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# FOURTH WAVE TECHNOLOGIES IN CONSTRUCTION AND ARCHITECTURE: FROM IDEA TO REALIZATION (PART 2)

## ТЕХНОЛОГИИ ЧЕТВЕРТОЙ ВОЛНЫ В СТРОИТЕЛЬСТВЕ И АРХИТЕКТУРЕ: ОТ ИДЕИ ДО РЕАЛИЗАЦИИ (ЧАСТЬ 2)

*The Industrial Revolution is the restructuring of society under the influence of innovations in technology and technique, which is accompanied by a jump in productivity. Today, the 4th revolution is taking place, which is rapidly changing the landscape of various areas of life, including architecture and the construction industry. The Industry 4.0 revolution connects technologies used in organizations and people's daily lives. It combines physical and digital technologies. But it doesn't develop as a daily simple life in architecture and construction industry like many other industries like as automotive, aircraft, electronic etc.* ***The relevance of the study*** *is to study and analyze the stage of the historical event on the industrial revolutions (specially fourth industrial revolution) and his realization in today's construction and architecture industry. A comprehensive review of contemporary and historical literature related to fourth industrial revolution, and his realization level in the industry with specific focus on construction and architecture industry. Thus,* ***the main tasks of the study*** *can be distinguished as follows: review of historical literature and basic understanding of the industrial revolutions; understanding of Industry 4.0 and its principles and benefits; reveal and introduce Industry 4.0 in construction and architecture industry; some samples about using Industry 4.0 in construction and architecture industry. Part two of the research is devoted to the idea and explanation of fourth wave technology in construction and architecture. The research used the* ***method of analysis*** *of scientific and historical literature and documents related to the Industrial Revolution (specially fourth industrial revolution) and his achievement in the construction and architecture industry to achieve and formulate conclusions.* ***The conclusion of study*** *is about today's stage of realization of fourth industrial revolution in the construction and architecture industry and his point of view to next industrial revolution which start from 2017. The author believes that the development of the construction and architecture industry now and in the future depends on the attention and use of new industries and professionals in this industry specially IT specialists and technology. The conclusion of the second part of the study articulates fourth wave technologies in all areas of construction and architecture.*

***The scientific novelty of the study*** *is to study, analysis, identify main factors of Industry 4.0, and collection of some samples of realization of this technology (fourth wave technologies) in construction and architecture industry.*

*Промышленная революция — это перестройка общества под влиянием инноваций в технологиях и технике, которая сопровождается скачком производительности труда. Сегодня происходит 4-я революция, которая стремительно меняет ландшафт различных сфер жизни, в том числе архитектуры и строительной отрасли. Революция «Индустрия 4.0» объединяет технологии, используемые в организациях и в повседневной жизни людей. Она сочетает в себе физические и цифровые технологии. Но в архитектуре и строительстве она не развивается так, как во многих других отраслях, таких как автомобильная, авиационная, электронная и т. д.* ***Актуальность исследования*** *заключается в изучении и анализе этапа исторического события, связанного с промышленными революциями (в частности, четвертой промышленной революцией), и его реализации в современной строительно-архитектурной отрасли.* ***Цель исследования*** *— это всесторонний обзор современной и исторической литературы, связанной с четвертой промышленной революцией и уровнем ее реализации в отрасли, с особым акцентом на строительстве и архитектуре. Таким образом, основные* ***задачи исследования*** *можно выделить следующие: обзор исторической литературы и базовое понимание промышленных революций; понимание Индустрии 4.0, ее принципов и преимуществ; выявление и внедрение Индустрии 4.0 в сферу строительства и архитектуры; несколько примеров использования Индустрии 4.0 в строительной и архитектурной отраслях. Вторая часть исследования посвящена идеи технологии четвертой волны в строительстве и архитектуре. В* ***исследовании использован метод анализа*** *научно-исторической литературы и документов, связанных с промышленной революцией (особенно четвертой промышленной революцией), и ее успехи в строительной и архитектурной отраслях для достижения и формулировки выводов.* ***Вывод исследования*** *заключается в сегодняшнем этапе реализации четвертой промышленной революции в строительной и архитектурной отраслях и ее точки зрения на следующую промышленную революцию, которая началась с 2017 года. Автор считает, что развитие отраслей строительство и архитектура сейчас и в будущем зависит от вни-*

*мания и использования новых отраслей и профессионалов в этой сфере, особенно IT-специалистов и технологий.*
*В выводе второй части исследования сформулированы технологии четвёртой волны во всех сферах строительства и архитектуры.*
***Научная новизна** исследования заключается в изучении, анализе, выявлении основных факторов Индустрии 4.0 и подборке образцов реализации этой технологии (технологии четвертой волны) в строительстве и архитектуре.*

***Keywords:** construction, fourth wave technology, 4IR, Industry 4.0, construction robot, artificial intelligence, augmented reality (AR), virtual reality (VR), extended reality (XR)*

***Ключевые слова:** строительство, технология четвертой волны, 4ИР, индустрии 4.0, строительный робот, искусственный интеллект, дополненная реальность (AR), виртуальная реальность (VR), расширенная реальность (XR)*

## Introduction

*The relevance of the study.* The Industrial Revolution is the process of transition from an agrarian economy characterized by manual labor and handicraft production to an industrial society dominated by machine production. The history of human activity related to the invention, design and manufacture of technical products and devices. It is a story of evolution from the handicraft production of single objects to the assembly industrial production of series products [1, 2]. The development of mankind is inextricably linked with the progress of science and technology, which is confirmed by several industrial revolutions. Construction and architecture which appeared in ancient times and as an industry that creates complex technical devices, such as buildings and structures – is also evolving in this direction and went through several stages of evolution.

