APPLICATION OF AUTOMATION AND ROBOTICS IN CONSTRUCTION WORK EXECUTION

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The article presents a partial result of project VEGA nr. 1/0840/11 Multi-dimensional approaches supporting integrated design and delivery of construction projects.

Abstract: In this paper are in particular presented the results of the survey on the usage of automation and robotics technologies in construction work execution by Slovak contractors. The results of the questionnaire developed within the survey pointed out some notable aspects in terms of the current usage of automation and robotics systems in the Slovak construction industry and offered some implications related to the future advance in this scope within the country. Moreover, the paper mentions the benefits of automation and robotics technologies application during construction work execution and in brief gathers the factors that form barriers to more substantial use of the technologies in the sites.

Keywords: automation, robotics, automation and robotics technologies, construction industry, construction site, construction work, on-site construction

1 Introduction

In construction, the scope for automation and robotics technologies implementation can be fairly broad, including all stages of the construction life-cycle, from the initial design, through construction of the building on site and building maintenance or control after the building has been completed to the eventual dismantling or demolition of the building. This would encompass the use of automation and robotics technologies in all stages of construction, from the automation of the design process through the use of Computer Aided Design, the production of cost estimates, construction schedules and project management through the use of costing and planning software to actual ingenious machines that use intelligent control during on-site operations. The degree of automation and robotics systems implementation in construction varies significantly from one construction phase to another. Readily, automation of design through the use of CAD is highly commonplace nowadays, unlike the use of automation systems or robots for on-site operations.

The most significant benefits of robotics and automation systems application in construction industry are [1]: enhancing productivity and work efficiency with reduced costs, solid quality with higher accuracy than that provided by skilled workers, occupational safety enhancement for workers and better safety for the public by deploying machines for dangerous works, work environment conditions improvement in that common manual work is reduced to a minimum, the workers are discharged from uncomfortable work positions, etc.

2 Automation and robotics in on-site construction work

The construction of any building includes different stages of construction processes from earthworks, through construction of structure (concreting, frames assembly, walling ...) to finishing works. Traditionally, the applied construction technologies within these stages are known as labor intensive and conducted in various dangerous situations. Moreover, problems relating to instability of labor force supply and the increasing labor costs are surfacing in the construction industry. It is desirable to lower the level of labor force dependence and increase efficiency by applying a specialized automation in construction sites. Hence, several researchers have intensively searched for suitable ways to introduce automation and robotics into construction sites.

As to the range of automation and robotics applications in construction sites, construction robots and automation include three categories: enhancement to existing construction plants and equipments, task specific robots, and intelligent or cognitive machines [2]. Enhancement to existing construction plants and equipments can be realized through the attachment of sensors and navigational aids, so as to provide improved feedback to the operative. Once the machine is placed in position in front of its work area, digging and placing of spoil can be done automatically through the addition of sensors and controls that enables program-controlled operation. Laser controls and ultrasound is commonly used. Task specific, dedicated robots, mostly developed in Japan, generally work under tele-operation or program control. The robots perform a specific, well defined task, but adaptation to other tasks is generally not possible. They are commonly used within a specific area of the construction process. There are several examples and can be divided into these categories: robots for structural work (e.g. concrete placing, steelwork lifting and positioning, ...), robots for finishing or completion work (e.g. exterior wall spraying, wall or ceiling panel handling and positioning, ...), robots for inspection works (e.g. external wall inspection) and robot for maintenance work (e.g. window and floor cleaning). Intelligent or cognitive machines present the least developed category, most are still under research. It is likely that if the machines of this type were developed, it would be a convergence of the technologies from two categories described above.

In Europe [3], most of the research efforts in the UK have predominantly been in the universities, with Reading (design for automation), Imperial College (simulation of jointing), City (masonry laying), Lancaster (excavation), Portsmouth (wall climbing) and the West of England (wall climbing) active to varying degrees. German efforts are mostly on enhancement to plants and equipments used in concreting. At the Robotics Lab in Spain, the research and development activities in the field of automation and robotics in construction industry started in the early 1990s. Several industrial projects related to the automation of pre-fabrication of glass-fibre reinforced concrete parts manufacturing were developed, dealing with the robotic spraying of panels and the optimization and rationalization of the whole factory, involving panel transport and storage. Other recent research that has taken place in Europe includes the control system for a semi-automatic façade cleaning robot and user oriented interactive building design in Spain.

