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## MODERN TRENDS IN THE DIGITALIZATION OF PROCESSES AT CONSTRUCTION ENTERPRISES

*А. Чумаченко, О. Корся, А. Конон, П. Шилов, Д. Шилов. Сучасні тенденції цифровізації процесів на будівельних підприємствах.* У статті досліджено сучасні тенденції цифровізації процесів на будівельних підприємствах України, які потребують оцінки в контексті післявоєнного відновлення країни. Розглянуто ступінь інтеграції цифрових технологій у різноманітні етапи життєвого циклу будівельного об'єкту та їх вплив на ефективність діяльності будівельних компаній. Проаналізовано актуальне фінансово-економічне положення підприємств будівельного сектору, що визначено як кваліфікуючий фактор, який гальмує інноваційно-інвестиційне оновлення діяльності суб'єктів галузі. Запропоновано розглядати використання SWOT-аналізу цифровізації процесів на будівельних підприємствах як інструментарій вивчення комплексу факторів, що задають вектор становлення сектору, що створює передумови для переходу учасників будівельного бізнесу до цифрових стандартів та актуалізує його як релевантне доповнення до діалогу про цифрові перспективи будівельного бізнесу. Проведення ґрунтовного дослідження сильних та слабких сторін, переваг та недоліків процесів цифровізації проектування на будівельних підприємствах, дозволяє надати об'єктивну оцінку готовності менеджменту будівельних компаній застосувати сучасний інструментарій задля удосконалення комплексу бізнес-процесів. Наголошено на необхідності реформування підходів до управління бізнес-процесами на будівельних підприємствах на засадах цифровізації, яка є одним з ключових чинників забезпечення стійкого розвитку та конкурентоспроможності будівельних компаній. Деталізовано використання цифрових технологій у відповідності до специфічного напрямку діяльності будівельної компанії. Робота підкреслює важливість підтримки цифрових змін для економічного відродження країни та конкурентоспроможності будівельних підприємств в умовах Індустрії 4.0.

*Ключові слова:* будівельні підприємства, діджиталізація, економічна система, Індустрія 4.0, інноваційні трансформації, повоєнне відновлення, цифрові технології

*A. Chumachenko, O. Korsia, A. Konon, P. Shylov, D. Shylov. Modern trends in the digitalization of processes at construction enterprises.* The article explores the current trends in the digitalization of processes at construction enterprises in Ukraine, which require assessment in the context of the country's post-war recovery. The degree of integration of digital technologies into various stages of the construction project life cycle is examined. The current financial and economic position of enterprises in the construction sector is analysed and it is identified as a qualifying factor that influences on the innovative and investment renewal of the sector's activities. The use of digitalization as a benchmark for evaluating developers is proposed, which will contribute to increasing the transparency and reliability of their financial and economic activities. The SWOT analysis of the digitalization processes in construction enterprises is suggested as a study of a complex set of factors that set the vector for the sector's development, creating the preconditions for the transition of construction business participants to digital standards and establishing it as a relevant addition to the dialogue about the digital prospects of the construction sector. Conducting a thorough analysis of the strengths and weaknesses, advantages, and disadvantages of digitalization processes in design at construction enterprises provides an objective assessment of construction company management's readiness to use modern tools to improve a range of business processes. The need for reforming business process management approaches at construction enterprises on the basis of digitalization is emphasized, as it is one of the key factors for ensuring the sustainable development of construction companies. The work highlights the importance of supporting digital changes for the economic revival of the country and the competitiveness of construction enterprises in the context of Industry 4.0.

*Keywords:* construction enterprises, digitalisation, economic system, Industry 4.0, innovative transformations, post-war recovery, digital technologies

### 1. Introduction

The study of the specifics and degree of integration of digital technologies into the economic activities of construction enterprises in Ukraine is of particular importance in the context of the need to address the task of post-war reconstruction of Ukraine. The current state and vector of implementation of innovative changes in the activities of construction industry entities determines the qualitative aspect of the implementation of works on restoration of infrastructure and housing affected by Russian aggression. The introduction of innovative changes and the degree of digitalisation of activities can serve as an assessment element for selecting the most innovative construction industry entities that will be able to implement plans to rebuild infrastructure facilities and destroyed and damaged housing. The introduction of an assessment of developers will serve as the basis for their rating according to the criterion of information transparency and reliability of financial and economic activities, since digitali-

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sation primarily involves changing the format of data storage and maximising the digitalisation of various business processes. Thus, it is fair to say that the creation of a high-quality new information-transparent market for construction works and services is a qualifying factor for the national economic recovery. Since the construction industry is one of the key drivers of the national economic system, the presented vector of changes deserves a positive assessment in the context of the development of Industry 4.0. Therefore, the study of the peculiarities of the use of digital technologies in construction enterprises of Ukraine is necessary to identify the depth and readiness of the construction industry entities for innovative changes and adaptation of the best world practices.

