Mechanisation and automation technologies development in work at construction sites

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Abstract. Implementing construction work that creates buildings is a very complicated and laborious task and requires the use of various types of machines and equipment. For years there has been a desire for designers and technologists to introduce devices that replace people’s work on machine construction, automation and even robots. Technologies for building construction are still being developed and implemented to limit people’s hard work and improve work efficiency and quality in innovative architectonical and construction solutions. New opportunities for improving work on the construction site include computerisation of technological processes and construction management for projects and processes. The aim of the paper was to analyse the development of mechanisation, automation and computerisation of construction processes and selected building technologies, with special attention paid to 3D printing technology. The state of mechanisation of construction works in Poland and trends in its development in construction technologies are presented. These studies were conducted on the basis of the available literature and a survey of Polish construction companies.

1. Introduction

Construction works that result in the creation of buildings are very labour-intensive, complicated and require the use of different types of machines and equipment. For years builders - constructors, technicians and managers - have wanted to put in place machines and robots as a replacement for people’s work on the construction. This has resulted in the development and implementation of technology for building construction and related work, leading to the elimination of people’s hard work and increasing the productivity and quality, in order to achieve extremely innovative architectural and construction solutions [1]. As such, new opportunities for improving work on the construction site include the computerisation of technological processes as well as the management of construction processes and undertakings.

The aim of the paper is to analyse the state of work mechanisation in relevant building technologies. The paper discusses mechanisation, automation and computerisation development and their application for selected works and construction technologies, with a special focus on 3D printing technology. This technology represents a new approach to building construction. It promotes high mechanisation and automation of the technological process and is introducing an information revolution into the construction industry. It allows for improving many aspects of the construction site organisation, such as shorter lead times, limited construction site requirements, logistical support, staffing needs etc. Despite the many advantages of this technology, attention has been paid to the problems of its implementation, especially from the point of view of raw materials and printing materials. The state of
mechanisation of construction works in Poland and trends in its development in construction technologies are presented.

2. Methodology
The analysis of the state of mechanisation and automation of building robots in Poland and the perspectives of their development is based on literature research, building site observation and survey research. The survey was conducted using a questionnaire sent out to a hundred companies. The eighteen that responded were mostly medium-sized companies (employing more than 250 people). The questionnaire contained closed and open questions. In order to determine the development trends of construction technologies and their mechanisation and automation, the obtained results were supplemented by data from the Central Statistical Office in Poland.

3. Construction works mechanisation development
In the construction industry, as well as in the production of many other different material products, the occurrence and development of work patterns from manual work through mechanisation, automation and robotics can be observed [6].

Construction works are complex production processes, combined from simple processes, operations and activities that are executed in different ways. Six of these ways are distinguishable, depending on the extent of the installation:
- mechanisation: partial, complete or complex mechanics,
- automation: partial and total,
- robotisation.

A special way for constructing a whole buildings is to print the elements and objects by means of so-called 3D printing technology.

Partial mechanisation is a partial execution of simple processes or work operations in a given technological process, e.g.: earth works (foundation filling), reinforced concrete (roofing), plastering, etc., by machine or by hand. If all the executed work is creating a technological process, and it will be made by machines, then we can call it total mechanisation. Such examples can be found in earth works, e.g. embankments. Comprehensive mechanics is when most of the basic work is done by different machines selected in such a way that their efficiency, reliability and time and place of work are harmonised (Figure 2). Consequently, you can use them in a rational way and achieve the highest productivity of this machine set.

![Figure 1](image1.jpg)
**Figure 1.** An example of automation in lifting the formwork. Visible ACS system forming shaft and external walls [5].

![Figure 2](image2.jpg)
**Figure 2.** Example of complex mechanization of excavation work [4].
In the mechanised work, the machine is controlled by the operator and, if the machine does repetitive activities for which it was designed, automatically, we are speaking here about work automation. The automaton does not require an operator, only the controller who, if necessary, will carry out repairs, thus restoring the machine for conducting further repetitive work. If part of the complex building process is done by means of automates and part by machines or even by hand, then this is what we call partial automation (Figure 1). Comprehensive automation of complex manufacturing processes can be achieved by introducing automatic machines and their work synchronisation for performance, reliability, space and time. There are automated auxiliary plants in the building industry, e.g. concrete prefabrication factories where serial production is made, or centralised concrete mix factories etc. Complex automation is not implemented directly on construction sites when performing building works. Automation in the construction industry covers a wide range of issues, from the manufacturing of building materials to the complex construction of buildings.

