Mobile bricklaying robot as a breakthrough technology in construction: advantages and problems

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Abstract. The article discusses the concept of "breakthrough technologies" and its criteria in relation to a bricklaying robotic system. In order to become a breakthrough, a new technology must be able to deeply integrate into the relevant industry. This requires the fulfillment of a number of criteria, both technical and beyond. Therefore, a number of such criteria have been formulated for a mobile robotic bricklaying system to assess the degree of compliance with industry requirements and readiness to become a breakthrough innovation. Also the systemic problems hindering the implementation of the technology in the construction industry are considered. The developed approach can also be used for other technical systems and complexes that require significant development costs and at the same time offer some innovative approaches to solving the problems in their fields.

1. Introduction

Traditionally, the construction industry is considered to be weakly responsive to innovations. Many of new technologies introduced in construction are borrowed from other industries. An innovative building technique or material must meet the following criteria:

- to simplify and speed up the construction process;
- to reduce the cost of real estate and operating costs;
- to increase the life time of a building;
- to increase the energy efficiency of a building.

According to the works of Clayton M. Christensen, innovations are divided into "supporting" and "breakthrough" [1].

A supportive innovation aims to improve existing products. A breakthrough innovation means developing solutions that radically change global markets. Breakthrough innovations are products that are based on a new and still relatively imperfect technology. Such innovations are usually a new product of a new offer for the market.

Supporting and breakthrough innovations usually complement and replace each other and become triggers for new science and technology cycles in industries. The main role of supporting innovations is...
urging the scientific and technological progress by improving the previously existing technologies, and the breakthrough ones break a scientific and technological cycle and begin its new turn [2].

2. Mobile bricklaying robots as a breakthrough technology

Assessment of the use of mechanization and automation tools in construction is usually based on their technical and economic features, such as cost and duration of construction. Together they can be considered as generalized efficiency of a solution. The main aspects of the generalized efficiency of a mobile bricklaying robot are shown in [3]. However, mostly economics-based approach does not reveal the essence of changes in the production process, features of the technology itself and their impact on organization of production, focusing only on cost and building time reduction.

To assess innovativeness and the degree of compliance of the mobile bricklaying robot technology with the criteria of breakthrough innovations, the following aspects are highlighted:

1. Technology. Applying mobile bricklaying robots cause changes in bricklaying technology due to the features of operation algorithms (including algorithms of moving of the manipulator and the whole robot), and due to different organization of a construction site [4]. The use of automated bricklaying tools changes the flows of building materials. The increased construction speed requires faster supply of materials, primarily blocks. The very principles of placing objects in the site are also changing, since the use of a mobile robot requires providing it an obstacle-free corridor for the robot’s cyclic route. Figure 1 (a) shows a variant of the traditional structure of a construction site, while figure 1 (b) shows its structure when a mobile bricklaying robot, is used. In this case a robot can move freely along the inner perimeter of wall sand also can be easily supplied with building blocks from the places of their storage within its closed trajectory.

![Figure 1](image_url)

**Figure 1.** Structure of a construction site (1 – scaffolding; 2 – blocks storage place; 3 – mortar producing equipment; 4 – corridor for a mobile bricklaying robot; 5 – mobile bricklaying robot).

In case of using a mobile bricklaying robot there is no need in installing scaffolding for bricklaying, which also reduces the total costs and time of construction. Also, one should take into account that the structure and size of a group that works in collaboration with the robot will also differ from that in current practice. In addition, the accuracy of the masonry performed by a robot is usually higher than obtained using manual labor. In turn, this increases the structural safety of buildings [5].

2. Ergonomics. Considering the energy component of workers’ labor, it should be noted that some types of block materials are rather heavy for manual moving, mass of a block can exceed 15-20 kg. Manual laying such blocks causes excessive fatigue and stress on workers and can lead to work injuries.
An obvious solution to the problem is using mechanisms for lifting and moving high weights. Mechanization is able to reduce human energy consumption by several times in comparison with manual labor [6]. However, the use of a mobile bricklaying robot significantly changes the type of work at the construction site, minimizing or even eliminating operations with heavy loads.

3. Mechatronic approach. According to [7], during evolution and development mechatronics always meets new problems that were not considered in the classical concepts of mechatronic approach. These are, first of all, the problems that are connected with new properties of complicating complex objects. In the considered area of construction automation, the most striking example is movement towards collaboration between robots and workers.