## **2. Analysis of literature data and problem statement**

The topic of improving the competitiveness of construction industry entities in the light of digital changes is covered in a wide range of works by both domestic and foreign scholars. At the same time, the aspects related to determining the set of organisational, technical and economic conditions for the digitalisation of processes at construction enterprises to ensure the sustainable development of the industry need to be deepened. In order to clarify the vectors of research on the prerequisites for the digitalisation of processes in construction enterprises, a number of literature sources were analysed. The issue of economic security of a construction enterprise is considered as a key factor in its competitiveness in the face of current challenges in [1, 2]. A practically oriented study of the factors is provided in [3], which answers the question of digital maturity in certain categories of construction sector entities. The current conditions of operating activities in the construction sector are disclosed in [4], which allows taking into account the current features of construction markets and business entities.

In order to detail the environmental conditions that determine the speed and quality of changes in the construction industry, studies [5, 6, 7] were analysed, which gave the authors the impetus to develop a comprehensive vision of the SWOT analysis of the processes of digitalisation of design at construction enterprises in the presented scientific article.

The specifics of the transformation of the national economic system on the basis of digitalisation, considered in [8], allowed to identify the key characteristics of the modernisation of the construction industry with the use of information and communication technologies. The basis for improving the categorisation of the use of digital technologies in construction was the literature [9 – 14], which allowed us to study current trends and prospects for the development of digitalisation of the construction industry. The information support of digitalisation processes in the construction industry is described in publications [15, 16], which gives an idea of the software that is integrated into the operational activities of enterprises. It should be noted that the presented study stands out by considering digitalisation not just as a trend, but as a critical factor for the successful restoration of infrastructure and housing destroyed by Russian aggression.

The scientific community is also interested in current methodological approaches to assessing the digitalisation of construction industry enterprises, however, a thorough review of the available literature [17, 18, 19] has indicated the need to develop a new approach using the study of the integration of digitalisation into the activities of developers, which will help to increase the transparency and reliability of financial and economic activities in the industry. After all, the deepening of digitalisation trends implies the need to develop the concept of transparency of a construction company [20], as one of the components of the national process of digitalisation of the economy and society within the framework of creating a single digital space [21].

Taking into account the impact of digital technologies on the economic efficiency of construction projects in the context of Industry 4.0 adds depth and relevance to the analysis. Thus, this study not only forms a new approach to the valuation of construction companies, but also emphasises the importance of digital changes for the country's economic revival. Thus, the uniqueness of the analysis lies in its focus on the specifics and degree of integration of digital technologies in Ukrainian construction companies, particularly in the context of post-war recovery.

## **3. Purpose and objectives of the study**

The purpose of the article is to determine the degree of integration and efficiency of digital technologies in the activities of construction enterprises in Ukraine, with a focus on their critical role in the post-war recovery of the country, which is considered as a criterion for assessing the industry's readiness for innovative transformations.

To achieve this goal, the following set of tasks needs to be addressed:

- to analyse the state of the construction sector of Ukraine under martial law, in particular, to clarify the qualifying factors of influence on the development of the industry;
- to conduct a SWOT analysis of the digitalisation of design processes in construction companies, which will allow assessing the strengths, weaknesses, opportunities and threats to the development of the construction sector;
- categorise the use of digital technologies in construction according to the specific area of activity of the construction company and identify key digital technologies for each stage of the construction cycle, including design, construction, asset management and completion.

#### **4. Materials and methods of research**

The experimental component of the study consisted of a practical investigation of the level of readiness of construction enterprises to implement digital technologies through a combination of empirical methods. This included:

1. Conducting a SWOT analysis as an initial step to determine the overall state of digitalisation of the construction industry, which allows assessing the strengths, weaknesses, opportunities and threats to the introduction of digital technologies in the construction industry.
2. An empirical study of the implementation of pilot digital technologies (e.g., BIM, drones, or Blockchain systems) in specific construction projects with further evaluation of their effectiveness.
3. Identification of key barriers and development of practical recommendations supported by the results of pilot tests.

