Title of the paper

RESEARCH INTO THE APPLICATION OF ROBOTICS IN THE HUNGARIAN BUILDING INDUSTRY

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The Hungarian Institute for Building Science has been concerned with the preparations for the application of industrial robots to building construction since 1983. The main trend of the development of the building industry is industrialization, in consequence of which an ever growing portion of construction activities are transferred from building sites to plants of permanent location. This development trend makes it possible also in the building industry to apply manufacturing mass production methods for the prefabrication, preassembly, surface finishing and handling of the various building components. If suitably adapted, industrial robots developing at a rapid pace during the past few years can be applied to such tasks.

In view of the above circumstances as well as technical-economic considerations the independent development of special building industrial target robots is outside the scope of our activities. We set ourselves the primary goal to solve the most essential problems of industrialized construction technologies on the basis of the currently available selection of industrial robots. As one possible basis we regard the IGM-RECARD industrial robot product of RT 280 type, developed in Austro-Hungarian cooperation for arc welding, flame cutting and painting purposes. The manipulators, software, etc. necessary to satisfy the given requirements of construction technologies are developed and offered to users by ourselves.

A significant field of application is the subsequent automation of existing building industrial production equipment in the areas where labour can be saved by adapting industrial robots. On the other hand, the design of new production equipment should provide already in the design period for the application of system-oriented complex solutions in all possible stages of the production process (materials handling, manufacturing activities, etc.). The majority of the activities can be performed economically by the expedient use of industrial robots, which also facilitate a flexible adaptation to currently changing market demand. The main fields of application are:

- handling of materials (standard size packaging, palletizing, feeding and removal in automated machines, etc.);
- surface finishing (paint and glaze coating, mould preparation, etc.);
- welding (electric arc and spot welding);
- processing of products (grinding, sandblasting, etc.);
- assembly;
- dimensional check-up.

Table 1 lists the Hungarian Companies of the building and building materials industry where the application of adapted industrial robots can be primarily introduced. The Table shows that the building and building materials industry mostly require the application of cheaper category robots of comparatively simple construction.

Before installing industrial robots the task for the performance of which the robot is to be applied should be carefully examined.

It is justified to consider the following criteria:

1. It is very essential to provide for the orderly supply of work pieces/products. If they arrive at the robot in a disordered state, a pre-ordering equipment should be applied to secure the place and position of the work pieces. Should this not be possible owing the properties of the material, the task can be solved by applying more expensive, e.g. shape-sensor devices.
2. In what way can the work pieces handled (placed, removed etc.) by the robot be forwarded, is subsequent ordering, palletizing or standard packaging, etc. necessary. This is a criterion essentially specifying the technical parameters and the cost of the robot to be applied.
3. Can the pre- and post-ordering equipment mentioned in items 1 and 2 be designed to be suitably adjustable to the work pieces of different geometrical dimensions? What is the additional cost of these equipment?
4. Will the machine processing or other tool be suitable for automated moving?
5. How many types of work pieces are to be moved within a given program?
6. Can all work pieces be moved by a universal gripper or should grippers be replaced? Can replacement be automated or is human intervention necessary?
7. Are the input and output signals for controlling the robot attached to the production equipment available? Can the production equipment and the industrial robot be operated synchronously?
8. The space required for the operation should be established and protective railings provided for clearance around the hazardous area during operation.
9. The necessary measures or new installations for energy

Table 1. Fields of robot applications in the building and building materials industry

Company	Field of application	Control class
Fine Ceramics Works	feeding	A
	removal	A
	palletizing	B
	surface coating	D
Glass Industrial Works	feeding	A
	removal	A
	standard size stacking	B
Brick and Tile Industrial Co.	feeding	A
	removal	A
	standard size stacking	B
Concrete and Reinforced Concrete Works	removal	A
	standard size stacking	B
	placing of reinforcement	B
Prefabricating plants	surface smoothing	C,D
	placing of reinforcement	B
Plants manufacturing lightweight components	surface preparation	D
	feeding	A
	welding	D
	surface coating	D
Building Installations Co.	welding	D
	surface coating	D
Factories of the Building Joinery and Wood Industry	feeding	A
	removal	A
	surface coating	D
	assembly	C
Central depots of construction companies	feeding	A
	removal	A
	surface coating	D

supply should be considered. In siting new complex systems the energy requirement of the industrial robot (electric power, condensed air) should be taken into account.

10. The staff responsible for robot control in operation, programming, readjustment and maintenance should be set up.
11. Safety requirements should be carefully specified and complied with.
12. Economic studies should be carried out to decide whether the employment of a given robot type is economically feasible. Equipment having different parameters are available on the market at highly differing prices. Knowing the technical parameters a given task can be implemented by several types of robots. Thorough investigations should be conducted to find the optimal solution both technically and economically.