Robotisation means replacing human work with work by a robot, a machine that is capable of working in variable and difficult conditions, sometimes even in an inaccessible environment for a human. Such a machine has components that recognise conditions, executive components and controls for adapting to the recognised operating conditions variables. As such, it follows that automation and robotisation can be regarded as higher levels of mechanisation, at which the machine replaces not only the physical but also the mental work of man [12, 13].

Use of information technology development and computerisation in work mechanisation has resulted in the construction of 3D printing technology in products creation and even whole building construction. The development of this method has been observed and deserves further discussion (see Chapter 4).

All of the aforementioned ways of doing work enable:
− increasing labour productivity,
− shortening lead times,
− replacing the hard physical labour of man by a working machine,
− improving the quality of the works.

In fact the state of mechanisation of construction works on Polish construction is varied. The authors conducted a survey on the subject and the results of the research allowed for characterising the economy by means of the mechanisation of works:
− enterprises have (purchased or leased) a limited range of basic construction machinery (excavators, bulldozers, trucks - dump trucks),
− in the case of a larger range of requested works, the machines are additionally rented, and also when construction site is located at a larger distance from the company machinery,
− specialised machinery and equipment are rented (formwork, concrete mix pumps, road milling machines, tower and mobile cranes, GPS equipment),
− hiring a team of machines with service,
− power tools (hammers, drills) are purchased by companies.

In the surveyed companies, the age of construction machines ranged from 0 to 15 years, while power tools were up to 10 years.

4. 3D printing technologies in construction
3D printing is the process of producing a three-dimensional physical object using computer technology based on a numerical model. There are many models and technologies for 3D printing. The first 3D printing technology was patented in 1986 as stereolithography (SLA). In 1992, FDM (Fused Deposition Modelling) technology was patented; its methods and techniques of manufacturing products are the most suitable for use in construction. In the FDM, the head can move along the X, Y, Z axes, but in existing implementations of this technology on a small scale (desktop printers) one moves to the axis on which the object is standing. By adapting to the construction output, due to the size of the building and the construction of the structure already at the destination, the material feed head should move in three-dimensional space.
The printing process consists of seven steps to produce a ready-to-use item. The start-up phase of the manufacturing process is the execution of a 3D model of the product using CAD software. Most often it is saved in STL file format. Then, the three-dimensional model of the product is converted to write ‘understandable’ for the data preparation software for the device. Before printing, the printer must be ready for use. At this stage a 3D element prints, which consists in creating and applying layers of material of a certain thickness. Once the finished product is obtained, the printing device is cleaned. The final production step is the finishing of the printed product [11].

The rapid development of 3D printing technology can be observed in the construction industry. In the subject literature, and especially in the Internet, many buildings have been realised from different materials, using different techniques [e.g. 2, 3, 8, 11]. The first projects were mainly buildings made from concrete mixtures (Figures 3a, 3b). Current printing methods of other objects such as road infrastructure (Figure 4) and small architectural objects (Figure 5) are under development from materials such as metals and resins.

In Figure 3a we can see a solution proposed by American researchers from the Contour Crafting project, where the printer will print concrete elements with the ability to simultaneously connect all installations in the building. Initially, the machine has to print the walls of the objects and then, using special arms, lay out ready-made components of which current 3D printing technologies do not allow printing without the need for proper supports. The machine is moving on special rails, with the possibility of replacing the head depending on the stage of construction. The team also deals with research on the construction of human habitats on other planets.

