Survey of Building Robots

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1. INTRODUCTION

The Employment of robots in building construction tasks has been studied, developed and tried on site over the last 15 years. Cases of development and implementation of potential and actual applications have been extensively described in a wide body of publications.

The purpose of this study was to review these applications and to assess their implementation in practice. A survey was conducted for this purpose. The following paper will describe the findings of the survey and draw the necessary conclusions from them.

2. THE SURVEY

The general objective of the survey, as stated above, was to determine the scope of application of robotics in building construction. In more specific terms the objectives of the survey were:

a. To review the publications describing the development and implementation of robotic applications in building construction.
b. To determine the success of these applications, with an aid of a structured survey. For this purpose the exact status of the application was determined for each case.
c. To analyze the findings of the survey and draw conclusions regarding the extent of success of building robotics, and the reasons for success/failure.

A building robot was defined for the purpose of this study as "an automated device employed for a building task on a construction site".

The survey involved the type of application, the characteristics of the robot - its configuration, its control and sensors, the stage of its development/employment and the reason for not continuing, if the development/employment was abandoned at some stage.

The stages of the development of the purported applications were defined as follows:

a. Under development (physical development in a laboratory).
b. Prototype tested in laboratory conditions.
c. Product tested under regular conditions on a building site.
d. Product employed in an actual construction process on the building site.
e. Product commercially marketed to users.

The survey involved all sources of information which were described in the following publications:

a. Annual Proceedings of ISARC (1-XII).
b. Journal of Automation in Construction (Volumes 1 - 3).

c. IAARC's newsletters (1-11).
d. Publications of robot developers.
e. Other trade and academic publications.

The questionnaire included questions on the following subjects:

a. General information about the robot.
b. Its state of development.
c. If the development was abandoned - the reasons not continuing.

The survey was conducted in two stages. The initial stage included a structured questionnaire and the second stage - verification and augmentation of the forwarded responses.

3. THE RESULTS

3. 1. The scope

The survey involved 81 identified development cases. 72 answers (89%) were received from the following countries (the percentage points were rounded and may not add up to 100%):

Japan	52	(72%)
US	5	(7%)
Germany	7	(10%)
UK	4	(6%)
Finland, France, Israel, Sweden (each)	1	(1%)

58 (81%) of these developments were reported by private companies and 14 (19%) from public institutes.

3. 2. The applications

Altogether 15 intended applications were identified, the breakdown of which was as follows:

– Floor finishing	10	(14%)
– Exterior painting	6	(8%)
– Quality control (mainly exterior walls)	6	(8%)
– Board installation	9	(13%)
– Load handling - interior	6	(8%)
– Load handling - exterior	6	(8%)
– Brick/block masonry	4	(6%)
– Welding, connecting	3	(4%)
– Cleaning	2	(3%)
– Fireproofing/steel painting	4	(6%)
– Painting interior walls	1	(1%)
– Tiling	3	(4%)
– Reinforcement installation	2	(3%)
– Concrete handling	4	(6%)
– Clamping	2	(3%)
– other	2	(3%)

3. 3. The configuration of the robots - the following types of robots were used:

a.	Interior finishers (antropomorphic, cylindrical, spherical)	17	24%
b.	Floor finishers (rectangular)	13	18%
c.	Exterior wall finishers (rectangular)	14	19%
d.	Handlers (large crane like)	25	35%
e.	Other	3	4%

3. 4. About 40% of the replies referred to the control system, the breakdown of which is:

a.	On- off	2	(3%)
b.	Teleoperated	16	(22%)
c.	Pre-programmed	13	(18%)
d.	Pre-programmed with sensors	3	(4%)
e.	Intelligent (own work planning)	2	(3%)
f.	Not available	36	(50%)

3. 5. The sensors employed were: ultrasonic; touch, tension meters, laser, optical, infrared, position measurement, pressure transducers, and inclinometers.

