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НЕОБХІДНІСТЬ І ПЕРСПЕКТИВИ РОЗВИТКУ ТЕХНОЛОГІЇ «SMART CITY» В УКРАЇНІ

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Анотація. Цифровізація в будівельній галузі з кожним роком набирає все більшої популярності, однак в порівнянні з іншими сферами життя, використання цифровізації істотно відстає. На зміну використанню в будівельній галузі двомірних креслень, приходять BIM технології проектування і експлуатації будівельних об'єктів, які несуть у собі велику кількість інформації і мають стати основою для створення «Smart City». Технологічний прогрес в проектуванні дозволить підвищити рівень комфорту мешканців мегаполісів при раціональному споживанні ресурсів. Технологія «Smart City» має стати основою для швидкого відновлення населених пунктів після війни та забезпечити основні вимоги сучасності з безпеки, енергоефективності та комфорту. Головною метою статті є аналіз концепції «Smart City» та виявлення основних вимог до будівництва сучасних українських міст. Актуальність статті полягає в відображенні необхідності впровадження концепції «Smart city» в процес управління українськими містами та висвітлення переваг для міста та мешканців. Світова практика підтверджує ефективність таких технологій. Українські міста не можуть бути такими як раніше і будуть відновлюватися з урахуванням усіх викликів сучасності.

Ключові слова: *енергетичні ресурси; smart city; енергоефективність; генеративний дизайн; BIM*

NECESSITY AND PROSPECTS OF "SMART CITY" TECHNOLOGY DEVELOPMENT IN UKRAINE

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Abstract. Digitalization is more and more utilized in the construction sector, although its adoption has been slower than in other areas of life. The use of 2D drawings in the construction industry is being replaced by BIM technology for the design and operation of building projects, which carries a wealth of information and should form the basis for the creation of a "Smart City". Technological advances in design will increase the comfort level of inhabitants of megacities while consuming resources rationally. "Smart City" technology should be the basis for the rapid reconstruction of settlements after the war and provide the basic requirements of today for safety, energy efficiency and comfort. The main purpose of the article is to analyse the "Smart City" concept and to identify the main requirements for the construction of modern Ukrainian cities. The relevance of the article lies in reflecting the need to implement the "Smart City" concept into the management of Ukrainian cities and highlighting its benefits for the city and residents. Worldwide practice confirms the effectiveness of such technologies. Ukrainian cities cannot be the same as before and will be rebuilt with all the challenges of modernity in mind.

Keywords: *energy resources; smart city; energy efficiency; generative design; BIM*

Introduction. A large number of residential buildings and infrastructure facilities were destroyed in Ukraine due to the war. A large amount of building facilities need to be rebuilt, and new ones need to be built to replace those that have been damaged. Some Ukrainian cities have suffered significant damage, so it will no longer be a question of rebuilding, but of building new cities and districts. They must be modern and safe.

The President of Ukraine Volodymyr Zelenskyi stated he had instructed the government to create a special state program to rebuild every Ukrainian city affected by the Russian invasion: “After the war, after our victory, we will rebuild everything that is destroyed. Very fast and very high quality. A special state program for recovery will be created for each affected city” [1].

According to the mayor of Kharkiv Igor Terekhov, during the design a lot of attention should be paid to the design project, so that the neighborhoods differ from each other and use the latest developments in energy saving. Today we need bomb shelters and dual-purpose underground parking lots. The mayor also stressed that Kharkiv is a city of IT technologies, so there are plans to build a city center of European level [2]. All these challenges pose serious challenges for Ukrainian architects and engineers. Such a major recovery is possible only thanks to modern technology, world best practices and close work with IT professionals.

Analysis of publication. There are definition of ”Smart City”, advantages and perspectives of this technology are described in research and publications [3−7; 13; 14]. Concepts and directions of building of new cities were described in Kubrakov’s O. publication [8]. Main directions were defined: security [9], environmental friendliness and energy efficiency [10−12], digitization and digitalization [15−16]. The basis for “Smart City” has to become digital twin [17] operated on BIM models [18].

Main part. Of course, the new Ukrainian cities will be not as before. Ukraine must move away from typical Soviet-era buildings. Modern requirements and trends are aimed at greater comfort for people. With such a large-scale reconstruction of cities, many urban issues can be resolved. These include parking spaces near houses, improving energy efficiency of housing, reasonable planning of apartments and areas of the city. Much attention should also be paid to the location of infrastructure. Planning should be based on the principle of infrastructure for people, not people for infra-structure.