There are many reasons why construction has not yet evolved into precision housing. Many of these reasons lie in the realm of finance and marketing rather than engineering and technology. Where modern products of the automotive, aircraft, electronic and other industries of mechanical engineering have been phenomenal in reducing product costs through mass production and in increasing sales through clever marketing and distribution, the construction industry has choked. In light of the development of the concept of "Industry 4.0", the term "Construction 4.0" appeared but this term didn't develop in real life of humans like another industries!

Thus, the *research objectives* are as follows:

▪ basic understanding of the industrial revolutions *(see part 1 of this article)*;

▪ review and analysis of literature about the industrial revolutions specially about Industry 4.0; its principles; main challenges and benefits *(see part 1 of this article)*;

▪ reveal and introduce Industry 4.0 in construction and architecture industry;

▪ search and find some samples about using Industry 4.0 in construction and architecture industry.

*Research methodology* would be used literature review, pattern recognition, identification and conceptualization method for contribute the results of study. For this occasion, main stages and methodology of this research are like as follows:

▪ Literature review and analysis method: latest scientific literature, interdisciplinary text and documents with a suitable thematic analysis related to industrial revolutions, Industry 4.0, construction and architecture;

▪ Pattern recognition is the ability to see patterns in seemingly random information. The goal is to note the main patterns and concepts in the results of the first step. The second step looks for similarities or patterns in the sample and codes the results by concept;

▪ Identification method: to recognize specific, problems and characteristic of Industry 4.0 and its relation to modern construction and architecture (results of part one and two);

▪ Conceptualization method: in order to find a suitable theoretical connection between the identified concept and its relation to Industry 4.0, urban development, modern construction and architecture.

## Main part

The Industrial Revolution is a period of global changes related to industrial production processes, machines and technologies that took place in Europe in the 18th and 19th centuries. This historical period led to tremendous economic, social and technological progress and was one of the most significant in world history. The technological changes that were taking place at that time gave impetus to innovation not only in industry, but also in many other areas of life. The process of industrialization began with the transformation of agriculture, the mining industry and the textile industry, which improved the lives of millions of people. One of the main industries which effected by industrial revolutions are architecture and construction industry.

Thus, the purpose of this article is to study the history and causes of the industrial revolution, as well as its consequences and effect on the latest industrial technology (4th industrial technology) in construction and architecture. Article review the key facts and events associated with this area, as well as discuss all the changes that it made to the development of mankind especially associated with architecture and construction industry.

## III. Fourth wave technology in construction and architecture

The fourth industrial revolution is capable of transforming our daily ways of producing products and providing services, and it will also help in providing better medical and health care and working conditions. In most cases, the absorption of technology in construction industry has faced many problems. The construction industry is opening its way to the digital world. Although this industry has always been at the bottom of the list of industries that embrace digitalization and is much slower to adopt digital tools than other industries, the Covid-19 pandemic has forced construction players to go digital and use technology. This mandatory adoption helps keep projects from stalling and highlights the positive impact these tools have on construction projects. This becomes more evident when we think about the efficiency and productivity of these projects. At a time when many expected to see a decrease in productivity in this area, the use of these previously unwelcome tools has given rise to completely new and dynamic ways of working. Undoubtedly, this new method will transform the ecosystem of the construction industry. Now more than ever, construction stakeholders are realizing how critical digital solutions are to maintaining efficiency and helping the industry grow. There are no signs that the pace of digitization in this area is slowing down, and now more than ever we need to focus on collective growth. We should not miss the opportunities that the fourth industrial revolution brings to the construction industry.

Asite's CEO, Nathan Doughty, wrote in an article titled "What's Holding Back the Adoption of New Technologies in the Construction Industry". He points out that the structural complexities and the problem of the dispersion of fields, non-standard data, lack of transparency about data ownership, lack of skills and negative attitudes about technology have held the construction industry back in this field [3]. If construction industry stakeholders can finally overcome their distaste for the digital world and get on board, the fourth industrial revolution could have a huge impact on the construction industry.

The fourth industrial revolution (Industry 4.0), which in the field of construction is called the fourth revolution of construction, can change the way of doing construction projects. Because the fourth revolution of construction refers to the digitization of that industry and the automation of its processes [4, 5, 6].

Fred Sherrat, Associate Professor in the Department of Construction Management at Anglia Ruskin University in the United Kingdom, in his article in the New Civil Engineer journal has claimed that in the fourth industrial revolution we should expect the emergence of a wide range of new initiatives, including:

- Improve communication and data management;
- Planning projects with the help of artificial intelligence and machine learning;
- Construction robots;
- Research drones (drones in construction);
- Advancement of Building Information Modeling (BIM);
- Projects that have been completed virtually before the start of work;
- Computer optimized design;
- Real-time processing of information with the help of Internet of Things (IoT);
- Digital twins of designs to optimize the manufacturing process.

### 3.1 Improve communication and data management

To better understand the importance of these point we should see next information: According to surveys, 82 % of construction companies' customers believe that they need more cooperation with the company; 52 % of rework in the construction industry stems from poor project data and communication; approximately 9 % of the total cost of the project is direct and indirect cost of rework; 35 % of the time of specialists in construction companies is spent on non-productive activities such as searching for project information, fixing mistakes and rework; customers are 67 % more likely to spend a second time doing business because of the great service you provided [5].

CRM software is the most widely used software that provides construction management and construction projects for organizations and companies. The prominent features of the software include task management, accounting integration, reporting, mobile application, etc., and it allows people such as architects, engineers and construction management companies to collaborate on projects and view documents.