3. 6. The stages of development of the surveyed robots were:

a.	Initial development: this stage included the development of the concept and some progress on the physical development at the laboratory	4	(6%)
b.	Prototype (off site): included a complete development of a prototype and its testing/employment in laboratory conditions	15	(21%)
c.	Tested on site: included one, or more, testing of the device in the actual conditions of a real construction site	22	(31%)
d.	Employed on site: in order to be classified as such the robot had to be employed at least 5 times at a frequency of at least once a year	21	(29%)
e.	Sold to others under commercial terms	10	(14%)

3. 7. The status of employment:

Out of the total number of 72 investigated cases 34 are, or were, employed on actual building sites, and 38 were never used on site.

3. 8. In terms of their current use the cases were classified as follows:

a.	Discontinued at development (at pre-development or at a prototype stage)	29	(40%)
b.	At development with some chance of implementation	9	(13%)
c.	Not in use, after being employed on site	16	(22%)
d.	In use	18	(25%)

Out of these in use, 9 (13%) were produced in more than 5 items and 9 (13%) were used on site more than 10 times.

3. 9. The employment of the robots, currently in use, was as follows:

–	Board placing/materials handling	7	(39%)
–	Floor finishing	4	(22%)
–	Clamping	2	(11%)
–	Crane control	1	(6%)
–	Concrete distributing	1	(6%)
–	Quality control	1	(6%)
–	Interior wall painting	1	(6%)
–	Other	1	(6%)

3. 10. The type of control of the robots currently in use was:

Teleoperated	12	(67%)
Pre-programmed, or teleoperated with a pre-programming option	6	(33%)

3. 11. The reasons for abandonment of development or employment were these (there is no percentage breakdown because many respondents cited more than one reason):

a. Lack of appropriate building sites.
b. Need for further development/adaptations.
c. Lack of economic justification.
d. Lack of interest of the company's management.
e. Availability of better equipment for the same function.

4. SUMMARY OF THE FINDINGS

The findings of the survey can be summarized as follows:

4. 1. About a quarter of the robotic developments are still in use today. Only c. 13% were produced in more than 10 pieces. It is quite obvious that the application will not be economically feasible if the investment in the robot development and production are charged to a small number of pieces or if the robot is unemployed for long periods of time.

4. 2. Most of the robots still in use today are of the following two types:

a. A material handling robot.
b. A floor finisher.

Two thirds of them with a continuous direct human operation by a remote control.

4. 3. This very meager success of application can be explained by the following reasons:

a. Lack of economic justification .
b. Organizational problems.
c. Problems with robot design.
d. Problems with building design.

Each of these reasons will be now discussed in more detail.

4. 3. 1. Lack of economic justification can be traced to the following causes:

a. The main advantages of industrial robots as perceived by their users are "tangible" gains in productivity and production cost, and "non-tangible" gains - improved quality, increased safety and dependability. The "non tangible" gains result-in also economic gains, albeit less evident.

The non-tangible gains are considered by the industrial users as equally important, or even more so, than the tangible ones. Unfortunately this is not the case in construction companies which are almost in all cases oriented towards tangible benefits.

b. A construction robot can usually replace 3-4 workers in a well structured application. This is usually enough even for a purely economic justification based on tangible benefits alone, if the replaced labor costs $15-20 per hour. In many developed countries the cost of labor is even higher. However, it is difficulty to justify the robot on purely material grounds if it is to compete with cheap local, or imported, labor. In such case the robot can be competitive in a developed country only if the disadvantages of imported labor are sufficiently appreciated.

c. In order to be cost-wise competitive with manual labor, the robot must be utilized to a sufficient extent, i.e. at least 1,500 - 2,000 hours of site employment per year. It will be shown later why it is difficult, at the present construction conditions, to arrive at such an extent of utilization.