Complete exclusion of workers from the direct building process is almost impossible within the modern technological environment. Firstly, construction includes various types of unique operations, and many of them should be performed at each building being constructed with relatively small volume of such operations. Automation becomes economically efficient mostly for simple and repeating operations, so creating enough universal robotic means for covering wide range of operations is also almost impossible in the nearest future. Secondly, construction process provides large number of uncertainties for automated systems. Such problem can be solved mainly either by advanced intellectual control systems, or by a human taking part in building process together with robot and helping it making some decisions. Since the practice of using, and consequently development of automated systems in construction is rather poor, creating so advanced intellectual control systems for construction will take significant time. In this regard, the only possible way now is moving first to collaborative systems “worker-robot”. The consequence of such approach is that the balance between the robot-performed and human-performed operations becomes a significant factor both for designing and analysis of robotic systems in construction, and of course the volume, list and complexity of such operations also must be taken into account. Such balance shows the degree of replacement of human labor by automated means. Since nowadays manual labor totally dominates in construction, the shift of the balance towards the robot-performed operations can be considered as a measure of belonging of the technology to breakthrough technologies.

At the same time, a collaborative approach must necessarily put at the forefront the safety issues of human-robot interaction. Breakthrough technology must lead to qualitative changes in the corresponding sphere, so focusing only on technical aspects is not applicable. Based on the industrial safety principles, when reducing the number of human-performed life and health hazardous operations by machinery, a machine itself must not become a source of such or new hazards. The principle of close human-robot interaction during collaboration implies constant contact between these two subjects, or the possibility of such contact. In this regard, collaborative robotic systems should be provided with an advanced sensory system and means of processing information from sensors, which will ensure the absence of work injuries caused by a machine. So, the following components should be integrated into a mobile bricklaying robot in order to meet the mentioned requirements:

- distance sensors based on laser technologies (lidars) for obtaining the up-to-date environment map, determining the type and location of obstacles around the robot;
- optical machine vision systems operating in addition to lidars in order to increase the stability and quality of obstacle recognition;
- additional safety sensors showing mechanical contact in areas where such contact is possible;
- algorithms for processing multisensory information, able not only to determine the current configuration of the surrounding space, but also to predict the nearest possible changes in it. Primarily is should predict movements of people around for the time, enough to prevent undesirable interaction. Developing such algorithms is achievable using modern forecasting methods based on machine learning [8, 9].

Accordingly, the design process should take into account the functional relationship and ensure deep integration of the elements of the mechatronic system [10].
Thus, only compliance with all mentioned requirements and criteria can ensure the deep introduction of a new technology into industry and create changes in significant enough to consider such innovation as breakthrough.

3. Problems of implementation of the breakthrough construction technology

The problems of implementation of the breakthrough technologies in construction will be considered by the example of Russian Federation.

According to the information of "TechnoConsult" company, there is a sufficient amount of still unimplemented scientific developments in construction, and more than 70% of patents correspond to the actual world level. But the realization of the scientific potential is possible only if construction companies are ready for transferring R&D results into the investment-construction cycle in both organizational and technological aspects. Innovation can be realized only when all necessary new technologies, materials, solutions are introduced into construction practice. But there are a number of objective and subjective barriers to the transfer of technologies into the investment-construction cycle.

One of them is connected with the limited vision, when companies consider only product innovations (e.g. new types of building materials) and do not consider the potential of process and organizational innovations. The scientific researches mostly focus on a limited range of innovative topics, mostly "new building materials" (39.1% of publications) and "energy saving" (32.3%). At the same time, the world construction practice and science focuses more on improving construction technology and process innovations (34.2% of publications in the EBSCO Publishing, Scopus databases). Such parameter as the duration of the construction cycle of the “universal warehouse” is highly representative for describing and illustrating the situation.

The average level of construction productivity in the Russian Federation today is estimated as 21% of the US and 33% of the European level. The rate of construction of residential buildings in the USA is 84 m² per year per a builder, in Canada - 53 m², in Sweden - 51 m² and in Russian Federation - 13 m² [11]. In many ways, low productivity is due to physical wear and obsolescence of the basic production assets of construction organizations, another reason is using ineffective methods of labor organization. When assessing labor productivity, the World Economy Statistic uses the duration of the construction cycle of the “universal warehouse” as a comparison base. Thus, Russia is at the end of the rating list with the cycle time of 72% higher than the world average, and 10 times higher than for Singapore as the leader of the rating. With that, it shows not only a problem, but and a great perspective for improving the construction industry [12].

