Zeszyty Naukowe Politechniki Częstochowskiej
Budownictwo
ISSN 0526-5916

Zeszyty Naukowe Politechniki Częstochowskiej nr 28 (2022), 55-60
DOI: 10.17512/znb.2022.1.08

Automation and robotization in civil engineering

Izabela Major[1], Givi Gavardashvili[2]

ABSTRACT:
The construction industry plays a vital and significant role in national and global economies. Its development is closely related to automation and robotization processes, which are still much less developed in the con struction industry than in other industries, such as the manufacturing sector. This contributes to both the low productivity of the construction industry itself and the risky working conditions. Due to the rapid development of computer hardware and software over the last few decades, significant progress can be observed in the development of work related to robot control modules as well as work related to design, mapping and planning. This article concerns the current and increasingly important issues related to the need to increase the pace of construction investments as well as the issue of the use of technology in the process of automation and robotics in civil engineering. The authors of the article showed how both of these processes contribute to the development of the construction sector. This paper presents the advantages of the introduction of BIM technology and shows how great a role this technology can play in the automation and robotization of construction processes. As an excellent example of robotization of construction processes, constantly developing 3D printing technology is presented in the article.

KEYWORDS:
automation; robotization; 3D printing; civil engineering

1. Introduction

Civil engineering as a branch of the economy is a very important element shaping its development and enabling the fulfillment of social needs manifesting in various aspects of people's lives. Today's civil engineering is largely based on technology, which effectively affects the pace of the investment process. Added to this is the technologically advanced process of manufacturing building materials, which significantly contributes to the development of cubature and non-cubature civil engineering resulting from the need for continuous and dynamic economic growth. The rate of economic growth is therefore directly related to the development of the construction industry, which currently bases its development dynamics on automation and robotization. It is therefore necessary to further develop automation and robotization in the construction industry and to look for new solutions that significantly increase the efficiency of construction processes.

Automation and robotization are processes that in civil engineering come down to replacing people with machines. This increases the efficiency of work and contributes to reducing the costs of construction investments, which have specific time frames and the need to meet strictly defined technical, normative and quality conditions [1]. Automation in the construction industry gives a significant increase in efficiency and reduces the number of complicated design aspects. The development of computer hardware and the development of software made it possible

[1] Czestochowa University of Technology, Faculty of Civil Engineering, ul. Akademicka 3, 42-201 Częstochowa, Poland, e-mail: izabela.major@pcz.pl, orcid id: 0000-0003-1234-9317
[2] Georgian Technical University (GTU), Ts. Mirtskhulava Water Management Institute, 60, I. Chavchavadze Avenue 0179 Tbilisi, Georgia, e-mail: givi_gava@yahoo.com

to computerize various types of projects. As a result, the design process is now faster and more accurate, and the entire construction investment process has been streamlined by the available technology. The concept of automation in the construction industry is also associated with the independent performance of work by a machine in the scope of a strictly defined activity, but the control over the implementation of this process is still held by a human being. Robotization, on the other hand, is a process that is performed independently by a properly programmed machine, which is also able to independently adapt to the changing conditions of its work. Automation and robotization in construction processes are mainly used in the implementation of heavy works performed in difficult conditions and often in conditions that are dangerous for people [2]. It can be indicated that in the field of land construction, these will include earthworks and underground works, as well as assembly works with the use of large-sized and heavy elements.

2. Automation processes in civil engineering

Automation is a process that minimizes human intervention through the use of a technique, method or system to operate or control the process by means such as electronic devices, control systems or information technology. Automation is also the implementation of information technology and control systems in order to reduce the need for human effort in the production of goods and services [3].

In the construction industry, the earthmoving sector is a forerunner in implementing new technologies to reduce operating costs, increase automation and safety, and improve productivity. Automated steering and control of machines, fleet tracking and management systems and devices that detect proximity and provide warning of accidents are just some examples of equipment used in earthworks. An overview of the applied solutions is presented in the article [4].

Many earthworks and road works are now carried out with unmanned machines that use automated systems that allow the work to be carried out in accordance with the design assumptions. Due to the fact that full automation of works is extremely difficult between manual handling of the construction process and its full automation, five steps have been proposed in accordance with [1]. The authors of the work list in turn: manual operation, in-sight tele-operation, tele-remote operation, assisted tele-remote operation and fully autonomous. In the first step the operator is sitting in the machine manually performing all the tasks, in the following steps, the handheld remote control is used and audio-video feedback from the machine and the operator performs a supporting function until the last fully autonomous step, where the machine performs all tasks by itself and man intervenes only in emergency situations.

