DEVELOPMENT OF MODELS AND METHODS FOR RESEARCH ON ROBOTICS IN THE CONSTRUCTION PROCESS AND DESIGN

MAURIZIO COSTANTINI *
ROBERTO VINCI **

0. ABSTRACT

1. INTRODUCTION

In the building and construction industry the question of buildings and constructions as complex systems is becoming increasingly relevant. Buildings are not just an ensemble of concrete, steel, brick, gypsum and plaster: they are a dynamic entity that must be able to undergo a variety of different uses and functions.
Scope modifications, usability changes, management of ageing, durability and management economics, flexibility in operating facilities are a *must* in the new ongoing approach and 'mentality'.
Thus, in triggering a new course of action and supporting what appears to be an irreversible trend, robotics may become a highly significant technology. At the same time, experience compels us to consider technology –and its more advanced issue, robotics– as only a single tool to be matched with a far more complex situation involving users' and clients' expectations, flow of requests and quantity goals, resource and finance aspects, labour quality and availability, contractors and building industry size and organisation, et cetera. This may explain why in our country, and perhaps in Europe in general, a gap between the above-mentioned needs and an effective use of the tools currently available is noticeable, in spite of a rapid surge of interest in robotics at the present time

2. A SCENARIO FOR ROBOTICS: SOME TOPICS IN ITALIAN BUILDING PROCESSES AND THEIR RELATIONS WITH EUROPE

In order to establish a common base-line and to understand the present situation, as well as a foreseeable future in which robotics may play a part, it will be useful to offer a brief synopsis of the state of the construction industry in Italy.
First, we note that there is no longer a problem of quantity: much of what was needed has been built, in a paradoxical situation in which construction activity has often reached a peak in crisis periods.
What is currently lacking may be arranged under two main headings:
– really big works, mostly related to few, widely extended sites; such works are linked with a huge financing effort concentrated on a limited amount of non-standard cases,

* Associated professor of Building Materials Technology, University of Pavia, Italy; scientific consultant to QUASCO, Bologna, Italy
** Co-ordinator of "Progetto Finalizzato edilizia", SP3, "Quality control and technology innovations"; in charge of Information Dept., ICITE/CNR, Milan, Italy

mostly dealing with: hospitals (some tens of new health care "poles"), public and individual transportation (long distance high speed railways, urban underground railways at urban and sub-regional scale, underground parking towers, people and goods interchange nodes), hotels and leisure resorts: in short, large-scale, non-standard works are now absolutely of the essence;
- widespread maintenance and rehabilitation works, which should be undertaken with reference to much of public housing stock, roads, accommodation buildings and urban facilities (mostly sewers and water supply facilities).

As a matter of fact, in the construction industry, labour in Italy must be considered as skilled, abundant *and* relatively cheap, which normally means no push towards industrialisation. Sudden emergency in demand or absolutely intensive money flows dedicated to a single task appear to be the one possible spur towards industrialisation: if scant labour is on offer and available technologies are too slow to operate, the chance to bid and compete could even be disregarded altogether. Hence, the scenario in which robotics might become sufficiently diffused is possibly identified by a market that has become far more competitive after the disappearance of technical barriers in Europe; in this new situation, we can expect that open system industrialisation will be more widely adopted —to cope with requested non-standard solutions — if minimal tender sizes effectively rise. In that case, robotics should be regarded *not* as money-saving tools, but as *time*-saving tools, i.e. as strategic management factors.

In Italy, this scenario is by no means unlikely — even independently of the coming European open market; it could be aimed at backing up sudden requests for large quantities of construction, and at following up the "stop and go" which is typical of the Italian construction industry, widely dependent on the push and pull of public financing. The construction landscape in Europe features a number of problems to be taken into account, which will necessarily need to be tackled with new robotics opportunities under investigation. A specific study on this topic is currently being performed by the European Sprint Research Program, with contributions from France, Italy and The Netherlands. This study also underlines the dispersive and fragmented nature of the building sector. Furthermore, the business structure —and the contractors themselves— are strongly fragmented while markets, construction sites, building techniques, products and materials are spread over a wide range of solutions. According to the market structure, the chances of a priority in robotics are consequently oriented towards construction and public works, followed at some distance by non-residential buildings.