2.1 Implementation of automation and robotics technologies in on-site construction process

Automation and robotics in construction work execution has various advantages that could help the implementation of these systems [4]. Among the most meaningful advantages belong:

i. less dependency on direct labour – fewer problems related to quality and the repetitiveness of work carried out, as well as costs may be reduced by reducing labour, whereas less operators are needed for the automated system;
ii. productivity increase – besides the speed of production increasing the productivity is improved by disengaging the operation of the limitations of the human factor;
iii. occupational safety increase – the automated systems may carry out their work in dangerous zones for humans, this makes it possible to reduce labour injuries;
iv. quality increase – operations with automated and robotized systems are typically carried out with less variability than human workers;
v. greater control over the productive process – problems may be detected in an easier was as each stage of the process is controlled in order to verify the correct functioning of the system and the result of each one;
vi. greater control over the final result of the process – the final result may be controlled in a more efficient way by controlling the result of each step of the aforementioned process.

Robots are primarily intended and developed for the sectors in which poor labour conditions prevail and in which a decreasing of the load is prospective. The high frequency of working injuries as well as the high statistics of work-related sickness in the building industry is an indication for the special requirements. Robot systems should take over the task of

handling heavy loads, of performing dangerous or dirty work or of working at hardly accessible locations and in ugly physical positions. Above all robots should function as tools of the human being. They are to be developed as intelligent tools and must not force the human being to the limits of working activities. It must be possible to integrate the robot systems into labour procedures. These must not disturb the existing communications structures and cooperation, for example, within the scope of a crew. Robot development should therefore be implemented together with those persons who will operate these systems at the building site at a later point of time. Changes in the labour environment and labour organisation by the application of robot systems must be at least oriented to the working people in the first step and then in the second to technology. An important aspect is high system flexibility to adapt the robots to the prevailing structures. Fully automatic systems are therefore only suitable in exceptional cases, for examples in areas with high safety risk. Unlike, semi-automated machines can be flexibly monitored and applied. The focus of development must therefore lie on semi-automated systems. Other industrial sectors have in the mean time also withdrawn from the aim to achieve inappropriate full automation. Semi-automated systems are by far cheaper and more flexible than fully automatic systems. They can be applied by small-sized and medium-sized construction companies to improve their competitiveness.

2.2 The factors restraining the automation and robotics systems implementation in the construction sites

The barriers to construction automation and robotics are major for on-site construction when comparing to other construction phases. Use of automation technology in design and planning management of construction projects is preferred. Automation technologies such as software used in these early stages of construction to improve efficiency are noticeably cheaper and readily available compared to automation and robotics technologies used in on-site operation.

One of the main obstacles for robotics implementation within the sites is the variability of construction processes and the variable conditions of construction environment. Unlike other industries, in the construction the form of processes execution may vary significantly between two different construction sites. Executing the same operation in different construction sites depends on various factors that influence its possible automation. The difference of the materials employed in the execution of an identical process implies the use of tools adequate for each material. The processes that form a constructive activity relates on the type of material and the tools used. The process flow may vary for the same activity if one of these two elements varies. The complexity of the installations for automation due the very low level of standardization is obvious.

An automated construction site can face more difficulties, such as technological and economical. The technological barriers are that a robot must cope with the complexity of the construction process implying a very dynamic and naturally evolving site, together with the need for performing multiple tasks with differing characteristics. With reference to [5 and 6] the barriers to the implementation of automation and robotics in construction sites may be outlined into these groups: economic and cost, structure and organisation of the construction industry, features of construction product and work processes (mainly uniqueness and complexity), technology (the nature of the construction work processes itself), and culture and human factor. These categories may be presented mainly by:

i. high investments are needed to incorporate the technologies,
ii. the work place is not static, construction sites are too much dynamic and unstructured, construction methods can be too complicated for robots and need for more mobile robots for transport and lifting of heavy components,
iii. there are frequent changes or advances in automated technologies and users have difficulty in keeping up with the changes,
iv. construction sites are usually unique and do not present the same set of problems; construction is a diverse industry and must to cope with an almost unique set of circumstances on each project and site,
v. temporary works and weather impact is substantial, etc.

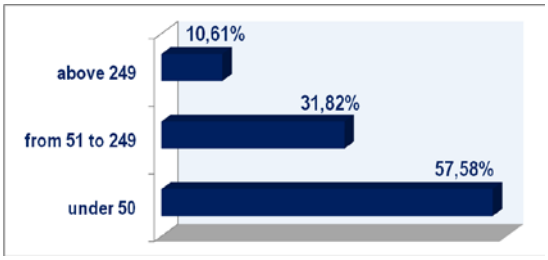
3 Methodology and results of the survey on the usage of automation and robotics systems by Slovak contractors

In order to ascertain the present level of automation and robotics technologies implementation among Slovak building contractors, the analysis of the data collected in the survey was made. It was accomplished through the questionnaire survey, so the information on the use of automation and robotics technologies by the sample group is obtained. The type chosen was a closed questionnaire, several potential responses were ready entered, and respondents were requested to choose one or more responses. In order to avoid rigidity of available responses, an "other" and "specify please" was included in the choice of answers in some cases of questions.