The introduction of digital technologies in the field of construction and architecture has significantly simplified and accelerated the design and construction of facilities. One of the important concepts of modern cities is the construction of “Smart City”.

“Smart City’ is the effective integration of physical, digital and human systems in an artificial environment for a sustainable, prosperous and comprehensive future for citizens. This definition was provided by the British Standards Institute (BSI). “Smart City” is the only system in which urban communications, information technology and IOT (Internet of Things) devices are organically interconnected [3].

“Smart City” is the effective integration of physical, digital and human systems in-to an artificial environment for a sustainable, prosperous, developed and integrated future. “Smart City” is a unique set of interconnected systems. In these systems there is an organic interconnection of data transmission technologies, equipment and urban communications “Smart Cities” use technologies and innovations to improve the urban environment, which leads to improved quality of life, improving the well-being of city residents.

Digital city twins are used to implement many tasks of development, construction of new and reconstruction of old urban buildings. 3D twin cities have existed not so long ago, but the progress in their creation is already quite significant. We can see the creation of digital twins of cities around the world: Singapore, Helsinki (Finland), Boston (USA), Jaipur (India), Newcastle (UK), Rotterdam (Netherlands), Rennes (France), Stockholm (Sweden). ABI Research, a consulting firm,

found that about 500 new digital duplicates of large cities are likely to emerge over the next three years [4].

Software packages for the construction of digital twin cities allow you to model the plan to the stage of project implementation, choosing the best option. It will also help create a more flexible management system and reduce the misuse of both material and energy resources, thereby optimizing food, water and energy consumption. Markets and Markets estimates the digital city twin market at $ 3.8 billion in 2019, but its value is expected to increase significantly (tenfold) by 2025, citing key forecasting factors such as continued new technologies, including “Internet of Things”, digitalization in the fields of education, health care and transport [5].

The introduction of “Smart Cities” will increase economic efficiency. The study found that each “Smart City” with 10 million inhabitants saves:

– $ 4.95 billion a year, mostly on streetlights and “smart homes”;

– $ 14 billion from the transport business (will come to the rescue unmanned trucks and drones);

– About $ 26.69 billion a year will be saved on utilities through the use of intelligent control systems and counters [6].

The city's digital counterpart should be used to preserve cultural heritage. In April 2022, more than 150 cultural heritage sites were destroyed, 30 of them in Kharkiv. Ukrainian Cultural Foundation has created a “Map of Cultural Losses”. Damage to architectural monuments and the possibility of their restoration will be recorded on the map. The digital duplicate would help in the reconstruction of the city, as it would contain important information about buildings and could record damage to historical sources.

The development of such a large-scale product can be partially undertaken by Ukrainian and world higher education institutions. A large number of students of architectural and engineering specialties could do term papers and dissertations at these sites. Such an approach to the creation of digital twins of cities on the one hand would provide higher education students with the necessary theoretical knowledge and practical skills, and on the other hand would reduce the cost of projects [7].

After the war, the requirements for building codes will change significantly based on modern realities and challenges. Minister of Infrastructure Oleksandr Kubrakov stated that after the war, houses in Ukraine will be designed in the same way as in Israel − with mandatory fortified underground parking, bomb shelters and other security measures [8]. In the construction of modern cities, the main tasks should be:

– Security;

– Environmental friendliness and energy efficiency;

– Digitization and digitalization.

Security. Security is a key issue in building future Ukrainian cities. Cities need to be increasingly safe in both ordinary and emergency situations. In addition, the development of underground urbanization is needed to solve many security problems and create new opportunities, such as those that are developing in major cities in Canada. The underground part of the Canadian city of Montreal is about 30 square kilometers. The «underground city» has everything for a comfortable life: banks, universities, shop-ping malls, bus stations, subways and even railway junctions. It is possible to live in such a city for months. It is autonomous and has all the necessary utilities (ventilation, water supply, air conditioning). Montreal is far from the only example. The operation of the underground part of the city will allow more efficient use of space and reduce the load on city roads. Various man-made emergencies are possible, even in peacetime, and modern measures in buildings, roads and networks are needed to protect against these emergencies. The environment of modern cities is actually very fragile, and this fact can no longer be ignored. Public places must be particularly safe, as must social infrastructure, transport and engineering. And the underground buildings of the modern city must unite and protect the whole city.