As far as maintenance and rehabilitation are involved, the scenario is somewhat different: in this case, works are performed by small and very small groups —the average dimension is 3.4 employees per firm—, labour is sometimes less skilled, and nevertheless more expensive. Quality control and responsibility are virtually non-existent when the amount of works is small, and big contractors are seldom interested in this field but, rather, in the "bear" market. Moreover, technical situations are non-standard: nevertheless certain operations are frequently encountered, and could be standardised, such as cleaning façades or sewers, or sealing leaks in pipes belonging to large networks.

3. STATE OF THE ART AS SHOWN BY ICITE/CNR AND OTHER RESEARCH ACTIVITIES IN EUROPE

In Italy at the present time much effort is being devoted to research into construction and building. The research project is a scientific undertaking by the National Research Council (Consiglio Nazionale delle Ricerche, CNR, located in Rome, with area branches in Milan and other main Italian cities); the project is carried out by the Central Institute for Industrialisation and Building Technology (Istituto Centrale per l'Industrializzazione e la Tecnologia Edilizia, ICITE, located in Milan). The project (Progetto Finalizzato Edilizia, PFEd) is a 5-year, goal-oriented research programme, designed to financially support building organisations. The research project allocated funds up to a total amount of 115 billion lire (some 82 million dollars) and was launched in May 1989: its third Executive Program has already been undertaken and partly completed at the time of writing. PFEd aims to act as a link between the research field and the production field to foster actions and processes leading to modifications and innovations in the building sector and able to encourage national operators on the European market.

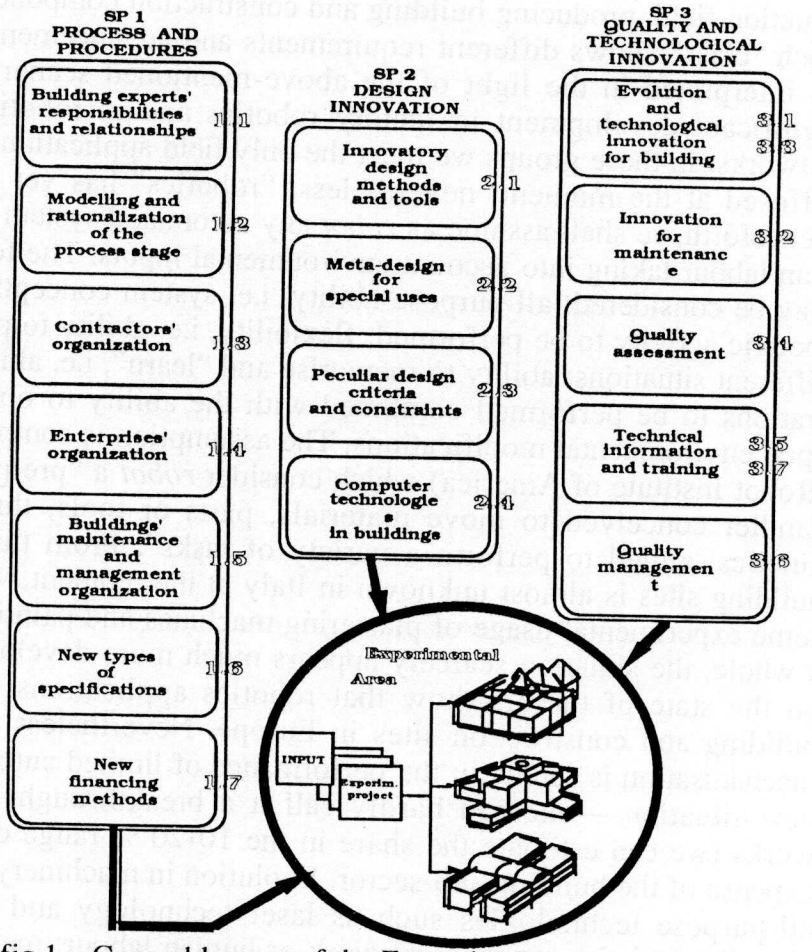

fig.1 – General lay-out of the Executive Program of PFEd.