There were 66 responses out of the 300 questionnaires sent out, which translates to a response rate of 22%. The respondents were given the option of responding through web application, the questionnaire was unpretending, designed to be as user-friendly as possible, respondents were required to scroll down, click and point to select the appropriate responses for each question. The web application reference was sent to construction enterprises from all around the country. It was sent with an accompanying letter introducing the investigation, brief stating the background and objectives of it and with confidentiality statement.

The first five questions were developed to reach the background information regarding the questionnaire participants, including number of full time staff, gross annual revenue, length of the company practice in the Slovak construction market, type of construction processes which they have operated and countries where they have participated in construction projects.

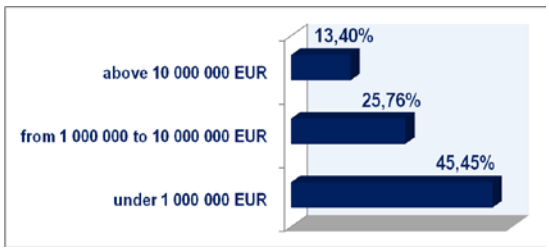
The responses on the question (Graph 1) related to the number of the staff could at first sight designate that "only" small and medium companies (89,4% together) have provided the answers in the investigation. This flows from the organizational structure of the Slovak construction industry, where from around ten thousand enterprises, only twenty-two are the companies with more than 249 employees. So the satisfying fact is that almost a third of big enterprises existing in the Slovak construction market has participated the survey.



Graph 1 The number of full time staff in the company

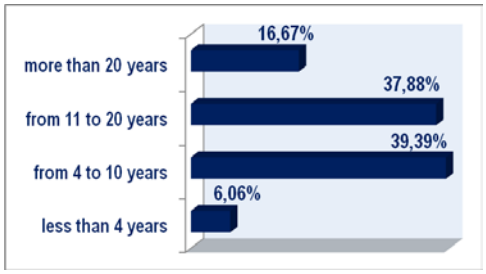
As illustrated in the bar chart bellow (Graph 2), the gross annual revenue of the majority of the respondents (45,45%) is less than 1 million EUR. Although not all the respondents have answered this question (approximately 15 % not answered), their questionnaires were included to evaluation as the goal of the survey was to obtain information about usage of automation and robotics technologies in the sites and this question was just one from "additional" questions aiming to recognize the profile of respondents. On the other hand, this information could be substantial in consideration about automation and robotics implementation within the company works. It is well known that the construction industry is indeed price sensitive towards automation and robotics technologies application. The costs usually present a significant factor in deciding on technologies

implementation. Consideration regarding the costs involves not only buying costs, but also the technologies maintenance costs and level of efficiency and productivity enhancement. The bigger companies (especially those with more branch offices) usually have the monetary capacity to acquire the technology, they can afford it (the buying costs, the costs of updating) as their profit base is much greater compared to a smaller company. They may even get return for the technology acquired if it is used many times.



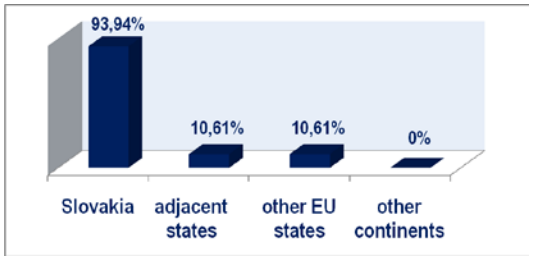
Graph 2 The gross annual revenue

The responses on the question related to the length of the company practice in the Slovak construction industry market (Graph 3) indicate that most respondents are not absolute beginner in the market but they were developed after the period of socio-economical changes in the country related to the year 1989.