The printer proposed by the Russian company Apis-cor has dimensions of 4 x 1, 6 x 1.5 m and weighs 2 tons (Figure 3b). The small dimensions of the machine allow for easy transport of the printing device. Only two people are required to operate the printer - one for machine operation and the other for material delivery. The whole process of manufacturing objects is completely automated. Objects are made of fibre concrete or geopolymer, and the mixture is administered in appropriate portions. The printing process itself involves applying layer over layer of successive batches of material, leaving no excess of material and no workplace clean up.

The world’s first 3D print bridge was built in Madrid’s Castilla-La Mancha in Alcobendas Park (Figure 4). This project was carried out by the Institute of Advanced Architecture of Catalonia (IAAC). The bridge is 12 metres long and 1.75 metres wide and printed in micro-reinforced concrete.

MX3D from Amsterdam is involved in the design of a steel bridge over the Oudezijds Achterburgwal canal using 3D printing technology. In 2014, the company developed a multi-axis 3D printing device. They equipped the industrial robot with an advanced welding machine for which they developed software and its controls. This printer has 6 degrees of freedom of movement. This device enables the printing of metals and resins without the need for support structures (Figure 6a). The constructors plan to print a complex steel bridge over the water (Figure 6b).
Figure 4. Printed bridge [8].

Figure 5. Architectural printed details [9].

Figure 6a. Printed bridge [10].

Figure 6b. Steel bridge printing - visualization [10].

3D printing technology is a new approach to constructing buildings, promoting a high level of mechanisation, automatisation and computerisation in construction technologies. It allows for upgrading many construction site organisational aspects, for example: shortening the time, limiting the required area for the construction site, lowering the logistics service, reducing the number of workers etc. In spite of its many advantages, however, the technology also has many issues vis-à-vis implementation, especially for resources and 3D printing materials.

5. The mechanisation level in construction technology in Poland

From the perspective of inventories and manufacturers, very great progress has been observed in the mechanisation and automation development in construction works, which is leading to human labour replacement in construction works. However, construction in practice differs greatly from the offered capabilities and, in fact, in the commonly used construction technologies in construction, particularly in cubature regarding the construction of detached and multi-family buildings of medium height. These are often designed and built using technologies where the quality of the workmanship is low. Of course there are many examples of the application of complex automation in the construction of buildings and robots, especially in specialised construction (roads, underground sanitary installations and refurbishment of buildings - in the diagnosis of the technical condition).

Typical technologies used for building multi-family buildings in Poland are shown below (Figure 7).
Figure 7. Basic technologies statistic in multifamily buildings in Poland. Data provided by GUS 2005-2015 [7].

These include monolithic (reinforced concrete walls and slabs or skeleton structures) and others (not shown in the drawing due to considerably smaller quantitative range) such as prefabricated wooden frames, metal, multi-plate and column reinforced concrete, and even wooden logs. On the other hand, single-family houses in Poland are mainly made using traditional technology (Table 1).

The degree of unloading of construction works on the construction site in these commonly used technologies in residential construction is mainly limited to partial mechanisation and sometimes to complex mechanisation of the construction works (Table 2). On the other hand, in the production of construction products in industrial plants, technological processes are carried out on automated lines and even with the use of robotics.

It should be noted that the level of workmanship is dependent on many factors (the constructional system, construction materials used, functional/purpose of the system etc.) and, in particular, the type of works. In consequence, ground works as well as some foundation works can be done almost entirely by mechanised, high class machines - excavators, pavers etc. equipped with computers and specialised software. On the other hand, bricklaying or flooring works on the construction site are still done by hand.

Table 1. New residential buildings put into use by construction and cubic capacity [7].

| Methods of construction | Buildings completed excluding private construction | Buildings completed by individual investors |
|-------------------------|--------------------------------------------------|--------------------------------------------|
|                         | Cubic volume in m³ | Percentage shares | Average construction period in months | Cubic volume in m³ | Percentage shares | Average construction period in months |
| Total                   | 20288964          | 100,00%          | 22,4                                 | 49002204          | 100,00%          | 56,1                                     |
| Improved traditional    | 16215943          | 79,92%           | 21,9                                 | 48736733          | 99,46%           | 56,2                                     |
| Large panel             | 37651             | 0,19%            | 13,5                                 | 7675              | 0,02%            | 21                                       |
| Monolithic              | 4031110           | 19,87%           | 24,7                                 | 101398            | 0,21%            | 26,4                                     |
| Wooden construction      | 4162              | 0,02%            | 38,1                                 | 156398            | 0,32%            | 43,1                                     |
| Others                  | 98                | 0,00%            | 9                                    | no data           |                  |                                          |
Table 2. Mechanization technology scope of building in Poland. Own research.