4. 3. 2. The organizational difficulties can be traced to the following reasons:

a. Construction managers tend to be highly conservative with respect to innovations. Construction is considered a economically volatile industry and the managers are reluctant to add another risky factor to the ones already inherent in their work. To be accepted, an innovation must, therefore, be either widely applied by their competitors, which is not the case of robotics, or be very convincingly justified in tangible material terms. It can be assumed, that in order to overcome the reluctance to venture into something new and unknown, the robot must demonstrate a promise of a commanding profitability edge, probably of an order of 60% - 100%, over conventional manual methods.

b. Employment of robots mandates a complete restructuring of the building site and a different approach to the organization of the building site: easy transfer of robots between buildings and between floors; arrangement of building materials on site and their supply to robot work areas; robotics oriented purchasing system; clean and smooth floor surface in the path of the robot; tight tolerances of the building infrastructure on which the robotized work is to be executed; etc.

c. The actual work on site of the various trades is carried out today by independent subcontractors. The construction robot will be, therefore, employed by a subcontractor rather than by the general contractor. The previously mentioned site organization requirements, essential for the robot employment, can be provided, however, only by the general contractor. Lack of such support from the contractor who is not directly involved with the robot employment are further compounding the difficulty of introducing the necessary site reorganization.

d. An operation of the robot requires a technical and managerial expertise, well beyond what is available today in the building sector.

e. Many buildings are composed of small spaces not easily accessible to the robot. Careful planning is needed, therefore, in order to (a) determine if the project is economically feasible for robotized work and (b) allocate the work in an optimal manner divided to robotized and manual work.

4. 3. 3. Problems with robot design

The construction robot must fulfill various performance requirements in real site conditions, which, by far, exceed what is required from standard industrial robots. The robotized work must be considered as a system with the actual task performance being only one of its elements. In order to be successfully employed, the robot must not only perform its primary task, but also move easily in the building, have easy and reliable supply of materials, and sound maintenance procedures. Some of these difficulties are described here in detail:

a. All construction robots must move between various locations in the building. Most of them have the power for movement and task execution supplied with a cable from an exterior source. This cable makes the robot's movement highly cumbersome and restricted.
b. The robot must be light enough not to affect the load requirements of the floor, and on the other hand be robust enough to withstand the dirt and shocks of the construction work.
c. The robot needs very advanced and thorough maintenance work in view of the mechanical and electronic systems it employs.
d. The layout of a building floor is often composed of small not easily accessible areas. The robot must be agile enough to access these areas and operate in them. Most of the robots were not designed for this purpose.
e. Most of the developed robots were oriented towards a single task, usually with a narrow field of application. For example - a robot designed for a particular building exterior can be feasible only if such exterior is available in sufficient quantity. In order to succeed economically the robot must have a wide enough field of application.

4. 3. 4. The building design is usually not particularly friendly towards robotized application.

The main difficulties with the present building design with respect to robotization, are as follows:

a. The designed width of passages and entries is not sufficient to accommodate the robot's motion between the designated spaces.
b. The work allocated to a robot is often dispersed over wide areas. The robot may, therefore, spend a lot of time in transfers rather than useful work.
c. The building is ill adjusted for transfers of the robot between floors or locations on the building.
d. The work is often not structured well enough for robotized use. Work well adapted for robotized use must have:

    1) Simple and continuous trajectories of the tool: activities such as painting or welding are preferred to activities which require inserting or bolting.
    2) A single passage of the tool over a selected trajectory. Compounded activities which require several passages (such as application of several layers of paint) or even more - different applications - such as application of glue and then attaching - are not desired.

5. CONCLUSIONS

The findings of the survey reveal that the application of building robots today is still in a very preliminary stage. The reasons for it are the lack of economic justification, the organizational difficulties, the insufficient adaptability of the robots to the present conditions on the building site and the insufficient adaptability of the present building design to robotic needs.

The findings of the survey also reveal that Japan and Germany are the only countries where private companies have produced building robots. In the other countries the development was pursued by public research institutes, or universities.