### 3.2 Planning projects with the help of artificial intelligence and machine learning

Fred Sherrat noticed "Planning projects with the help of artificial intelligence and machine learning" in his document, but author think artificial intelligence and machine learning should not limited to planning in construction. This new technology would affect the whole construction industry. Artificial intelligence in construction acts like a person who has spent her whole life in construction. For example, it is enough to inject information such as the dimensions and geography of the land in question to provide the best map, schedule and cost estimation according to inflation and unforeseen challenges. But the difference is that an experienced person may have gone through 100 projects during her sixty years of useful work. But artificial intelligence can be injected with thousands of construction experiences from all over the world every second, and this technology will learn from all of them without any error. Although the costs of purchasing and implementing artificial intelligence may be challenging at first for a construction company, but after some time, the profit obtained from it neutralizes the initial costs [6, 7, 8].

In the following, we will describe some of the applications of artificial intelligence and machine learning in the construction industry:

*Planning or project design:* Traditionally, it takes weeks to manually design projects. But artificial intelligence makes this long process faster and more accurate. Generative design is a design method based on artificial intelligence. In this method, artificial intelligence is connected to a rich database of different construction plans. Designers and engineers can enter design goals and parameters such as space requirements, building performance type, materials, cost constraints, and more into generative design tools. This modern technology suggests the best designs by examining this information and the desired dimensions and time. In this process, it is also possible to customize according to the taste of each customer, which leads to easier sales. 3D modeling of structures helps professionals to plan, design, construct and manage buildings, infrastructure and alternative designs more effectively. Generative design allows professionals to instantly produce the most efficient, high-quality, and cost-effective designs based on any given parameter.

*Cost control during the project:* Artificial intelligence is able to provide the best price estimate according to the inflations in the market and its past experiences [6, 7, 8]. Most large projects, despite employing professional teams, still face excess costs. Artificial intelligence is able to predict costs by examining factors such as project size, contracts, schedule, competence level of managers, teams, etc. This technology estimates the future of the upcoming project by examining data such as the start and end date of construction of various projects and their costs.

Machine learning helps reduce costs by performing multivariate analyzes and adjusting variables that may lead to problems in the project. Also, the artificial neural networks in deep learning make it easy to handle complex project plans by analyzing employee performance, start date, material cost, and other variables. Since larger projects require larger investments, artificial intelligence and its sub-branches are a net benefit for the construction industry.

*Production and distribution of building materials:* Artificial intelligence can help people and different construction companies to predict the price of construction materials. For this purpose, artificial intelligence examines all the historical data and performance of various factors that affect the price of materials. In fact, with the use of artificial intelligence in the construction industry, it will be easier to manage the inventory of materials and their purchase price will be more economical. Also, artificial intelligence is able to take into account the need to recharge raw materials according to the amount of materials used in each construction site and take reorders automatically. This smart computer even identifies the best provider of building materials according to the quality of materials, punctuality in delivery, price, etc. and orders its purchase from there. This modern technology is used even during the construction of building materials and seeks to produce the highest quality ones. Companies manufacturing building materials can use artificial intelligence to produce the most suitable materials according to temperature, pressure, etc., according to data obtained from lasers, ultrasound examinations, cameras, thermometers, and other possible equipment.

*Construction safety:* Since the beginning of construction history, many workers have lost their lives. Most of these deaths were due to the lack of safety in the workplace. Accidents such as falling from a height, electrocution, falling of heavy objects, getting stuck between two obstacles, etc. have been introduced as sudden death accidents in the construction industry. Artificial intelligence is able to inform managers of the existence of danger by analyzing the work environment and scanning workers' protective equipment and comparing them with the history of such incidents [9, 10, 11].

*Risk reduction and management:* Every construction project has risks that appear in different forms such as quality, safety, time and cost risk. The larger the project, the higher the risk. Because several subcontractors in different jobs operate in parallel on job sites. Artificial intelligence solutions in the construction industry make it easier to monitor and prioritize risk (risk management) in the workplace. This helps the project team focus their limited resources and time on the biggest risk factors, thereby reducing risks.

*Labor shortage:* In European and American countries, the labor shortage is noticeable. According to CNN, the construction industry is facing a shortage of more than one million workers in the United States. According to McKinsey & Company, by using artificial intelligence, the productivity of construction companies will increase by 50 %. Artificial intelligence is able to create the best division of labor and machinery by monitoring different sites. It can also report which job sites are understaffed, overstaffed, or short on equipment and can they deliver the work by the appointed time or not.

*Self-driving cars:* During all construction projects, there are a number of repetitive and routine tasks. Demolition operations, concreting, welding, excavation, etc. are some of these works. Currently, a number of self-driving machines have been designed that can do all these things more efficiently than humans. In some cases, heavy machinery such as cranes, bulldozers, and excavators have performed very dangerously on construction sites. The use of artificial intelligence in the construction industry has also increased the security of these machines. Adding sensors and using machine learning and deep learning in machines creates faster, safer and more efficient workflows.

*Off-site construction:* Artificial intelligence in the construction industry is not limited to the above. It is also used outside the construction environment. For example, structures such as walls can be built by robots in companies far from the project site, and assembled at the project site. Such manpower can spend their time and energy on things like plumbing, air conditioning and electrical systems.

*Artificial intelligence for post-production:* Construction project managers and engineers can use artificial intelligence long after construction is complete. They can gather information about a structure through sensors, drones, wireless technologies, advanced analytics, and artificial intelligence-based algorithms. They will gain such valuable insights about the performance and quality of a building, bridge, road, etc., and use them in future projects. Artificial intelligence can also be used to monitor problems, determine when preventive maintenance is needed, etc.