The methodological component of the study was based on a comprehensive approach to analysing digitalisation in the construction industry, including methods such as analysing data from the State Statistics Service of Ukraine, assessing the economic impact of digitalisation, and categorising innovative tools for different stages of the construction cycle. The use of modern approaches to analysing digitalisation tools, such as Blockchain, drones, augmented reality, BIM and Digital Twins, has allowed us to develop new approaches to managing construction projects in the context of Ukraine's post-war recovery.

#### **5. Current trends in the digitalisation of processes at construction companies**

##### **5.1 Analysis of financial results of construction companies**

Conducting a SWOT analysis of the processes of digitalisation of design at construction enterprises (Table 1) should become the main direction for management, creating for its information and analytical support for managing the current challenges of the economic environment under martial law. After all, in an environment where the digitalisation process is key to ensuring the sustainable development and competitiveness of construction companies, it is critical to assess the readiness of management to apply modern tools to improve the complex of business processes.

Thus, the SWOT analysis of the digitalisation of design processes at construction companies can be viewed as a study of a set of factors that set the vector for the sector's development and create the preconditions for the transition of construction business participants to digital standards, which makes it a relevant addition to the dialogue on the digital prospects of the construction sector.

##### **5.2 Categorisation of the use of digital technologies in accordance with the specific area of activity of the construction company**

When analysing the potential opportunities and benefits of implementing digitalisation processes at construction companies, attention should be focused on the expected economic effect on the financial and economic activities of construction industry entities, which can be measured in four areas, according to Deloitte experts:

- “design, financing and procurement work”: a 10...30% reduction in the working hours of the relevant staff of the construction company;
- “construction works”: a 5...10% reduction in the estimate for construction works;
- “asset management activities”: reduction of operating expenses in the range of 10...20%;
- “decommissioning / dismantling/demolition”: 5...10% reduction in the period of decommissioning [11].

To detail the use of digital technologies in accordance with the specific area of activity of a construction company, see Figure 1.