The duration of the construction cycle not only connected with time of obtaining the object by its customer, but also largely determines the cost of the objects. High cycle time negatively affects the volume of investments due to deterioration of asset allocation lag, payback period, internal rate of return of investments.

Another important aspect is that the most effect of innovations often can be obtained only after a certain period. For example, the economic effect of energy-saving technologies in construction can be obtained only after the start of operation of building by reducing a consumer’s costs for heating and lighting. Innovative design and survey methods show up in reducing the duration of the construction phase. Thus, the economic effect of the implementation of the innovative potential can be obtained and assessed only within the full life cycle of a building [13].

4. Conclusion

Technological processes in construction are developing faster than market needs. Currently, innovative technologies in the construction industry are mostly “supportive”. The main reason for that is a difficulty with fast and reliable assessment of the positive effect of innovations. At the same time, analysis of the factors maximizing the effect of their implementation should be made already at the designing stage. Conservatism of the construction industry, however, at the same time can be considered as a factor providing ample opportunities for the introduction of new technologies, including at the level when they can be called “breakthrough”. Having sufficient cumulative effect, introduction of robotic means of
block construction can make such technology breakthrough and lead to revision of a number of standards and traditions in construction in order to get even better positive effect.

The presented methodology for calculating the numerical indicator of the efficiency of the mobile bricklaying robot allows implementing adequate assessment of construction production along with technical and economic indicators. However, improving the robot, in particular improving its operation algorithms, may require including additional indicators for estimating its efficiency.

References

[1] Clayton M Christensen 2004 The innovator's dilemma (Moscow: Alpina Business Books) p 239
[2] Gorobnyak A A, Malinina D I and Klyueva N N 2016 The supporting and subversive innovations in construction industry Integration, partnership and innovations in construction science and education (Moscow: Moscow State University Press) p 285-8
[3] Malakhov A V and Shutin D V 2019 The Analysis of factors influencing on efficiency of applying mobile bricklaying robots and tools for such analysis J. Phys.: Conf. Ser. 1399 044102
[4] Malakhov A V, Shutin D V and Popov S G 2020 Bricklaying robot moving algorithms at a construction site IOP Conf. Ser.: Mater. Sci. Eng. 734 012126
[5] Malakhov A V and Shutin D V 2020 Applying the automated and robotic means for increasing effectiveness of construction projects IOP Conf. Ser.: Mater. Sci. Eng. 753 042055
[6] Leonenko K A and Shalennyi V T Taking into account the ergonomics requirements when improving the masonry technology Construction the Formation of Living Environment (Moscow: Moscow State University Press) p 954-7
[7] Sergeev S F 2011 AI-Mechatronics system design methodology Izvestiya Tula State University 5 245-9
[8] Sridhar R S and Nandhini M 2018 Ensemble human movement sequence prediction model with Apriori based Probability Tree Classifier (APTC) and Bagged J48 on Machine learning Journal of King Saud University - Computer and Information Sciences
[9] Yucheng Z, Guangtao Z and Xiongkuo M 2018 The prediction of head and eye movement for 360 degree images Signal Processing: Image Communication 69 15-25
[10] Semenchenko A K, Shabaev O E, Semenchenko D A, Khitsenko N V and Gavryukov A V 2007 System representation of road construction machinery as a mechatronic object Bulletin of kharkov national automobile and highway university 38
[11] Schenyatskaya M A, Avilova I P and Naumov A E 2015 On the issue of taking risks into account when analyzing the effectiveness of investment construction projects Education and science: current state and prospects of development (Tambov: Consulting company Ucom) p 180-3
[12] Korovina T A and Naumov A E 2015 Basic principles and methods of risk management in investment construction projects Education and science: current state and prospects of development (Tambov: Consulting company Ucom) p 116-9
[13] Krylova D D and Abakumov R G 2015 Problems of assessing innovation in construction investment Strategy of socio-economic development of society: management, legal, economic aspects (Kursk: University Book) p 161-4