***Some Artificial intelligence and IT base technology programs in Construction technology***

*Programming/design with GenMEP and Generative Design (design):* Building System Planning, headquartered in California, has launched the GenMEP system. The Autodesk Revit add-on included in GenMEP focuses on various aspects of mechanical, electrical, and plumbing (MEP) design. For example, when a 3D building model is created in Autodesk Revit, GenMEP can automatically design the routing of an electrical system in the building model. This plugin is able to take into account the complexities of different shapes and geometries of buildings and provide the best solutions for all sub-projects.

Through Generative Design resulting from machine learning, this system is able to create alternative designs and possible permutations to solve a problem, and it becomes richer and more productive every time.

*BIM 360 Project IQ by Autodesk (Construction safety):* With the launch of Autodesk's BIM 360 Project IQ, there is hope in construction to reduce mishaps. This smart plugin can identify high-risk issues and subcontractor risks of projects using connected data and machine learning. This software flags problems and then assigns the right person to fix it. In some cases, it also provides details on how to fix the problem. This plugin is very accurate and sensitive in rating and selecting qualified subcontractors.

*Security with Smartvid (Construction safety):* The Smartvid platform, which includes a SmartTag engine, is used to manage videos and photos. Using machine learning, this technology recognizes risks several times faster than human intelligence. In a test, this smart engine was able to identify 446 images of people without helmets and wearing inappropriate clothes out of 1080 in less than 10 minutes. This is while humans spent about four and a half hours to identify 414 cases.

*Spot the Dog robot (Labor and equipment management):* The Spot the Dog robot is designed to guard, monitor and scan the entire project, workers and equipment. The robot detects potential problems and distributes workers among different sites. It is also able to identify workers who do not have the required efficiency with its face recognition capability.

*Komatsu project (Self-driving cars):* One of the largest manufacturers of construction and mining equipment in Japan started its cooperation with NVIDIA in 2015. This big project, which is called the Komatsu project, is to increase the safety and strengthen the machines and objects in the sites.

### 3.3 Construction robots

Construction is one of the most labor-intensive branches of human activity. A huge variety of work requires the involvement of specialists with very different qualifications. However, the construction industry has a persistent shortage of workers, which was further aggravated last year by social distancing. And the industry has to adapt to such difficult conditions and solve the problem with a lack of experienced personnel in various ways. This is not only the active work of recruiters; high technologies are becoming increasingly important for solving the personnel issue in construction. In particular, even today innovative machines and construction robots come to help a person, and sometimes to replace him. We mean here an automated machine with certain functionality that help in the performance of certain construction works. And we note right away: leading experts in the field of cybernetic technologies are sure that robots do not take away jobs from humans, but modernize them. And it promises to give great results.

The most well-known concept of the robot – a humanoid-type metal mechanism – has long been far from the only option. The configurations of robotic mechanisms used in the construction industry are striking in their diversity. A robot refers to the most dissimilar concepts from each other, from unmanned vehicles to humanoid mechanisms that can work in this industry. In total, there are 4 key types of robotic assistants suitable for the construction industry:

- Industrial robots;
- Drones;
- Self-propelled construction vehicles;
- Humanoid robots.

***Industrial robots***

Such mechanisms have long and effectively been used in manufacturing enterprises. Initially, it was for the needs of industry that engineers began to develop automatic assistants. And in parallel with the development of technology, the possibilities of using robotics to perform a wide range of operations are also expanding. Industrial robots are most commonly used in the following processes:

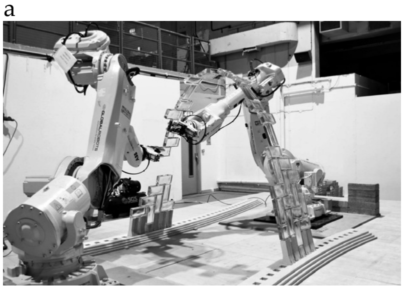
*Production with articulated arms;* They are articulated type robots. Externally and in their movements, they are very similar to the human hand, this allows them to be used in a wide range of jobs from simple automated assembly to complex welding work. In fact, articulated robots are so versatile that they are even used for building in space. For example, the Canadarms series of devices are robotic cranes located on the ISS, where they effectively replace humans in many tasks. In addition, they have already played a large role in the implementation of the Lunar Getaway project (Pic. 1a).

*3D printing using cartesian robots;* These mechanisms, also known as linear or portal, are robotic installations, the articular working parts of which move in a three-dimensional cartesian coordinate system. These robots have long been actively used for a variety of tasks, primarily for loading and unloading. However, in the past few years, they have been actively changing their specialization and turning from a loader crane into a unique 3D printer.

Three-dimensional printing is generally called perhaps the main trend of the modern construction industry. This technology allows you to create not only individual structural elements, but even entire houses. And if you combine the functionality of a 3D printer with artificial intelligence and the accuracy of robot actions, you can literally automate production, guaranteeing high quality of the finished structure. Moreover, such construction will be much cheaper, which in the future can seriously help in solving the housing problem, especially in poor countries (Pic. 1b).

*Collaboration between human and robot;* Collaborative robots, also known as cobots, are high-tech mechanisms that can work not instead of a person, but together with him and perform tasks that would be too difficult for a person or a robot separately. Persistent labor shortages are a reality in the construction industry, and cobots could be an effective solution to this problem and one day replace humans by taking on unskilled jobs (Pic. 1c) [12, 13, 14].

a



Production with articulated arms

b

3D printing using cartesian robots

c

Collaboration between human and robot

Fig. 1. Industrial robots

***Drones***

Drones have already become a real lifesaver for the construction industry. Their functions and capabilities are used in a wide variety of jobs and ultimately provide security and accelerated projects. Because drones are controlled remotely, they are able to provide the most up-to-date information on the progress of work without the involvement of a person [15]. As a result, you can see how the construction is going on almost in real time. And you get a clear picture with a high level of detail. We would be explained more about drones in next part.