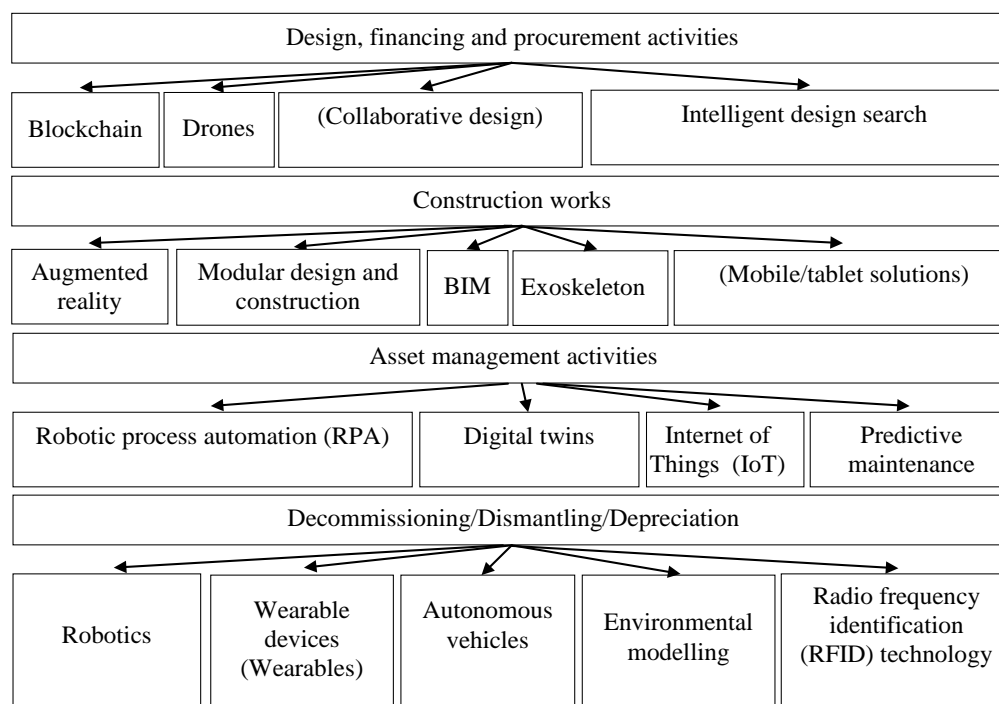
**Table 1**

SWOT analysis of design digitalisation processes at construction companies

Strengths	Weaknesses
<ul style="list-style-type: none"> <li>– the ability to apply the latest design methods and tools;</li> <li>– spreading the trend of digital culture;</li> <li>– government initiatives are focused on creating a favourable environment for the digitalisation of construction companies;</li> <li>– significant production and intellectual potential for investment and innovation development of construction companies based on digitalisation;</li> <li>– improving the accuracy of data and information processing;</li> <li>– expanding opportunities for cooperation in international projects, attracting new clients and partners;</li> <li>– competitiveness of construction works and services of Ukrainian companies.</li> </ul>	<ul style="list-style-type: none"> <li>– lack of qualifications and necessary competencies for the construction company's staff to operate in the digital space;</li> <li>– lack of financial resources to implement digitalisation mechanisms in the operations of construction companies;</li> <li>– resistance to innovation is an urgent problem for construction companies;</li> <li>– limited compatibility between different software platforms;</li> <li>– the need for additional investment in training and retraining of employees;</li> <li>– lack of adequate digital infrastructure to implement innovative solutions;</li> <li>– the lack of a system of standards for digitalising processes can make it difficult to implement them and control the quality of design processes.</li> </ul>
Features.	Threats
<ul style="list-style-type: none"> <li>– reduced project preparation time, increased efficiency of planning and resource management;</li> <li>– reducing the cost part of the construction project estimate;</li> <li>– reducing the number of defects during construction work;</li> <li>– optimisation of the logistics supply chain for materials;</li> <li>– Improving accounting support and monitoring resource provision;</li> <li>– support for the expansion of related industries and the economic system as a whole;</li> <li>– growing demand for construction products and services in the context of post-war recovery in Ukraine's regions;</li> <li>– the use of green energy sources, which helps to reduce the harmful impact on the environment;</li> <li>– increased social responsibility in the construction segment;</li> <li>– coordinated communication between all project stakeholders, which ensures an appropriate level of transparency and prompt access to information.</li> </ul>	<ul style="list-style-type: none"> <li>– imperfect digital and cyber security at construction companies, threats of cyber-attacks and privacy violations;</li> <li>– poor information security and the risk of losing confidential data in the event of a breach of security protocols;</li> <li>– lack of funds to continuously support innovative updates in the context of the digitalisation of construction companies;</li> <li>– migration of qualified personnel under martial law;</li> <li>– the likelihood of new regulatory restrictions being imposed by the government;</li> <li>– dependence on external providers to implement digital solutions in financial and business activities;</li> <li>– the threat of losing production capacity as a result of security risks under martial law;</li> <li>– the risk of blackouts and stabilisation power outages, and poor-quality internet connections;</li> <li>– financial instability in the economic system, recession risks, imperfect and volatile regulatory framework.</li> </ul>

At the first stage of the construction cycle, which includes design, financing and procurement, the following digital technologies are the most widely used: Blockchain, drones, collaborative design, and intelligent design search.

**Blockchain** is a secure digital information register that is similar to a database, which is accessible to all participants in the construction process. Blockchain solves the problem of ensuring information transparency of operations during the construction process, auditing and monitoring in real time. However, companies mostly avoid implementing blockchain technologies due to the high cost of integration into financial and business activities and problems with compatibility with existing infrastructure. In addition, many market participants were waiting for confirmation of blockchain's greater efficiency in maximising profits compared to existing technological mechanisms, which hindered its inclusion in the activities of construction companies. Analysing global best practices, we can conclude that a growing number of construction industry participants prefer to implement digital technologies to optimise design and construction processes.



**Fig. 1.** Categorisation of the use of digital technologies in construction

The use of drones makes it possible to improve the inspection, verification and topographic survey of a construction site. Improving the remote work of the project team using augmented reality devices, which qualitatively updates the standards of geoinformation accuracy in the construction industry. One of the key obstacles to the introduction of drones into the activities of a construction company is the lack of unified rules and basic principles to ensure the reliable use of these UAVs [23]. Thus, to ensure the widespread use of this toolkit, a number of regulatory, economic and organisational issues should be addressed, as well as appropriate analysis to adapt innovations to existing design and construction algorithms.

Collaborative design **technology** in the construction industry is driving progress in 3/4/5D modelling and visualisation based on data from cloud platforms, enabling several employees to work together on a project simultaneously using VR/AR tools. In addition to financial, organisational and technical aspects, as well as the issue of data storage reliability, as the main problems of using this form of digitalisation of construction processes, it is necessary to emphasise the need to implement appropriate tools for project management and communication, overcoming conflicts, because collaborative design requires effective coordination between different teams and project participants.