From an operational point of view, PFEd is divided into three sub-projects, as follows: SP1, Building process and procedures; SP2, Project and design improvement and innovations; SP3, Quality control and technology innovations.

Each sub-project aims to support R&D in the field, triggering and spreading the availability of tools and/or knowledge. Particularly, sub-project 1 aims at improving the status of the building process and the organisation of its relevant procedural stages. Sub-project 2 is intended to provide a basis for developing tools and cultural skills to help designers to cope with and manage the design process in building. Sub-project 3 is oriented towards developing new technologies and towards supporting standardisation, experimental activities and quality control activities. In what follows, this paper briefly

reports the results obtained by PFEd as far as robotics is concerned. IPFEd primarily showed different fields of action applied –or to be applied– in the building and construction field. Aactivities can be classified as follows:

- robotics at building site;
- robotics at construction site;
- robotics in factories;
- robotics in building maintenance;
- robotics in road maintenance;
- robotics in sewer and water supply management and maintenance.

The term "factories" refers, of course, to factories operating in the building and construction field, producing building and construction components, elements and materials. Each "class" shows different requirements and advancement. A quick resume of results — interpreted in the light of the above-mentioned scenarios— gives some idea of a significant development in factory robotics and in robotics for underground facility networks: in these groups we meet the only field application that seems to be sufficiently diffused at the moment; nevertheless, "robotics" has yet to be defined in this paper. Henceforth,we shall assume as *robot* any automated system able to substitute skilled human labour taking into account environmental inputs. The following main characteristics may be considered: all-purpose ability, i.e. system conception relatively independent of specific activity to be performed; flexibility, i.e. ability to perform different functions in different situations; ability to memorise and "learn", i.e. ability to input sequences of operations to be performed combined with the ability to operate a feed-back depending upon environmental modifications. The assumption is compatible with the RIA definition (Robot Institute of America) which consider *robot* a "pre-programmable, multi-function handler conceived to move materials, parts or tools, through variable, programmed kinetics, aimed to perform a variety of tasks". From this point of view, robotics at building sites is almost unknown in Italy at the moment, with the possible exception of some experimental usage of plastering machines and painting machines. Over Europe as a whole, the situation scarcely appears much more developed. The PFEd investigations on the state of the art show that robotics applications are virtually non-existent on building and construction sites in Europe. Nevertheless, some trace of human labour mechanisation is found, in the performance of limited automation by site machines. This new situation —one can hardly call it a breakthrough— is mostly related to public works (we can estimate the share in the 10÷20 % range of site machinery stock) at the expense of the building sub-sector. Evolution in machinery is basically obtained by using all-purpose technologies such as laser technology and micro-electronics technology aimed at assisting mechanical work or human labour: machines of this kind are already enlisted in U.S. and Japanese production.

In the building field, some devices are available as well, such as façade elements or internal partition board positioning machines built in Japan, but their usage is virtually unknown.

As far as R&D applied to robotics is concerned, the European effort looks comparable —in terms of expenditure— to that of the U.S. or Japan, but regretfully action remains uncoordinated at the moment: the SPRINT Program, in which Italy participates, and other policies grew out of realisation of this limit, with the aim of creating an acceptable frame of co-ordination and overcoming duplication of activities and expenditure among

different European countries. A sketch of the present situation could include the Scandinavian countries, the Netherlands, Germany and to some extent the UK may be considered countries —among EFTA countries, i.e. countries of the European Free Trade Association—which enjoy greater competitive advantage in the robotics R&D field: the ability of this "club" stems from no mere chance and is certainly due to higher co-ordination levels among different actors such as university departments, R&D structures, machinery manufacturers, contractors, building products manufacturers, engineers' and architects' organisations and, last but not least, workers' unions.
A picture like the above derives its existence from a simple enough state of affairs: innovation in the construction and building industry is still widely dependant on R&D dedicated to "individual", case by case, solutions, while there is a basic need to keep prices low *and* to increase quality in building. A direct consequence is that the main obstacle —and the great opportunity— consists in the operating flexibility of robotics.