***Self-propelled construction vehicles***

While the automotive industry is still only working on the development of unmanned public vehicles, autonomous vehicles are already quite actively used in the construction industry. In this segment, Built Robotics stands out, specializing in upgrading standard heavy equipment by combining it with AI-based control systems. The company's current product range consists of fully autonomous bulldozers, excavators and compact track loaders. The main problem that such automation of heavy equipment solves is the safety of road construction and repair. Road works in conditions of saturated surrounding traffic pose a danger to builders, and even the best security system cannot completely eliminate the human factor. Automation of construction machines makes it possible to significantly reduce human involvement and, as a result, minimize the likelihood of errors by workers. And in general, interaction with "smart" construction equipment is much less dangerous for workers than the use of traditional machines. Here we nominated some benefits and sample of self-propelled construction vehicles like as:

*A new level of efficiency with ATL:* Autonomous track loaders (ATL) from Built Robotics are equipped with a LiDAR system that measures the distance to an object using light pulses, and a powerful GPS complex. As a result, the loader can work completely without an operator. With its help, you can easily and quickly solve simple construction tasks, for example, to carry out earthworks in the adjacent area.

*Doing more with smart bulldozers:* Bulldozers are versatile machines that can perform a wide range of jobs from moving heavy objects to leveling various types of soil. And the technology from Built Robotics can do the same, only without the driver sitting behind the wheel (Pic. 2a).

*High productivity with autonomous excavators:* Automated excavators from Built Robotics can do all the traditional work. Their creators have carefully worked out the mechanism of interaction between equipment and the operator – thanks to this, even workers without special experience can control an autonomous machine. The whole process is intuitive and consistent. At the same time, the International Union of Operating Engineers (IUOE) has already launched training courses with Built Robotics for future smart machine operators (Pic. 2b).

***Humanoid robots***

Such machines can become even more effective substitutes for missing personnel. Of course, while their development remains a project to a greater extent, however, there are already real humanoid robots that may well become the beginning of a new era of cybernetics.

*HRP-5P – robot builder from Japan:* This robot was developed by the National Institute of Advanced Industrial Science and Technology as a prototype adapted for civilian use. Artificial intelligence and thoughtful functionality allow it to fix and move heavy objects, use doors and stairs, detect obstacles in its path and avoid them, as well as work with hand tools. A complex set of machine vision and object recognition technologies is responsible for the orientation of the HRP-5P in space. At the same time, this robot cannot yet be considered even an approximate replacement for a real worker – its artificial intelligence is not yet so powerful and capable of self-learning (Pic. 3a).

*Valkyrie – NASA works for space colonization:* The American space agency is actively developing

a


Self-propelled bulldozer

b


Autonomous excavator

Fig. 2. Self-propelled construction vehicles

a

HRP-5P

b

Valkyrie

Fig. 3. Industrial robots

almost fantastic projects for the conquest of space, and it approaches them purely utilitarian. In particular, one of the important tasks that many specialists worked on was the development of tools for space construction. For this (but not only) purpose, NASA's R5 robot concept, also known as the Valkyrie, was created. The developers describe it as a "robust, rugged, all-electric humanoid robot capable of operating in degraded or damaged environments". There is already an opinion that the Valkyries will be the pioneers of the colonization of Mars (Pic. 3b).

Technological perfection is always progress and improvement. In the context of robotization of construction, improvement should be understood not as the displacement of a person by a robot, but the improvement of the work process and its results. Construction robots are positioned as assistants that can simplify the adaptation of the construction industry to rapidly changing external conditions. One of the most important aspects of any work on any construction site is still the safety of workers. Therefore, most innovations are implemented primarily to ensure security. The same goal is realized by robots. Therefore, the answer to the question of whether robots are replacing humans is a bit more complicated than just yes or no.

However, there is no doubt that in the near future robots will not be able to completely replace people. Even those machines that are used today still require human participation to one degree or another. And it is unlikely that in the foreseeable future technology will develop to such a level when construction machines can work completely without human intervention. However, the very fact that the robotization of construction has already begun can no longer be rejected.

### 3.4 Drones in construction

As the industry continues to evolve and integrate more and more innovations, the use of drones in the construction industry will only increase. But already today they have practically monopolized a number of tasks, offering them previously unattainable solution possibilities:

*3D mapping:* with the help of drones, detailed aerial photography of various areas can be taken, from which a detailed and accurate 3D model can be subsequently built. This greatly simplifies the process of territorial planning and site preparation for work. In addition, a detailed model of the area planned for development helps you plan your budget more accurately and save money in the long run.

*Remote monitoring and inspection of workplaces:* instead of renting lifting equipment, which costs money and requires your employees to be distracted from their work, drones will help you easily and without extra labor to inspect the working area, the facility under construction, and the results of individual works.

*Ensuring security:* safety is one of the most important and at the same time problematic aspects at the construction site. The total annual volume of theft from construction sites is estimated by various experts at $300 million to $1 billion. It is possible to return to the place no more than 25 % of the stolen. One of the reasons for this situation is the limited possibilities of a person. To control the entire territory of the construction site, a whole staff of security guards would have to be hired. However, they can be replaced by drones that will control the situation from a bird's eye view, fixing everything that happens at once [15].

### 3.5 Advancement of Building Information Modeling (BIM)

BIM is an acronym that stands for Building Information Modeling. This technology makes it possible not only to design intelligent 3D models, but also allows you to create a complete virtual analogue of a structure and work with all project participants, wherever they are in one information space. The term BIM literally means "building information modeling", but this includes any other infrastructure. For example: airport; stadium; parking; residential premises; engineering network (electrical, sewerage, gas, etc.); railway; tunnel; bridge; etc. BIM greatly increases efficiency in all phases of a project's life: planning, design, construction, operation and maintenance. All this allows you to look into the future properties and characteristics of a real object in order to effectively manage it.