Intelligent design search is based on the processing of a significant amount of data from past projects to generate analytical conclusions and make the most optimal design decisions. The main problem of integration into companies' operations is the low level of staff training and insufficient infrastructure to support the functioning of a complex intelligent system. In this regard, the issue of acquiring and continuously updating skills, knowledge and competencies by employees of construction companies in the context of the trend of active spread of digital technologies in the world is becoming more relevant [13].

When considering the digitalisation of the building construction process, it is fair to identify building information modelling (BIM) as the cornerstone of digital innovation in the construction industry. BIM is an approach to the digital design of buildings and infrastructure facilities that includes all their components and properties, enabling better planning, design and management. BIM ensures the design of a construction project as an integrated system, where a change in one of the parameters automatically adjusts other related elements and characteristics. At the state level, the Concept for the Implementation of Building Information Modelling (BIM) Technologies in Ukraine, as well as a phased action plan for its implementation during 2021 – 2025, was adopted, which is aimed at further reforming, modernising and digitising the construction industry in Ukraine [24]. The main advantages of implementing this technology in the activities of construction companies are to reduce risks, shorten

construction time, reduce costs, improve quality and reduce negative environmental impact, which together have a positive effect on the economic performance of construction projects [13]. Thus, BIM can be defined as a comprehensive method of construction project management, which makes it a qualifying factor for the profitability of the construction industry. According to analysts, more than half of construction companies in developed economies have introduced the use of BIM technology, which is mainly due to the regulatory requirements of the operating environment. In Ukraine, the use of BIM technologies is currently limited to large market players.

Innovative technological solutions such as augmented and virtual reality, modular design and construction, exoskeleton, mobile/tablet solutions, 3D printing, etc. are also widespread at the construction stage. The main advantage of these digital technologies is an increase in the quality and speed of construction work, minimisation of errors and the impact of the human factor, as part of the construction process is automated and the degree of danger to builders is reduced.

The third stage of a construction company's asset management activities uses a number of technological tools such as Robotic Process Automation (RPA), Digital Twins, Internet of Things (IoT), and Predictive Maintenance.

**Robotic process automation (RPA)** provides the greatest benefit to a construction company when dealing with cyclical, labour-intensive, regulatory business processes. This software allows companies to spend less time on administrative processes and focus on tasks that add economic value.

**Digital twins** are a widespread digital technology used in various sectors of the economic system, except for construction, such as logistics, forestry, etc. In the construction industry, this technology involves the creation of an identical electronic copy of a construction object, which is formed using 3D visualisation, analytical capabilities and sensors that transmit information in real time. Digital Twins can also be used to design new construction projects. Among the benefits of using Digital Twins are effective management of the facility's life cycle, an improved form of operational control, timely forecasting of breakdowns or malfunctions, and access to up-to-date data from all team members. Thus, Digital Twins is used in conjunction with the Internet of Things (IoT) tools, which allows monitoring various indicators of the construction facility's assessment and troubleshooting if necessary. The disadvantage of using the presented digital technologies is the need to minimise potential cyber risks and eliminate the possibility of data leakage.

The final digital technology at this stage is predictive maintenance, which has certain bottlenecks, namely unpredictability and complexity of forecasting in unique conditions and the risk of underestimating or overestimating breakdowns. In construction practice, there are cases that are difficult to assess using typical predictive maintenance methods, as the specifics of each object can affect the accuracy of the forecast. Also, if the system generates incorrect positive results, it can cause unnecessary maintenance costs. In the case of incorrect negative predictions, when an existing fault is not diagnosed in a timely manner, significant delays or dangerous accidents can occur.

The Decommissioning / Demolition / Demolition stage of a construction company's operations covers a wide range of digital technologies: Robotics, Wearables, Autonomous vehicles, Environmental modelling, Radio Frequency Identification (RFID) technology.

The use of robotics significantly minimises risks at a construction site. For example, according to [25], the forms of robotics that are not widely used in Ukrainian practice include sensors and digital components of RTC for human-machine interaction, technologies of sensorimotor coordination and spatial positioning, sensors and processing of sensory information. The main reasons that hinder their development are the need to create a regulatory framework for their regulation, the use of other technological approaches, including the development of innovative materials.