National Union of Architects proposes to build dual-purpose underground storage

facilities. In peacetime, these premises can be used as commercial. This will help solve problems for many small businesses. This approach will allow the premises to be maintained at the expense of business, and if necessary, these premises will serve as bomb shelters [9].

"Smart City" also provides a new level of digital security. It is necessary to create a central network of video surveillance and signaling, which will make moving around the city safer. At the same time, "Smart City" technology is a challenge in the field of cybersecurity, as it involves the storage and processing of large amounts of data. Thus, the technologies of the "Smart City" will further stimulate the development of cybersecurity. For example, in January 2020, the UK government released a bill to protect IoT devices, which contains requirements for manufacturers of "smart" de-vices.

Environmental friendliness and energy efficiency. Due to the risks of global warming and resource scarcity, the prudent and efficient use of natural resources has become a priority in finding new management solutions. Realizing what irreversible damage has already been done to nature, humanity is trying to change its approach to economic activity. The same applies to the construction industry. It is estimated that buildings consume 40 % of the world's energy, and that buildings account for 40 % of global greenhouse gas emissions and generate about 40 % of landfill waste. Among other things, 90 % of energy and 80 % of gas emissions from buildings account for the period of their active operation [10]. European countries, the United States and Canada have accumulated sufficient experience in the field of eco-building. Hamburg, Freiburg, Zurich, Malmö, San Francisco, Portland, Reykjavik, Vancouver and others are cities where green building principles are being actively implemented today. Moreover, the development of modern technologies allows you to create not just "green buildings", but also entire ecological neighborhoods. Similar projects have been built in Freiburg (Erlicon and Roselfeld districts) [11], the western Gurber district in Malmö, Sweden [12]. Ukraine is simply obliged to adopt the experience of creating ecological districts.

EU policy at present is aimed at creating measures in the implementation of which buildings during operation would consume almost no energy from external non-renewable sources. Ukrainian legislation is also being improved in this direction. In recent years, the Parliament and the Government of Ukraine have been adopting laws, orders and decrees aimed at more rational use of energy in construction. So, the state is trying to stimulate a reduction in energy consumption in buildings. One such document is the Law "About energy efficiency of buildings". The act itself defines the basic principles of state policy in this area, in particular, it is about:

– creating conditions for attracting investments in order to implement measures to ensure (improve) the energy efficiency of buildings;

– ensuring thermal modernization of buildings, stimulating the use of renewable energy sources;

– development and implementation of a national plan to increase the number of almost zero energy consumers.

Due to the optimal combination of technologies on the scale of both the building and the whole district and city, «Smart City» offers the maximum quality of re-sources. By 2050, according to the UN, 68 % of the world's population will live in "smart cities". "Smart Cities" strives to improve the quality of life of residents, as they are becoming more and more in cities in general [13]. According to architect and researcher Carlo Ratti, urban overpopulation can be avoided in 2050 by functionally improving site planning and use, optimizing energy consumption, expanding spaces for social activity and consolidation [14].

In Ukraine, the largest consumers of energy resources are residential and public buildings. Today, a lot of extra energy is needed to ensure their livelihoods, due to the worn-out state of the energy system and the obsolescence of most households. Out-dated equipment, low thermal resistance of building envelopes and increased heat consumption for

heating, ventilation and hot water supply of buildings are the problems of the construction industry.

Generative design has become an important element in the introduction of new technologies in construction and everyday life. It is already widely used in the design of various construction projects. Its advantage is that the software independently processes a different number of design options, and then gives the most optimal result. It is through a combination of generative design methods that productivity can be increased at different stages of project creation. At the same time, generative de-sign can take into account data from Building Information Models (BIM), which in turn will allow for more accurate calculations and get better solutions.

Generative design can be used to solve one problem, such as the choice of material and geometric parameters of the insulation, and for a set of measures to improve the energy efficiency of the building. Generative design helps the specialist to obtain options, using calculations to estimate project parameters and create results that the user would not be able to estimate. The user defines the rules and objectives of the generative design process, and computer software creates possible results within the specified parameters. The goal is to optimize solutions for one or more design purposes within building codes and budgets.

Generative design also reduces costs not only by optimizing the productivity and use of materials, but also by reducing the time spent searching for optimal solutions, which can be hundreds or thousands. The designer will navigate a wide range of de-sign options and weigh the features and trade-offs.