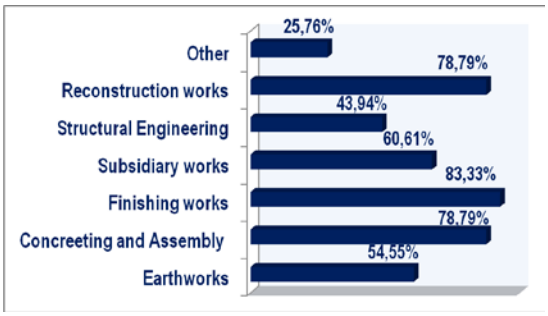
Graph 3 The length of the company practice

The majority of the companies involved in the survey (Graph 4) participate as contractor or subcontractor exclusively in construction projects within the Slovak territory. Let us assume that the companies that operate internationally on a global scale should more use automation and robotics technologies compared to those operating only locally. If a company would be successful in global market sharing and thus must compete with companies from all over the world, taking up of innovative technologies is almost inevitable. Moreover, the company sharing not only local market can afford to acquire the technologies, as it gains economies of scale by using it repetitively throughout its numerous construction projects. However, transporting of a piece of big high-tech equipment between projects can be expensive. That should not be a problem, if the automation or robotics technology is of relatively small size and mobile.



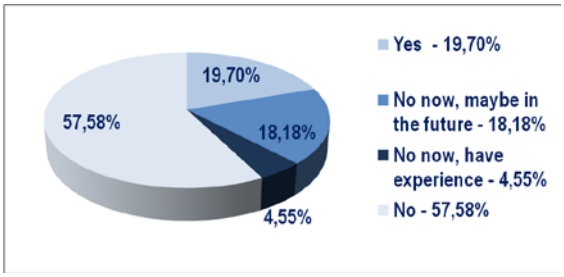
Graph 4 The countries in which the companies participated in construction projects

In the bar chart bellow (Graph 5) is presented the type of construction works that the companies usually execute in the sites. Naturally, the respondents could choice more than one option. Following the results, we can state that a great number of the enterprises included in the survey usually perform almost all the construction works typical for most construction project.



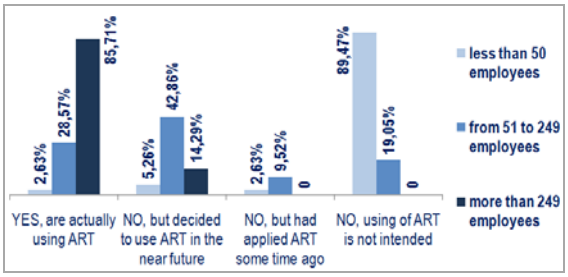
Graph 5 Type of construction works executed by the company

The most essential question of the survey (Graph 6) divided the respondents into two main groups. In the first group are the companies that are actually using some automation and robotics technologies during construction works (marked as „YES“). However, many more companies came under the second group, as they noticed that they: i) are not using any automation and robotics technologies and are not decided to use it in the near future (marked as „NO“); ii) are not actually using any automation and robotics technologies, but they had applied it some years ago (marked as „NO NOW, HAVE EXPERIENCE“) and iii) are not actually using any automation and robotics tehcnologies, but they are resolved to implement it in the near future (marked as „NO NOW, MAYBE IN THE FUTURE“). More than seventy percents of respondents have never used any automation and robotics technology.



Graph 6 Usage of automation and robotics technologies in on-site construction

In order to confirm the hypothesis that larger companies operating on a global scale use the automation and robotics technologies (ART) more when comparing to small companies, the relation between the company size (relating to the number of employees) and the usage of automation and robotics technologies in on site construction is presented in the Graph 7. As expected, the majority of large enterprises implemented automation and robotics in its operation in the site whereas the technologies usage in small companies is not in contemplation ever. This probably relates with low awareness of automation and robotics benefits within small enterprises owners.



Graph 7 Relation between the size of the company and the usage of automation and robotics technology

The following question (Table 1) was answered only by respondents which in the past question introduced that they have never used any automation and robotics technologies ("No" and "No now, maybe in the future", together 75,76% respondents). They were requested to specify the barriers that discourage them to apply some innovative automation and robotics technology in the practice. Naturally, the respondents could indicate more than one from offered answers. The results indicate that respondents find costs of the technologies (74%) and low availability (68%) as the main hindrance to adopting these technologies in their companies. The one third of respondents (33%) is of the opinion that the automation and robotics technologies could not involve higher effects of their operation in the sites. Acceptance by the workers and by the company management (6%) is not seen as very significant in creating barriers to implementation.

Table 1 The barriers discouraging the contractors to implement the automation and robotics technologies

The factors that make difficult for implementation on automation and robotics technologies	
missing information (low awareness)	22 %
high acquiring, maintenance and updating costs	74 %
incompatibility with current practices and construction operations	40%
difficult to use and not easily understood (low technology literacy)	21 %
unavailable locally (difficult to acquire)	68 %
not accepted by workers and by the management (untrustworthy)	6 %
no effective to use	33 %
other	12 %

Some automation and robotics technologies intended on on-site application are not easily understood. The barriers to use these technologies may be psychological as well, people do not want to use something what they do not understand and many people think that the technologies are difficult to use. Moreover, most contractors are confident that automation suit to repetitive and standardized work processes or areas where standard components are used, best in prefabrication constructions.