**Wearable devices** have a multifunctional use both in tracking workers involved in remote locations and in assessing the parameters of the external environmental conditions of a construction site (radiation, concentration of toxic gases).

**Autonomous vehicles** are based on the use of sensors and software solutions that allow for unattended transport. Combined with innovations in battery technology, the construction site can be transformed into a safer and greener space with less need for employees.

Environmental **modelling** involves predicting environmental restoration after decommissioning of engineering facilities, which allows for an assessment of environmental risks using GIS (Geographical Information Systems). The international community considers this technology as an element of Green BIM, which combines the principles of sustainable construction with building information

modelling technologies [26]. Since the Concept of Implementation of Building Information Modelling Technologies (BIM technologies) in Ukraine is still at the initial stage of integration, the transition to Green BIM is a delayed step.

**Radio Frequency Identification (RFID) technology** is used to identify the position and track the movement of objects on construction sites using a radio **frequency** signal. RFID has not become widespread in Ukraine, unlike in developed economies, due to a lack of funding, slow digitalisation of the construction industry, and insufficient awareness of the construction sector. However, with the development of technological solutions and increased requirements for accuracy in construction works, interest in the use of RFID will gradually gain momentum in Ukrainian practice.

## 6. Analysis of research results

The study focuses on digitalisation as a critical factor for the effective restoration of infrastructure and housing damaged as a result of military aggression. The peculiarity of the presented approach is the proposal to use the level of digitalisation as an indicator for assessing the construction sector entities, which will help to increase the transparency and efficiency of financial and economic activities in the construction industry. The analysis also takes into account the impact of digital technologies on the economic performance of construction projects in the context of the Industry 4.0 concept, which adds both theoretical and practical value to the study. In summary, the analysis presented here forms an innovative approach to the valuation of construction companies and emphasises the key role of digital transformation for the country's economic recovery, especially in the post-war period.

## Conclusions

The digitalisation of the construction industry is a key factor in Ukraine's post-war reconstruction, as the introduction of innovative technologies helps to improve the efficiency of construction processes. The degree of integration of digital technologies in the construction industry in Ukraine remains at an average level due to a significant number of barriers, but the industry has a high potential for digital transformation.

1. The analysis of the financial results of construction companies illustrates that the Ukrainian construction sector has faced significant financial and economic difficulties caused by a decline in consumer demand and the impact of martial law, which limits the ability of entities to digitise business processes. The share of unprofitable companies in the construction sector exceeds the market average for the financial system as a whole, indicating structural problems in the industry. The main factors behind unprofitability are logistical difficulties, the decline in the production of construction materials, the destruction of infrastructure due to military operations, and rising transport costs.

2. The SWOT analysis of the digitalisation of design processes at construction companies can be interpreted as a study of the set of factors that shape the vector of industry development, creating the preconditions for the transition of construction companies to digital standards, which makes it an important addition to the discussion of the digital future of the construction industry. The use of technologies such as Blockchain, augmented reality, intelligent search for design solutions and others contributes to the growth of the quality and speed of construction work, minimising the impact of the human factor. The key barriers to innovation include a lack of financial resources, gaps in the regulatory framework, insufficient staff training, limited compatibility with existing infrastructure, and the need to increase the level of digital literacy in the construction industry. Based on the above, the successful digitalisation of the construction industry requires active support from the state and companies to ensure the sustainable development and competitiveness of Ukrainian construction companies. The effectiveness of digitalisation will depend on overcoming obstacles of a financial, organisational and technical nature.

3. Digital technologies such as Blockchain, drones, collaborative design systems, BIM (Building Information Modeling) and RFID (Radio-Frequency Identification) are important tools for optimising construction processes and improving resource management. The use of these technologies allows for transparency of operations, cost reduction, improved quality of work and shorter project delivery times. However, their integration into the construction industry of Ukraine is accompanied by a number of challenges, including high implementation costs, insufficient digital infrastructure, lack of qualified personnel and gaps in the regulatory framework.

To overcome these limitations, it is necessary to focus on creating favourable conditions for the development of digitalisation, including stimulating investment in digital infrastructure, training personnel with relevant competencies, and adapting regulatory frameworks to the requirements of the

modern technological environment. The use of digital technologies in the context of the digital transformation of the construction industry is a key factor in ensuring its competitiveness and sustainable development, which is of particular importance in the context of Ukraine's economic recovery.

Although Ukrainian construction companies are lagging behind global trends in the implementation of digital solutions, interest in technologies such as BIM, drones and RFID is gradually growing.

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