Such an autonomous example can be machines operating in the Real Time Kinematic system, which uses a GPS system and allows for real-time location of the machine. The accuracy of the location is very impressive here, which translates into an unattainable accuracy of operations performed by an experienced operator. In this way, it is possible to carry out various earthworks and works on the construction of highways using the so-called pavers that are able to lay the structures together with the pavement, moving over the prepared ground. For concrete pavements, automatic pavers do more than just pave but also dilatation dowels using a dedicated automatic system.

Another example of progressing automation in civil engineering related to underground works is tunneling. It is associated with high construction standards, huge safety risks, high construction difficulties and stringent construction management requirements. The issues related to tunneling in high-speed railways are discussed in the paper [2], in which the authors analyzed several key problems limiting the efficiency and safety of the construction of the aforementioned structure. Automation allows you to take full advantage of the benefits of mechanical equipment, improve the efficiency and safety of excavation works and reduce the amount of work, and this is possible with the use of machines that not only drill the tunnel

by removing the excavated material, but also lining it using prefabricated elements produced for this purpose. The automatic system of guiding shields for drilling a tunnel in the ground works very well here, and this solution is used not only in road construction but also in the construction of subway tunnels.

A more advanced concept for automating construction work is a mobile robotic arm for lifting and holding heavy materials. Such a solution is often used in the construction of cubature objects for specific implementation technologies. The construction investment process then requires less human labor, is more efficient and at the same time increases the safety of people. Not all devices used for work in underground mines and tunnels are fully automated, therefore theoretical and experimental research are carried out leading to the design of automatic control systems for such devices. In the article [5], the author carried out work on the automation of the rock mining process with the use of boom-type roadheaders commonly used in the construction industry for drilling roadways. He also developed an algorithm for the optimal control of the parameters of the cutting process.

Automation is also associated with the design process itself. The use of building information modeling (BIM) opens up new possibilities for meeting various needs and operations throughout the life cycle of a building. BIM allows for the collection of all information regarding the designed object, e.g. structural solutions, sanitary and electrical installations, in one model [6]. It can also minimize information loss. The use of BIM technology in the construction process has great advantages and can play a key role in the future automation of construction. The article [7] reviews the automation of the design process, especially its application in the design of building structures. The authors presented its application, advantages and challenges. Suggestions for further improvement of the automation process in the design of building structures through the use of artificial intelligence are also given. Automation is also an important element in the evolution of CAD systems. The computing power of computers should enable advanced calculations and generate results ready to be passed on to further stages of the construction process.

Automation will help speed up the design process, increase its accuracy and reduce errors that would arise during manual calculations. Calculations with the use of computer systems will enable the implementation of more complex projects and optimization of solutions, and the use of the capabilities of computer systems will allow for the creation of more creative and ingenious constructions [7].

3. Robotization in civil engineering on the example of 3D printing

In highly developed economies, people are now increasingly involved in problem solving and design, and routine and repetitive tasks are carried out by properly designed robots. Also, construction companies are increasingly willing to use robots to increase the efficiency of investment implementation and reduce the number of employees needed. In the experience of the Japanese, who are considered the precursors of this technology, it has been shown that the specificity of construction works does not allow for the use of universal solutions, and the robotization of construction processes still requires human presence.

The progress in the field of robotization with the achievement of more and more effective programming tools and new construction techniques, which include 3D printing, has undoubtedly initiated a new stage of construction transformation [8]. 3D printing owes its boom to the continuous development of artificial intelligence and BIM. Integration of virtual reality (VR) and augmented reality (AR) into one system allows to improve operational efficiency and drive changes in traditional construction. Artificial intelligence consists of various components such as machine learning and computer vision, and the goal is to make a machine capable of doing jobs that in the past required human intelligence. 3D printing in civil engineering is a multidisciplinary area, including various technologies, such as forming materials for 3D printing, designing automation for 3D printing, digital construction for 3D printing, robots for 3D printing and the BIM platform system for 3D printing [9].