The use of generative design in the choice of thermal protection of the building al-lows you to choose the most efficient solution by generating a large number of results. The concept of implementing such an approach can serve as a support for the construction of green houses and houses with zero energy consumption. This concept will help save public money on loans and subsidies through more targeted spending on energy efficiency of buildings.

Digitization and digitalization. Digitalization is a requirement of modernity, covering all areas of everyday life and development of the country. Digitalization will ensure the growth of the Ukrainian economy by 10−12 % per year. Currently, Ukraine is actively using the mobile application “Dija”, which is a new step in providing services to the public. Ukraine is the first country in the world in which digital passports in smartphones have become complete legal analogues of ordinary documents [15]. Advances in digital technology today bring the field of Internet technology to the forefront of innovation. However, digitalisation of cities is currently little used. The basis for such development can be a virtual double of the city.

Digitalization of the city can be used to solve problems with housing and communal services (housing). By analogy with the operation of the digital service “Dija”, it is possible to create software that will allow you to apply for repairs to the building and alarm. This approach will help reduce the bureaucratic part of this process. It is also possible to make more active use of smart resource accounting, which is currently gaining popularity [16]. “Smart Metering” is a software and hardware complex that allows you to automate the process of collecting and accounting for commercial and technological data on the consumption of utility resources. Currently, such complexes collect data on resource consumption and transmit it to servers for accounting. The results of such use are:

– automation of the process of collecting indicators of heat, gas and electricity consumption from commercial resource metering units;

– optimization of the process of technological and commercial accounting of re-sources, the exclusion of the human factor in working with commercial and technological data;

– reduction of costs for “bypass / detour” of metering units, reduction of losses from unaccounted resources, balance of the volume of supplied and consumed re-sources.

The introduction of digital technologies in the field of construction and architecture has

significantly simplified and accelerated the design and construction of facilities. One of the areas of use of modern information technology in the construction industry is the use of BIM-modeling. The BIM model contains the geometric and information component of the building. BIM technologies should be the basis for the creation of “Smart City”. This approach will allow you to create a model of the building and, thanks to geographic information system (GIS), integrate it all into “Smart City”. The information component of the model makes it possible to connect it with such innovations as “IoT”, “Big data”, “Digital Twins”. Such a connection is a promising and constant subject of research for scientists, business and IT professionals [17].

Given all this, it is extremely important to introduce BIM models in technical operations of construction and operation of cities. Successful implementation of this technology will have a number of benefits: reduced operating costs, increased maintenance through certification of buildings and equipment, planning maintenance and repair of equipment, reporting on performance, improving teamwork, the ability to quickly agree on new adjustments and changes. It is equally important that real estate transactions using BIM technology will improve the work of professional supervisors and reduce the likelihood of speculation in the real estate market. In addition, during the construction of new, repairs and modernization of existing buildings and structures, it is possible to choose the material and technical base, which includes a list of equipment with all the characteristics that will better form an application for repair, modernization, purchase of materials, inventory and write-off.

Accountability is one of the key principles of digitalization of cities. The functionality of such systems must be fully expressed in the digital dimension. This will help to better calculate costs, control energy consumption and change the city budget plan (increase funding for weak programs) based on all data.

Thus, it is possible to have up-to-date information on the timing of work and procurement of materials and to determine the amount of materials used to maintain public spaces. Automation of real estate transactions reduces the economic costs and working time required to perform work, as well as optimize energy consumption and energy control processes [18].

Conclusions. The “Smart City” concept in the future will be able to automate the urban environment and take the city to a new level of management. Firstly, this level of automation will help solve a number of environmental, safety and energy efficiency is-sues, as well as leading to greater comfort for “Smart City” residents. Secondly, smartisation will lead to significant savings in the city's budget and allow businesses to invest more. The process of implementing the “Smart City” concept can be greatly simplified with the help of BIM technology.

СПИСОК ВИКОРИСТАНИХ ДЖЕРЕЛ

1. Офіційне інтернет-представництво Президента України. URL : https://www.president.gov.ua/news/dlya-kozhnogo-ukrayinskogo-mista-yake-postrazhdalo-vid-rosij-73481.

2. Офіційний сайт Харківської міської ради, міського голови, виконавчого комітету. URL : https://city.kharkov.ua/uk/news/-50453.html.