| Construction technology | Working methods          | General mechanisation level |
|--------------------------|--------------------------|----------------------------|
|                          | Building construction    |                           |
|                          | Walls                    | Ceilings                  |
| Improved traditional     | Manual, mechanisation    | Manual, mechanisation     | 30%                        |
| Reinforced Monolithic    | Manual (reinforcement),  | Manual, mechanisation     | 60%                        |
|                          | mechanism (Concreting),  | automatisation, robotisation |
| Large panel              | Manual, mechanisation    | automatisation            | 50%                        |
| Wooden construction      | Manual, mechanisation    | automatisation            | 40%                        |
| Steel construction       | Manual, mechanisation    | automatisation, robotisation | 50%                      |

6. Conclusion

The analysis shows the great opportunities offered by the market for inventors and manufacturers in the field of devices, including machines that allow for the mechanisation, automation and even robotisation of construction works. There are still many questions vis a vis the field of spatial printing technology, in particular the raw materials and materials for use in printers and those that meet the requirements of durability etc. in structures designed for safe use. Mainstream building technologies and construction projects, as well as executive and economic conditions, do not yet assist in exploiting the existing opportunities in the construction of construction works on a construction site. Work on a construction site is still the most difficult, laborious, cumbersome and often dangerous work.

On the other hand, the development of robotics and automation of the construction industry should take into account the following aspects:

a) adaptation of architectural solutions to industrial construction technology, prefabrication, logistics and production networks,
b) orientation of the management to the automated and robotised construction site,
c) use of scientific achievements, not only from the technical sciences but also from ergonomics, psychology and sociology, including demographic phenomena.

References

[1] Adamowski J, Lewandowski J 2012 Tendencje i wybrane problemy stosowania automatyzacji i robotyzacji w budownictwie Przegląd budowlany vol 7-8 pp 48-52 [in Polish]

[2] Apis cor we print buildings: www.apis-cor.com (available: 18.03.2017)

[3] Contour Crafting Robotic Construction System: www.contourcrafting.org (available 18.03.2017)

[4] Czernik S 2013 Maszynowo oznacza szybciej i taniej, www.raportsekocenbud.pl (available: 18.03.2017) [in Polish]

[5] Dziergielewski P 2013 Nowoczesne metody wznoszenia budynków wysokich. Budownictwo monolityczne vol 6 (16) [in Polish]

[6] Elattar S M S 2008 Automation and robotics in construction: opportunities and challenges, Emirates Journal for Engineering Research vol 13 (2) pp 21-26
[7] Kowalska M and team 2016 *Construction Activity Results in 2015* Statistical Information and Elaborations, Central Statistical Office, Construction Department, Statistical Publishing Establishment, Warsaw

[8] Large scale 3D printing, 3D printed bridge: www.iaac.net/research-projects/large-scale-3d-printing/3d-printed-bridge/ (available: 18.03.2017)

[9] Large scale 3D printing, Material: www.iaac.net/research-projects/large-scale-3d-printing/material (available: 18.03.2017)

[10] MX3D Bridge: www.mx3d.com (available: 18.03.2017)

[11] Sobotka A, Pacewicz K 2016, *Building site organization with 3D technology in use* Procedia Engineering ISSN 1877-7058 — 2016 vol 161 pp 407-413

[12] Witkowski P 2010 *Robotyzacja w budownictwie. Teraźniejszość i przyszłość - cz. I* Inżynier budownictwa vol 6 (74) pp 82-85 [in Polish]

[13] Witkowski P 2010 *Robotyzacja w budownictwie. Teraźniejszość i przyszłość cz. II* Inżynier budownictwa vol 7-8 (75) pp 75-78 [in Polish]