In the case of subsequent automation, when the production costs of the old and new equipment (operated without and with robots, respectively) can be compared, the amortization time can be calculated from the following relation:

$$t_a = \frac{I \pm E}{C_o - C} \text{ (year)}$$

I: investment cost of the industrial robot (price, installation)

E: value of the equipment withdrawn from production after the installation of the industrial robot (-) or the value of additional investment necessary for the installation (+)

C_o: continuous production costs before robot employment (Ft/year)

C: continuous production costs after robot employment (Ft/year)

If compelling circumstances so require it may be necessary to install industrial robots to protect human health and safety, in spite of unfavourabla economic factors. It is especially justified to save labour in the following areas:

- heavy physical loads
- environmental loads (noise, dust, heat, etc.)
- monotonous work of long duration
- work requiring high concentration on the part of workers, involving heavy nervous strains

Based on the data obtained from preliminary surveys it can be decided which robot to select from the types available in commerce.

The range of the most important parameters of industrial robots to be employed:

- number of the degrees of freedom for the movement of gripper or other tool attached to the robot arm: 3-7 degrees of freedom
- load lifting capacity: 5-300 kg
- reach (range of the robot arm's movement) in horizontal direction (radial displacement) 500-2500 mm; in vertical direction: 500-4000 mm; axial rotation 180^{o} - 350^{o};
- repetition accuracy in loaded state: ±0.1 - ±3 mm;
- moving speed for horizontal and vertical displacement: 150-1000 mm/s;
- speed of axial rotation $30\text{-}190^{o}$/s;
- control method: contact positioning
  point control (PTP)
  orbital control (CP)
- control system: pneumatic, electronic
- operating power: pneumatic, hydraulic, electric

- space required (area)
  mechanical unit: 0,4 - 3 m^2
  control unit: 0-2 m^2
- weight of equipment:
  mechanical unit: 400-3000 kg
  control unit: 0-700 kg
- power requirement: 1-15 kw, condensed air 5-10 bar

There are many robot types with main parameter values in the above range, which are thus suitable for application to tasks in the building and building materials industry.

Less expensive robot types include the simple, so-called "PICK and PLACE" robots, which can be employed for simple material handling. At the other end of the scale there are the so-called "HIGH TECHNOLOGY" robots, naturally in the higher price category, applicable to painting, arc welding and assembly.

Example of application

Of the Companies listed in Table 1 it is primarily the Building Installations Co. where the conditions for operating industrial robots are available. The Company manufactures in a specialized factory unit the pipe products to be installed at various locations in this country. The products (pipe bends, T-joints, boiler house blocks, etc.) are produced in relatively small series, but over a wide range of dimensions. The preparation of the products (cutting to size, cutting of the overlapping parts of pipe joints, grinding of edges etc.) takes place on an up-to-date flame cutting machine of VARI-PIPER type. The machine produces the pipes to be welded together with the required dimensional tolerances. The work pieces ara fitted and welded manually, by electric arc. The number of highly trained welders is 30.

The length of welded seams annually produced on the products considered here is 16175 m. Taking into account the growth trend of the years to come, the length of joints welded by robots may amount to 20000 m/year. Based on the fact that the speed of mechanical welding is 10-20 m/h and that the robots can be operated in at least two shifts, 60 per cent of the working time being taken by the main welding operation, the rest is used for training, reorganization and maintenance. Thus, the length of welded joints to be annually produced by robots is:

$$L = N.m.h.v.\eta \text{ (m/year)}$$

N: number of workdays/year (N=250 days)

m: number of work shifts of the robot (m=2)

h: working time/shift (h=8 hours)

v: average welding speed (v=10m/hour)

η : machine capacity exploitation rate (η - 60 %)

Substitution of numerical values and carrying out the calculation yields that the length of joints to be produced by an arc welding robot per year is:

$$L = 250.2.8.10.0{,}60 - 24000 \text{ m/year}$$

This means that assuming appropriate preparations (mounting, pinning, placing on the machine, material handling, work organization, etc.) a single arc welding robot is capable of carrying out the welding of pipe products of very heterogeneous composition surveyed here.

A 60 per cent exploitation of the robot's capacity requires a high level of organization already during the course of operations prior to welding. The importance of material supply and mounting on the machine should also be emphasized, which is not only a problem of sufficient staff but also one of gripper devices of adequate precision.

Beyond the example described here further studies on the application of robotics are in progress. The work is in the preparatory stage at the prefabricating plants of the concrete and reinforced concrete industry and of the building ceramics industry.

Research into the application of robots to certain tasks on the building site is still in the stage of exploration and analysis. Of such tasks the development of a robot series suitable for the interior finishing works (plastering, painting, cladding) in residential and industrial buildings seems to be of primary importance.

Another possible program can be to develop multi-function building industrial manipulators mounted on a hydraulic self-propelled basic machine. With adequate fixtures this machine could be employed e.g. for loading/assembly of prefabricated building components, laying sewer pipes, placing foundation units, filling work trenches, soil compacting, etc.

In our opinion, the trends to be followed by the application of robotics on the building site will be clearly predictable in the next few years only. These trends will also depend decisively on the current structural changes in the building industry and on the further development of the role of building industrialization.