Architects are indeed very important figures in building information modeling, but still the owner always has more weight. In general, the list of users (groups of specialists) of BIM will look something like this: the owners of the object; architects; constructors; subcontractors; operators; developers; engineering systems designers; engineering improvement of systems; civil defense and emergency services; repairmen; manufacturers of building products and structures; producers of materials and equipment; builders. At the same time, companies are now gathering a special BIM team that has access to all levels of the project in order to provide the necessary information to all participants. The BIM team is also responsible for maintaining the design technology. BIM manager; BIM coordinator; BIM author; BIM support; BIM master are some new specialties in this area [9].

McGraw Hill Construction conducted a survey among companies in the construction industry and found out what benefits they have received with the introduction of BIM. Thus, 41 % of surveyed companies noted a reduction in the number of errors after the introduction of technology; 35 % and 32 % paid attention to improving communication between managers and designers and improving the company's image. Benefits and disadvantages of BIM:

*Main benefits:*

▪ Automation of routine processes: office work, purchases, estimates, material recalculation, etc.;

▪ Changes are tracked automatically and taken into account in all related sections of the project;

▪ Coordination of the work of all specialists in one environment: this allows you to minimize collisions in the BIM model;

▪ Reduction of edits at the last stages of design;

▪ Increasing the quality of design solutions due to detailed visualization with technical specifications;

▪ Improving the accuracy of forecasts;

Improved cost control;

▪ Reduced project development time: discussions, approvals, decision-making and revisions happen faster.

*Main disadvantages:*

▪ Need financial investment;

▪ Creation and maintenance of IT infrastructure is required;

▪ You will have to retrain specialists or look for new ones;

▪ Implementation takes time;

▪ Difficulties with adaptation to government specific rules.

***BIM Software Samples***

There are a lot of software for BIM of different levels and purposes. There are already cloud products that combine several platform modules at once, such as BIM 360 or BIMcloud. But it is important to understand that building information modeling does not happen purely in one program on one computer or in the cloud. Usually in large companies and projects, this is a large complex of hardware and software. It will not be possible to consider all this diversity within the framework of one article, therefore we focus only on some popular software packages:

▪ *A set of BIM programs provided by Autodesk*

This software, for example, was used to build the 130-story Shanghai Tower (Pic. 4a). The complex includes: AEC Collection; Revit; BIM 360; BIM 360 Design; Civil 3D; InfraWorks; PlanGrid; Assemble; Building Connected; AutoCAD Plant 3D; AutoCAD.

▪ *GT's Digital Project program*

This software, for example, was used to build the Guggenheim Museum in Bilbao (Pic. 4b). The complex includes: Designer; Viewer; Primavera Integration; MEP/Systems Routing; Image and Shape; Photo Studio. Zaha Hadid received the Pritzker Prize (not to be confused with the Pulitzer Prize), which is awarded for achievements in the field of architecture, for her work in Digital Project based on Catia V5. She designed the stunning library and knowledge center of the Vienna University of Economics.

▪ *Software from Graphisoft*

This software, for example, was used to build the 92-story Eureka skyscraper in Melbourne (Pic. 4c). The complex includes: Archicad; BIMcloud; BIMx.

▪ *Bentley Systems software package*

The company even introduced the concept of BrIM (Bridge Information Modeling – information modeling of bridges) (Pic. 4d). On this software, for example, the Helix spiral pedestrian bridge in Singapore was built. The complex includes: OpenBuildings Designer; LEGION Model Builder; LEGION Simulator; MicroStation; ProjectWise Design Integration; Bentley Pointools; Descartes; LumenRT; OpenCities Map; SITEOPS; STAAD.Pro; Bentley Raceway and Cable Management; ProjectWise Deliverables Management; ProjectWise Project Performance Dashboards.

▪ *Nemetschek programs*

A musical theater was built on its software in the city of Graz, Austria (Pic. 4e). The complex includes: Allplan Engineering; Allplan Architecture; Allplan Bimplus.

▪ *Tekla Structures (Structural Design Complex)*

This software was used to restore the steel structures of the statue "Worker and Collective Farm Girl" (Pic. 4f). The complex includes: Steel Detailing; Reinforced Concrete Detailing; Drafter; Engineering; BIMsight.

Each of the development companies and their software has a rich history, and photographs of completed projects are just special cases from a huge variety of real objects. The effectiveness and viability of BIM software does not need to be proven – the illustrations above do this best. This, of course, does not mean that the software is perfect and does not require fixes and modifications. Quite the opposite – it is constantly evolving and being finalized, taking into account the comments of specialists working on it. In addition to the programs mentioned, there are many others, as well as new needs in construction and design, which is reflected in the continuous development of BIM technologies.

In the future, any design and operation of facilities will become informational – this is already

a

Shanghai Tower; construction with Autodesk BIM software

b

Guggenheim Museum in Bilbao; construction with Digital Project BIM software

c

Eureka skyscraper in Melbourne; construction with Graphisoft BIM software

d

Helix spiral pedestrian bridge in Singapore; construction with Bentley Systems BIM software

e

Musical theater of Graz, Austria; construction with Nemetschek BIM software

f

Worker and Collective Farm Girl monument in Moscow; construction with Tekla Structures BIM software

Fig. 4. Construction with different BIM software

fixed at the level of legislation, and also becomes a standard requirement of modern customers. The benefits of using BIM systems pay off not only the investment in terms of money, but also in other planes. BIM technologies, as a bridge between continents, have connected and rethought two eras of design: classical and informational, becoming a logical and at the same time necessary step into the future.