3. Myung-Hee K. Study on the Case of Songdo Smart City based on the Citizen Participation Approach. *Webology*. Vol. 19 (1). 2022. Pp. 4682–4691.

4. Hadeel m.taher Secure internet of things (SIOT). *International Journal of Civil Engineering and Technology*. Vol. 9 (6). 2018. Pp. 887−893.

5. Marketsandmarkets, Digital Twin Market by Technology, Type (Product, Process, and System), Industry (Aerospace & Defense, Automotive & Transportation, Home & Commercial, Healthcare, Energy & Utilities, Oil & Gas), and Geography – Global Forecast to 2025. URL : https://www.marketresearch.com/MarketsandMarkets-v3719/Digital-Twin-Technology-Type-Product-12544627.

6. Nick I. Smart cities could lead to cost savings of $5 trillion – report suggests. *Information Age*. Vol. 3. 2017. Pp. 1–5.

7. Чайка Ю., Гутнік О. Впровадження технологій BIM-моделювання в освітній процес. *Науковий вісник будівництва*. 2021. Т. 106 (4). С. 173–179.

8. Кубраков О. Нові будинки в Україні будуватимуть за типом ізраїльських. URL : https://pobudovano.com.ua/news/novi-budinki-v-ukraini-pislya-viyni-proektuvatimut-za-tipom-izrailskikh.
9. Настич І. Відбудова українських міст: починати роботу потрібно вже зараз. URL : https://propertytimes.com.ua/urban/vidbudova_ukrayinskih_mist_pochinati_robotu_potribno_vzhe_zaraz?fbclid=IwAR1T1RjL5Cn1o_NGb3ZQTfQ507Zf_TQZru_mD-_6iMgF8F9OdMIb3Q2nY5g.
10. Gruvberger C., Henrik A., Andersson B. Sustainability concept for a newly built urban area in Malmo, Sweden. *Water Science & Technology.* 2003. № 47 (7−8). Pp. 33–39.
11. De-Graft Owusu-Manu, Prosper B., Ernest K. Green construction and environmental per-formance: an assessment framework. *Smart and Sustainable Built Environment*. 2022.
12. Coates G. The sustainable Urban district of vauban in Freiburg, Germany. *International Journal of Design & Nature and Ecodynamics.* № 8 (4). 2013. Pp. 265–286.
13. UN: 68 % of the world's population projected to live in urban areas by 2050, URL : https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-pro-spects.html?fbclid=IwAR0S9zvWO1vSVwu6fy5_bZvXIjX1Ebc_HYADo3KTGogoM5BgtGFEpqOadpU.
14. Матвєєва О. В., Мироненко О. В. Сучасні проблеми мегаполісів та житлових кварталів. Методи реновації в умовах щільної забудови. *Науковий вісник будівництва.* 2019. Т. 98 (4). С. 127–132.
15. Федоров М. Цифровізація забезпечить зростання української економіки на 10−12 % на рік. URL : https://www.kmu.gov.ua/news/mihajlo-fedorov-cifrovizaciya-zabezpechit-zrostannya-ukrayinskoyi-ekonomiki-na-10-12-na-rik.
16. Fei Tao, Qinglin Qi. Make more digital twins. Nature. Vol. 573 (7775). 2019. Pp. 490–491.
17. Афанасьєв Д., Блонський О. Концепція впровадження BIM – Будівельного Інформаційного Моделювання в Україні. Київ : Видавничий дім «Професіонал», 2020.
18. Чайка Ю., Гутнік О. Smart city. *Науковий вісник будівництва.* 2020. Т. 100 (2). С. 269–274.