In order to recognize the usage area (Table 2) and the reasons of usage (Table 3), only the respondents, which introduced in the most determining question that they are actually using or some time ago have applied the automation and robotics technologies, were in ongoing questions requested to designate the types of construction works in which they apply it and the reasons or benefits that encourage them to use it.

Table 2 The usage area of automation and robotics technologies in on-site construction

The areas of application of automation and robotics technologies in construction work	
Earthworks	62,5 %
Concreting	43,8 %
Assembly works	31,3 %
Subsidiary works	12,5 %
Finishing works	37,5 %
Structural Engineering	37,5 %
Reconstruction works	6,25 %

Table 3 The benefits of automation and robotics technologies implementation in on-site construction

The benefits of automation and robotics technologies in construction work	
The finance saving	75,0 %
Less human labour	93,8 %
Higher productivity - the time saving	56,3 %
Quality increase	31,3 %
Occupational safety improvement	25,0 %
Less material disposal	25,0 %
Higher construction steadiness	62,5 %

All the respondents in the survey were also invited to enjoy the chance to take their opinion (stand point) to the future trends and opportunities of construction automation and robotics in general, regardless of their position in the technologies using in the practice. There was the list of statements on future trends and opportunities for the implementation of construction automation and robotics technologies in our country that the participants could agree or disagree to. The automation and robotics users as well as these who have never tried to use these systems could denote just o ne from proposed statements that in the best way represent their own opinion in terms of increased use of automation and robotics systems within on-site construction process. Most statements were deduced from findings of similar investigations on this topic made by foreign researchers [1, 4 and 7]. In the Table 4 is presented how many percents of respondents appropriated the different statements on the future using of automation and robotics in construction and denoted the statements as the most accurate for ongoing ten years.

Table 4 Statements on future trends of construction automation and robotics implementation in construction processes execution

Statements on the future trends of construction automation and robotics in construction work	
There will be a significantly greater scale of automation and robotics technologies available for use in on-site construction process and will be many more easier to install and operate in the sites	16,67 %
The automation and robotics systems will be more easily available across the country	1,52 %
The range of construction enterprises using automation and robotics technologies will increase significantly in the coming ten years	10,61 %
The using of automation and robotics technologies will provide companies to operate more efficiently and competitively in the industry	60,61 %
There will be greater awareness of automation and robotics technologies within the construction industry community	3,03 %
The automation and robotics technologies will be more affordable from buying, maintenance and updating costs point of view (also for small construction subjects)	6,06 %
The automation and robotics technologies will be readily accepted by the workers and the companies managers or owners	1,52 %

From the Table 4 is evident that the big mass of construction contractors participated in the survey (61,61%) is confident that the implementation of automation and construction in the company operation within the sites could raise its competitiveness and the companies could operate with higher effects all at once. On the contrary, only few of respondents correspond with the statements related to prompt acceptation of automation and robotics technologies by construction workers and managers and they do not suspect that the automation and robotics systems will be more easily available across the country in ongoing years.

4 Conclusion

In the paper are mostly analyzed the results of the survey intended on assignation of the level of automation and robotics technologies implementation in construction works operation by Slovak contractors. The questionnaire developed within the survey has highlighted some important points regarding the implementation of automation and robotics in the construction industry within the Slovakia territory and some implications related to future movements in this scope within the country.

As regards the Slovak construction industry, it can be concluded that the usage of automation and robotics in on–site construction works is low. It is expected that the automation usage in the

design and scheduling or other planning is higher compared to on-site operation. From the survey resulted that only approximately one fifth of construction contractors currently use the automation and robotics systems in their operation in the sites, although the systems application could admittedly bring many benefits not only to the very company but also to the society, as a whole. The significant barriers to implementation are presented by high acquiring, maintenance and updating costs and by low availability in our construction industry conditions. The greatest barrier may be overcome through the widening of the construction companies operating market, to enable them to gain the economies of scale through the repetitive use of the technologies and also by encouraging more repetitive and structured work processes.

All the same, many notable foreign researchers [2] expect that it is unlikely that there will be improvements in the near future in terms of affordability and availability of automation and robotics technologies. According to them the improvements might be seen in other areas of construction such as design rather than in on-site applications. It is unlikely that the technologies development and increased range of use and flexibility would refer to on-site technologies. But an area relevant to on-site construction could be in the development of modular building designs that fully use off-site prefabrication, transport and assembly in the site.

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Primary Paper Section: J

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