of the robot have to be resolved. Such considerations evidently will lead to the development of new construction materials and building construction elements, or adaptation of present materials and building construction elements to the demands of robotic systems. As for interaction between robotized construction processes (1 + 2 + 3 in Fig. 8) and society, financial problems and environmental impacts (high level of noise, vibration, dust) caused by the robot's work must be

resolved. Interaction with nature, in the form of environmental influences, will be explored, for example: climate, terrain configuration, hydrogeological conditions and other potential dangers during work by robots.

46. In the future the problems mentioned could lead to the transfer of part of the production process from the building site to the factory. There it will be possible, by means of robots, to produce the building elements suitable for handling by robots on the building sites. Besides this it is expeced that new building materials (well moulded, of programmable quality, low sensitivity to climatic influences) will be developed. Also resolved will be problems of the interaction between robotized construction systems and the technical infrastructure (transport, electricity, communications) used for robotization, and possible unfavourable influences on the course of processes (obstacles during the work, disturbance during signal transfer and danger from the destruction of technical equipment involved in robotic processes.

47. In conclusion, for the introduction of robots into construction processes it is imperative to proceed in an intricate and systematic way. The development of construction robotization will not bring any instant advantages and will need a high level of funding with governmental support. The introduction of robotization will need a complex restructuring of the construction industry. It would be of great benefit to create lines of international co-operation to exchange experiences in these matters.

Dr V. Hamata, *Technical University, Prague*

It should be emphasized that a wider application of robotics to the construction industry is based on computerization of the construction site and hence its better organization (as a well-structured site). There are three major factors that will influence the successful application of robots to construction (apart from the proper technology)

(*a*) logistical support
(*b*) real-time management
(*c*) on-site meteorology

and the wide use of computers implies the necessity of computer models of the building under construction (as-designed and as-built models).

49. There are two general trends that can be foreseen in robotization of the construction industry in Czechoslovakia. Firstly, there are totally new applications, based on the principles of complex automation, i.e. including the new technologies oriented primarily towards robotization (automation). Secondly, there is reconstruction (maintenance), particularly of housing construction, which represents an ever-growing problem. The application of robots to reconstruction of historical buildings is very limited, but in Czechoslovakia we have to take into account the great number of panel-constructed houses built from around 1955 that currently need (or will need very soon) serious maintenance work or reconstruction. The problem is that the technology used does not suit robotization.

Dr Wing

The importance of human factors research is emphasized and elegantly portrayed in Dr Vávra's Fig. 8. This concurs with the scenario given in the Paper (§ 8) that the completely autonomous robot will not find application in construction, and that overall human supervision will remain in the foreseeable future.

51. An increase in on-site production processes is already evident in current practice (§ 46), and as these factory processes are already substantially mechanized, robotization should not present serious technical difficulties. However, on-site manipulation processes will, as rightly emphasized in § 39, require much development, as they cannot be robotized by scaling up manipulators used in other industries. Teleoperation, again heavily dependent on human being–machine interaction, is probably the most promising approach for these processes.

52. 'The introduction of construction robots into the UK construction industry may be a slow development', to quote § 4 from the Paper; this point is certainly borne out by the lack of discussion response from that sector. It may well be that industry is awaiting the second generation robots (§ 41), but they would be well advised to start laying in the infrastructure — computerized management, planning, design, and database — on which forthcoming robots and advanced automation devices will be dependent.

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