The invention of 3D printers allowed the development of new technologies in civil engineering, including the Contour Crafting technique, which could revolutionize construction in the near future. Thanks to this technology, it is possible to reduce costs and time, minimize environmental pollution and reduce the number of injuries and fatalities on construction sites [10, 11]. For example, objects that are implemented in the Contour Crafting technology developed at the University of Southern California, implement the construction process based on the rapid application of successive layers of concrete mix using a 3D printer, which significantly shortens the construction process. The starting point for any 3D printing process is a digital 3D model that is created using 3D software. Transforming the project into a file readable by a 3D printer is related to "slicing" the designed model into layers. Then the material processed by the 3D printer is layered according to the design and process [10]. Materials for 3D printing in civil engineering should be characterized by a controlled setting time, due to the fact that they must be transported through a pipe, should have appropriate workability, and should also have excellent mechanical properties [9]. Today, there is a wide range of different types of materials that are supplied in different states, e.g. powder, fiber, granules, resin, etc. The printer moves on a gantry slightly wider than the width of the printed building. This solution assumes that the rails are arranged at the construction site in a spacing adapted to the printing parameters. The printing is based on a computer project from a properly prepared concrete mix, containing, for example, glass fiber and concrete additives. In this way, we obtain a printed object in a raw open state [12].

The 3D printing technology based on a properly prepared concrete mix also includes the printing of individual structural elements, which takes place in the factory. In this way, we print walls, stairs and roofs, and the printed elements in the form of prefabricated elements are delivered to the construction site and assembled there. Reinforcement in this process, necessary to ensure the stability of the structure and its adequate strength, is still made according to traditional methods. The time necessary to produce such a building is 50 to 70% shorter than in the case of using traditional technology, and the cost of production has an impact on the competitive price of flats in relation to traditional technology [13]. The printing technology of residential buildings is a manifestation of the robotization of the construction process and a constantly developed innovation in the construction industry. It includes more and more effective solutions for printing heads and the concrete mix itself, and allows for improving the methods and process of erecting various objects in 3D concrete printing technology.

Large metal objects can also be printed using this technology. This makes it possible to print metal elements of building structures in a 1:1 scale with parameters corresponding to traditional metal structures. This can be achieved thanks to the MX3D industrial robots from Wire Arc Additive Manufacturing, which can create 3D objects from iron alloys – carbon and stainless steel and non-ferrous alloys – bronze and aluminum. An example of such an object is a footbridge over one of Amsterdam's canals [14, 15]. The MX3D company declares that based on the technology developed by them, it is possible to build a bridge structure 10 to 1000 times faster than in the case of using traditional technologies. Such robots – printers can be used in the implementation of construction investment processes in which there is a potential threat to humans [14].

An important aspect of 3D printing is conducting research on printed samples. Microscopic observations show that 3D printed products have a layered orthotropic microstructure where each layer consists of parallel stripes. Performing laboratory tests will determine the mechanical properties of the tested objects and the damage characteristics of the tested materials [16, 17].

There are many benefits associated with the development of 3D printing technology in civil engineering. The first is undoubtedly cost reduction. The cost of printing structural elements of houses is much lower than with traditional methods, it is also influenced by the reduction of transport and storage of materials at construction sites. The advantage is also the reduction of the time needed to complete the building. In addition, wet construction processes are minimized, so that less waste and dust are generated during erecting a building compared to

traditional methods. Due to the fact that printers will be able to perform the most dangerous jobs, the number of injuries and fatalities on the construction site will decrease [11].

4. Conclusion

The progress of technology is a natural consequence of civilization development, and the issue of robotization and automation in civil engineering is its manifestation. Undoubtedly, this does not pose a threat to the human labor market, as a human cannot be replaced in many complex situations involving the construction process. However, it is worth emphasizing that in the coming future, the share of automation and robotization in the construction investment process will increase and therefore it is worth considering today what occupations in the construction industry will be needed in the future and which ones will disappear from the labor market.

People's fears that one day they will be replaced by robots or IT solutions are slowly becoming a tangible fact also in the sphere of broadly understood construction. It is worth accepting this thought and taking a broader look at the irreversible process that is taking place now. Currently, such a step would not be profitable either from the point of view of investment profitability or labor productivity. However specialized machines using today's technology are to take over a large part of the construction activities by the year 2030. There are good sides of the developing era of robotics and automation in civil engineering, as many jobs can be done cheaper, faster and safer. Moreover, the positive actions in the areas of ecology and environmental protection are already visible. The ongoing process requires paying attention to the problem of training appropriate staff who will pursue their professional careers on a modern construction site, where automation and robotization of construction works will dominate. This challenge needs to be started today.

References

[1] Dadhich S., Bodinyand U., Andersson U., Key challenges in automation of earth-moving machines, Automation in Construction 2016, DOI: 10.1016/j.autcon.2016.05.009.

[2] Zhang H., Sun J., Ma H., Chen S., Huang M., Development and application of mechanized matching equipment for high-speed railway tunnel construction, Procedia Manufacturing 2019, 32, 952-959, DOI: 10.1016/j.promfg.2019.02.308.