### 3.6 Projects that have been completed virtually before the start of work

Currently, experts agree that virtual and mixed reality technologies are beginning to be applied, and very successfully. But more – for interactive for the customer, high-quality visualization. This process does not yet carry a deep engineering idea, but it allows you to better understand the design intent, to "feel" the object.

Architects, constructors and designers could have created an information model of the object – BIM-model, and the client, using a special headset or just a mobile phone, can walk inside the object that has not yet been built. This allows you to move around and even interact with the building before construction begins. Experts are confident that such feedback from the client speeds up and optimizes work, allowing you to make more informed design decisions at the earliest stages [6, 13].

At the beginning of 2020, TECHNOmagazine talked about the "TOP 5 technologies that you should pay attention to in 2020". Among them, virtual and augmented reality were also noted. Messages about the development of new technological solutions based on VR, AR and MR (mixed reality) are coming in regularly.

*VR* is Virtual Reality. The term means a completely computer-generated digital world that is not tied to location in any way. To get into it, a helmet or virtual reality glasses are usually used. To interact with the objects of the computer universe, you will also need special devices – vr joysticks or touch controllers. Immersed in virtual reality, a person ceases to see and interact with the real world. Since the signal is broadcast in the closed space of a special device, which is tightly worn on the face and does not allow an external light source to enter. In the case of using a helmet or headphones, access to the sound of the surrounding real world is also limited (Pic. 5a).

*AR* is Augmented Reality. Unlike VR, AR – augmented reality – is already the penetration of the digital world into the real one. It is still not tied, or rather not completely tied, to the terrain. But you can see it without disconnecting from the real world. Human interaction with augmented reality occurs with the help of special glasses and all the same VR sensors or using a touch screen. Although there have already been software developments that allow you to scroll through the virtual menu and interact with your hands, without the use of sensors (Pic. 5b).

*MR* is Mixed Reality. This is essentially a kind of augmented reality, when virtual objects are tied to the area. The difference between MR and AR lies in the fact that mixed reality "fits" a virtual object into the real world the way this object should be (become) in reality. For example, when parking a car, lines of the trajectory of movement appear on the monitor – this is augmented reality. And, let's say, "fitting" the installation of equipment in a specific place of the production site before the start of installation – this is already MR (Pic. 5c).

According to experts, in the coming years we will see the introduction of a large number of new technologies based on virtual reality technology. Which ones will depend on the development of the aggregate base. After all, they require different devices to use them. They help to reduce the cost of construction, increase the efficiency and quality of projects being implemented.

### 3.7 Computer optimized design

Which of the practicing architects has not had to deal with errors in the implementation of their project? Trying to find explanations comes down to blaming yourself that the project documentation was not done sufficiently. These appeals miss an important part of the process: after designing in

a b c


VR sample in construction — AR sample in construction — MR sample in construction

Fig. 5. VR, AR and MR samples in construction

the most complex software, in 3D or even 4D, the documentation still reaches the contractor in the form of traditional drawings. Due to a sharp leap in the development of digital technologies, which should have brought design and construction closer together, the gap between them today seems to be even greater – projects are becoming more complex, while implementation remains at the level of many years ago. Institutions are paying more and more attention to the culture of handling software, and state expertise is moving towards checking projects in the form of a model, and not in the form of an album of drawings [16, 17].

The widespread introduction of computer programs in the last 25 years has led to revolutionary changes in the method of design and preparation of architectural documentation. Most programs are used either for visualization or reasoning about form in an academic context, or for technical writing and project management in practice. This separation of theory and practice is reinforced by the relationship that exists between architects and those who implement their design proposals. This gap between design development and building implementation, which in theory should be a single, coherent and interconnected process, was facilitated by the documentation way was exchanged, which was done manually and required the interpretation of the host. Today, this gap between the two ends of the spectrum is disappearing with the emergence of new capabilities that require concerted action from the parties – advanced analysis software is useless without the imagination of the designer, and back.

Digital tools have moved beyond the formal depiction of designs to include analysis, simulation and digital manufacturing. These new ingredients allow architects to more accurately translate their ideas into reality, as well as to innovate and change traditional ways of constructing buildings. The synthesis of these technologies and the need for efficient organization of construction led to the emergence of information models that radically changed the design and brought it closer to construction. Although modern technologies are not at an adequate level of development for the automated production of full-scale buildings, they allow building complex information models to more accurately transfer the virtual building structure into reality.

An article by Richard Garber, partner at GRO Architects and author of several books, focuses on the impact of digital technologies (in particular BIM) on design processes. The text was written in 2009, but is still relevant – the author predicts and considers many of the moments of the transition from reality to virtuality and back, and also considers the impact of this transition on design. In Garber's reasoning, virtuality, which is often the antonym of authenticity, suddenly becomes a cast and laboratory of the real world, in which we can test thousands of options and then simply export them to reality.

It seems, in the current Virtual to Reality paradigm, interpretation is no longer required because digital information models are already real. They are created, tested, reproduced and optimized in virtual reality, and all that remains to be done is to transfer them to the material world and actualize them.

### 3.8 Real-time processing of information with the help of Internet of Things (IoT)

The Internet of Things brings significant benefits to many industries, the next step is the introduction of smart devices in the construction industry. The Internet of Things is changing the world of smart buildings – it's data transfer speed. IoT devices are giving builders ideas to quickly respond to emerging trends. IoT applications allow structure managers to run various experiments to test the result of optimization. It also provides space for IoT devices to monitor building systems with a panel. The first means of this data exchange is the m2m (machine-to-machine) IoT sim, which was soon replaced by electronic ones, that is, real chips instead of a physical one.

The introduction of IoT in construction can significantly reduce any type of accident. Security is provided by digital solutions: for example, special sensors attached to work clothes and helmets that monitor the level of contaminants that are harmful to health in the composition of building materials. Another example is the connection of tracking sensors that monitor the movement of workers around the site and give warning signals when employees enter unsafe areas. Without a doubt, such smart devices make construction sites much safer [18].