4. CONCLUSIONS

For the foreseeable future one could reasonably forecast that the building subsector and construction and public works subsector will continue to be sharply differentiated.
In the short term, as regards the building sub-sector, prospects might focus on concrete production delivery and laying, as well as on pre-fabrication factory robotics.
In the middle term (10÷15years), while robots available at feasibility or pre-series level (basically, plastering and painting machines, internal board and brick positioning machines, vertical maintenance and cleaning machines) could possibly proceed from the experimental stage to small *routine* practice. Further, a wider use of CAD/CAM technology may be expected with regard to steel frame soldering operations as well as a much more extensive use of "intelligent" digitally operated machines in factory production; the last case should essentially be aimed towards covering an outstanding need to produce very small amounts of pieces in a wide variety of types. However –according to the CEBTP report "La robotique en Europe: le cas du BTP", "Robotics in Europe: the case of building and construction of public works"– this scenario poses serious cost problems, since the resulting over-costs may be as much as 30%. We have available no data or estimates that are likely to be valid in the long term.
As far as construction and public works are concerned (roads, water supplies, sewers, dams, etc.), and referring to non-manufacturing robotics, an increasing spread of already existing machines and technologies may be expected in the middle term: machinery dealing with inspection and maintenance in dangerous, inaccessible or toxic environments, tunnelling machines, paving machines, automatic excavation machines are significant examples of the trend. Continuous diffusion of public-work-robots is likely to emerge from an increasingly extended use of micro-electronics in "traditional" machinery; such a process should accelerate whenever repetitive operations are involved, shaped like a "production line on site". However, analysis in the CEBTP reports mentioned above specifies an estimated limit of 15 % in the amount of works as the upward limit of applied robotics.
Alongside attempts to make rational forecasts - which may be just as easy to refute as they they are to obtain - the kind of approach and frame of mind are decisive and critical topics in this field: again, the importance of method should be stressed, to obtain an

effective re-organisation of the building and construction process and to reduce or eliminate wastage in time, labour and materials. In other words, the challenge is not merely one of transferring applications or conveying technology *from* one sector to another. Inputs and background typical of information technology or advanced mechanics cannot without difficulty be "transferred" to building and construction. If risks of refusal or ... are to be avoided, a prime task must be that of *interpretation* in order to bear constantly in mind the needs and habits of the building and construction world. This would seem to be the best or the only way of proceeding if legitimate but hard-to-accomplish expectations are to be fulfilled. To take an example from a different field, it is well known that skilled language interpreters do not simply "translate" but render the proper *meaning* of the concepts to be communicated. The small experience developed in Italy in the subject under discussion, together with larger-scale activities elsewhere in Europe - added to the know-how derived from shocks and successes in building industrialisation in the sixties-seventies, may strongly suggest –as both conclusion and starting point– the suitability of an inter-disciplinary approach. The contribution of building and construction competence should be considered as absolutely relevant —side by side with support from specialists— in triggering and setting up a *system* of intelligent tools "tailored" to follow —and whenever possible anticipate— the user's needs and requirements. This would appear a good approach to start with: one oriented towards preventing the risk of depleting efforts which are costly in terms of money, people, and expectations.

BIBLIOGRAPHY

E.T. Keravnou, L. Johnson, "Comepetent Expert Systems", *McGraw-Hill, N.Y. 1966*

M. Colombard, A. Norsa, B. Turchini, E. Zambelli, "Il contesto delle costruzioni in Italia", *Cebtp, Paris 1987*

M. Colombard, A. Norsa, B. Turchini, E. Zambelli, "Situazione e prospettive nella produzione di alloggi", *Cebtp, Paris 1987*

M. Eyke, "Building Automation", *BSP Professional Books, London 1988*

R. Coyne, "Logic Models of Design", *Pitman Pub., London 1988*

AA.VV.,"Caractéristiques des filières de la construction en Europe", BIPE, Ministère de l'Equipement, Paris 1989

AA.VV.,"Technical-ecnonomical Feasibility of site robotics in Europe", *2.nd Phase Report to ECE Commission, Paris 1990*

AA.VV., "Open Industrialisation: a solution for Building Modernisation", *Conference Proceedings, Stuttgardt 1990*

AA.VV., "PFEd Annual Report", ICITE/CNR, Milano 1990

AA.VV., "Construction Research Needs in Europe", *Proceedings of the ENBRI Symposium, Luxembourg, oct. 31, 1990.*