REFERENCES

1. *Ofitsiine internet-predstavnytstvo Prezydenta Ukrainy* [Official online representation of the President of Ukraine]. URL : https://www.president.gov.ua/news/dlya-kozhnogo-ukrayinskogo-mista-yake-postrazhdalo-vid-rosij-73481. (in Ukrainian).
2. *Ofitsiinyi sait Kharkivskoi miskoi rady, miskoho holovy, vykonavchoho komitetu* [Official website of Kharkiv City Council, Mayor, Executive Committee]. URL : https://city.kharkov.ua/uk/news/-50453.html. (in Ukrainian).
3. Myung-Hee K. Study on the Case of Songdo Smart City based on the Citizen Participation Approach. Webology. Vol. 19 (1), 2022, pp. 4682–4691.
4. Hadeel m.taher Secure internet of things (SIOT). International Journal of Civil Engineering and Technology. Vol. 9 (6), 2018, pp. 887–893.
5. Marketsandmarkets, Digital Twin Market by Technology, Type (Product, Process, and System), Industry (Aerospace & Defense, Automotive & Transportation, Home & Commercial, Healthcare, Energy & Utilities, Oil & Gas), and Geography – Global Forecast to 2025. URL : https://www.marketresearch.com/MarketsandMarkets-v3719/Digital-Twin-Technology-Type-Product-12544627.
6. Nick I. Smart cities could lead to cost savings of $5 trillion – report suggests. Information Age. Vol. 3, 2017, pp. 1−5.
7. Chaika Yu. and Hutnik O. *Vprovadzhennia tekhnolohii BIM-modeliuvannia v osvitnii protses* [Implementation of BIM modeling technologies in the educational process]. *Naukovyi visnyk budivnytstva* [Scientific Bulletin of Construction]. Vol. 106 (4), 2021, pp. 173–179. (in Ukrainian).
8. Kubrakov O. *Novi budynky v Ukraini buduvatymut za typom izrailskykh* [New houses in Ukraine will be built according to the Israeli type]. URL : https://pobudovano.com.ua/news/novi-budinki-v-ukraini-pislya-viyni-proektuvatimut-za-tipom-izrailskikh. (in Ukrainian).
9. Nastych I. *Vidbudova ukrainskykh mist: pochynaty robotu potribno vzhe zaraz* [Reconstruction of Ukrainian cities: work must begin now]. URL : https://propertytimes.com.ua/urban/ vidbudova_ukrayinskih_mist_ pochinati_ robotu_potribno_vzhe_zaraz?fbclid=IwAR1T1RjL5Cn1o_NGb3ZQTfQ507Zf_TQZru_mD-_6iMgF8F9OdMIb3Q2nY5g. (in Ukrainian).
10. Gruvberger C., Henrik A. and Andersson B. Sustainability concept for a newly built urban area in Malmo, Sweden. Water Science & Technology. Vol. 47 (7−8), 2003, pp. 33–39.
11. De-Graft Owusu-Manu, Prosper B. and Ernest K. Green construction and environmental per-formance: an assessment framework. Smart and Sustainable Built Environment. 2022.
12. Coates G. The sustainable Urban district of vauban in Freiburg, Germany. International Journal of Design & Nature and Ecodynamics. Vol. 8 (4), 2013, pp. 265–286.
13. UN: 68 % of the world's population projected to live in urban areas by 2050, URL : https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-pro-spects.html?fbclid=IwAR0S9zvWO1vSVwu6fy5_bZvXIjX1Ebc_HYADo3KTGogoM5BgtGFEpqOadpU.

14. Matvieieva O.V. and Myronenko O.V. *Suchasni problemy mehapolisiv ta zhytlovykh kvartaliv. Metody renovatsii v umovakh shchilnoi zabudovy* [Modern problems of megacities and residential districts. Methods of renovation in conditions of dense construction]. *Naukovyi visnyk budivnytstva* [Scientific Bulletin of Construction]. Vol. 98 (4), 2019, pp. 127–132. (in Ukrainian).

15. Fedorov M. Tsyfrovizatsiia zabezpechyt zrostannia ukrainskoi ekonomiky na 10−12 % na rik [Digitization will ensure the growth of the Ukrainian economy by 10−12 % per year]. URL : https://www.kmu.gov.ua/news/mihajlo-fedorov-cifrovizaciya-zabezpechit-zrostannya-ukrayinskoyi-ekonomiki-na-10-12-na-rik. (in Ukrainian)

16. Fei Tao and Qinglin Qi. Make more digital twins. Nature. Vol. 573 (7775), 2019, pp. 490–491.

17. Afanasiev D. and Blonskyi O. *Kontseptsiia vprovadzhennia BIM – Budivelnoho Informatsiinoho Modeliuvannia v Ukraini* [The concept of implementing BIM − Building Information Modeling in Ukraine]. Kyiv : Vydavnychyi Dim “Profesional”, 2020. (in Ukrainian).

18. Chaika Yu. and Hutnik O. Smart city. *Naukovyi visnyk budivnytstva* [Scientific Bulletin of Construction]. Vol. 100 (2), 2020, pp. 269–274.

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