Construction site data is collected and processed in real time. This is possible because they are interconnected by sensors, surveillance cameras and even drones. All information is sent to the head office, where representatives of the top management of the company make decisions and approve changes. Various RFID tags and sensors on building materials and equipment make it possible to automate the monitoring of the material and economic base of the facility and warn in a timely manner about the need to replenish supplies or repair equipment. Also, special sensors on the used units automatically detect the impending need for repairs. The use of such digital tools saves companies from costly downtime caused by a lack of materials and free equipment.

The Internet of Things keeps projects running smoothly, and it also allows for continuous improvement through continuous data.

### 3.9 Digital twins of designs to optimize the manufacturing process

If organizations are planning to go digital, the best way to achieve this goal is to implement Digital Twins. A digital twin is a virtual copy of a physical object, process, or system, combined with technical information to understand and model overall performance.

In order to display status and conditions in near real time, Digital Twins are constantly updated with data from a variety of sources, including sensors and continuous imaging. It is this ability to continually update the Digital Twin that gives our users a competitive advantage over static 3D models. Infrastructure digital twins, known as iTwins, allow users to visualize assets, track changes, and optimize their performance. They are also constantly updated with data from the physical object. This information is used to understand and model overall performance.

The digital twin supports the life cycle of an object within a project. It enables collaboration, real-time data management, and analytics. When collaborating, it allows each project participant to share and access project data and information on the job site and in the office. Organizations can then begin collecting and managing real-time data to improve response time to any disruption. Finally, with the help of analytics, the construction industry can use intelligent data to make informed decisions.

***Creating a Digital Twin***

Digital twins of infrastructure facilities are created by combining 3D/4D visualization, reality modeling, mixed reality and geotechnical technologies. iTwins combine data from various types of data stores, including BIM models, drawings, specifications, documents, analytical models, photographs, reality models, IoT channels, and enterprise resource and enterprise asset management data. Some companies offer iTwin Services, which is a set of cloud-based services that enable organizations to create, visualize and analyze iTwins in order to support their users in their digital transformation.

***Benefits of using Digital Twins***

However, in addition to improved visualization and optimized asset performance, there are a number of other benefits of using Digital Twins in the construction industry. For example: with Bentley iTwin Design Insights, design teams gain insights into their work to help them understand the impact of design decisions on cost, schedule, materials required, safety and other key performance indicators (KPIs) early in a project. "ITwin Design Insights" gives users the ability to identify hot spots over a period of time to proactively identify potential conflicts and project risks. What's more, iTwin Design Insights offers users an easy way to create a business intelligence dashboard for Digital Twins. The solution integrates with Microsoft Power BI, thus offering a fairly simple way to create personalized interactive dashboards.

***Using Digital Twins in the Construction Industry***

Digital twins can bring significant benefits to the construction industry by helping users make data-driven decisions and deliver more predictable and optimized results. In the case of iTwins, they cover the entire life cycle of an asset, thus enabling better decision making, optimized and better results at all stages. ITwins give users the ability to model logistics and project schedules, track work progress and status, and view an up-to-date 4D model. All construction information is available in one place, including asset tags, work orders, maintenance records, inspection reports, and workplan details.

The following are some of the competitive advantages that users can gain by using iTwins in their work:

- with their help, users can quickly set the order of construction operations and perform simulations, which, in turn, allows them to detect and eliminate errors before work begins;
- they reduce the time of the project teams and, as a result, the costs of the owner;
- they can provide project analytics prior to commencement of work on the construction site;
- with their help, you can achieve a significant reduction in production costs;
- they can reduce project costs while gaining access to all data throughout the entire life cycle of an object;
- they allow real-time project monitoring with visual context.

There are various areas in the construction industry that will definitely benefit from the introduction of Digital Twins.

### Results

Based on the summary of this study (part 2 of article), we could draw the following conclusions:

- Consideration of fourth wave technology in today's construction and architecture shows new initiatives, including: improve communication and data management; planning projects with the help of artificial intelligence and machine learning; construction robots; research drones (drones in construction); advancement of building information modeling (BIM); projects that have been completed virtually before the start of work; computer optimized design; real-time processing of information with the help of internet of things (IoT); digital twins of designs to optimize the manufacturing process. This research tries to explain all indicated initiatives and shows some realization samples related to these points;

▪ Draw/Shows some sample application of the fourth wave technology in today's construction like as high-speed skyscraper's building; 3-d printing in construction; Internet of Things and Smart Sensors; Robots and drones in construction; Artificial intelligence (AI); virtual and augmented reality; and blockchain.

## Conclusion

During the last three industrial revolutions, not only did people's personal and professional lives change over and over again, but sometimes they were even threatened. After each revolution, the world took a new direction. This time, the fourth industrial revolution will change our lives; although the speed and dimensions of this change will be very different and bigger than the changes of the past three industrial revolutions.

In the coming years, the construction industry can radically change its appearance due to the introduction of IT technologies. Construction will become more transparent and understandable for everyone, which means that the advantage will be given to those companies that are already thinking about their efficiency, reducing costs and developing client work. The fourth industrial revolution and digital technologies in construction are able to increase labor productivity, improve safety at the construction site, ensure the "broach" of any little things throughout the entire construction process from design to operation of the facility. Perhaps now some technologies seem like science fiction or useless dreams, but large developers have already understood the prospects: they are strengthening IT departments and teaching employees' new digital specialties. In the coming years, the construction industry, in addition to the traditional shortage of workers, will face a shortage of IT specialists which would help them for using fourth industrial revolution and technology in construction industry.

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