[3] Vähä P., Heikkilä T., Kilpeläinen P., Järviluoma M., Gambao E., Extending automation of building construction – Survey on potential sensor technologies and robotic applications, Automation in Construction 2013, 36, 168-178, DOI: 10.1016/j.autcon.2013.08.002.

[4] Azar E.R., Kamat V.R., Earthmoving equipment automation: a review of technical advances and future outlook, Journal of Information Technology in Construction 2017, 22, 247-265.

[5] Cheluszka P., Optimization of the cutting process parameters to ensure high efficiency of drilling tunnels and use the technical potential of the boom-type roadheader, Energies 2020, 13, 6597, DOI: 10.3390/en13246597.

[6] Abanda F.H., Byers L., An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling), Energy 2016, 97, 517-527, DOI: 10.1016/j.energy.2015.12.135.

[7] Khairulzaman H.A., Usman F., Automation in civil engineering design in assessing building energy efficiency, International Journal of Engineering & Technology 2018, 7, 722-727, DOI: 10.14419/ijet.v7i4.35.23096.

[8] Major M., Minda I., Zastosowanie technologii druku przestrzennego w budownictwie, Zeszyty Naukowe Politechniki Częstochowskiej 2016, 172, Budownictwo z. 22, 238-247, DOI: 10.17512/znb.2016.1.23.

[9] Tan K., The framework of combining artificial intelligence and construction 3D printing in civil engineering, MATEC Web of Conferences 2018, 206, 01008, DOI: 10.1051/matecconf/201820601008.

[10] Sakin M., Kiroglu Y.C., 3D printing of buildings: Construction of the sustainable houses of the future by BIM, Energy Procedia 2017, 134, 702-711, DOI: 10.1016/j.egypro.2017.09.562.

[11] Hager I., Golonka A., Putanowicz R., 3D printing of buildings and building components as the future, of sustainable construction? Procedia Engineering 2016, 151, 292-299, DOI: 10.1016/j.proeng.2016.07.357.

[12] https://www.contourcrafting.com/building-construction. Access date: 10.11.2022.

[13] https://3dprint.com/38144/3d-printed-apartment-building/. Access date: 10.11.2022.

[14] http://www.dezeen.com/2015/10/19/joris-laarman-3d-printed-canal-bridge-amsterdam/. Access date: 10.11.2022].

[15] https://mx3d.com/industries/infrastructure/mx3d-bridge/. Access date: 10.11.2022].

[16] Feng P., Meng X., Chen J.-F., Ye L., Mechanical properties of structures 3D printed with cementitious powders, Construction and Building Materials 2015, 93, 486-497, DOI: 10.1016/j.conbuildmat.2015.05.132.

[17] Major M., Kalinowski J., Kosiń M., Wytrzymałość na rozciąganie elementów drukowanych z materiałów ABS, Materiały Budowlane 2022, 602(10), 82-85, DOI: 10.15199/33.2022.10.21.

Automatyzacja i robotyzacja w budownictwie

STRESZCZENIE:
Branża budowlana odgrywa istotną rolę w gospodarkach krajowych i światowych. Jej rozwój jest ściśle związany z procesami automatyzacji i robotyzacji, które w budownictwie nadal są znacznie mniej rozwinięte niż w innych branżach, których przykładem może być sektor wytwórczy. Przyczynia się to zarówno do niskiej produktywności samej branży budowlanej, jak i ryzykownych warunków pracy. W związku z szybkim rozwojem na przestrzeni ostatnich kilku dekad sprzętu komputerowego i oprogramowania można zaobserwować znaczny postęp w rozwoju prac związanych z modułami sterowania robotami a także prac związanych z projektowaniem, mapowaniem i planowaniem.
Niniejszy artykuł dotyczy stale aktualnej i coraz bardziej istotnej ze względu na konieczny wzrost realizacji tempa inwestycji budowlanych problematyki wykorzystania technologii w procesie automatyki i robotyki w budownictwie. Autorzy wskazali, jak oba te procesy przyczyniają się do rozwoju sektora budownictwa. W niniejszej pracy przedstawiono zalety wprowadzenia technologii BIM, a także wskazano, jak wielką rolę ta technologia może odegrać w automatyzacji i robotyzacji procesów budowlanych. Jako doskonały przykład robotyzacji procesów budowlanych przedstawiono stale rozwijaną technologię druku 3D.

SŁOWA KLUCZOWE:
automatyzacja; robotyzacja; druk 3D; budownictwo