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## **Optimising the construction process through digitalisation: Case studies of projects under unstable resource supply**

**Abstract.** This study aimed to investigate the impact of digital technologies on the optimisation of the construction process under conditions of unstable resource supply and to formulate practical recommendations for their effective implementation. The research methodology included an analysis of current trends in the field of digital solutions, including Building Information Modelling, Internet of Things technologies, artificial intelligence, digital twins, and cloud platforms. The possibilities of integrating these technologies to improve the planning, construction, and operation of facilities were considered, as well as their impact on increasing the efficiency of resource management. An analysis of real-world case studies was conducted, including the implementation of Building Information Modelling in the ASTON HALL project by the company DEHAUSS, which confirmed the significant potential of digital technologies. The Crossrail project

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was also considered, where BIM technologies ensured effective coordination between contractors, as well as digital twins in Singapore, which are used for the management of urban resources. The research showed that Building Information Modelling contributes to reducing errors in design and construction, improving coordination between project participants, and lowering costs. Internet of Things technologies provide real-time monitoring of the condition of building materials and equipment, which increases the level of safety and reduces the risks of downtime. The use of artificial intelligence enables the prediction of potential delays, the optimisation of logistics, and the automation of management processes. Digital twins allow for the testing of different construction process scenarios, which positively impacts the quality of the final outcome. The main challenges of construction digitalisation remain the high cost of technology implementation, the need for staff training, the difficulties of integrating software platforms, and cybersecurity issues. At the same time, the advantages, such as process automation, increased accuracy of load and energy efficiency calculations, optimisation of resource supply, and improved control over construction projects, confirm the strategic importance of digital solutions in the development of the construction industry. The results of the research demonstrated that a comprehensive approach to the implementation of digital technologies, the adaptation of construction processes, and the effective integration of digital platforms can significantly increase the productivity of construction projects, especially under conditions of unstable resource supply

**Keywords:** blockchain; building information modelling; geoinformation technologies; cloud computing; remote sensing

## INTRODUCTION

In the 21<sup>st</sup> century, the construction industry faces several challenges, including unstable resource supply, complex logistics for material delivery, the impact of external factors (economic, environmental, political), and the need to increase the efficiency of construction processes. Traditional approaches to construction management can no longer fully ensure process optimisation and loss reduction, which necessitates the implementation of innovative technologies. One of the key solutions for increasing construction efficiency is digitalisation, which allows for the optimisation of processes at all stages of project implementation. Digital technologies, such as Building Information Modelling (BIM), Artificial Intelligence (AI), Internet of Things (IoT), and cloud computing, enable effective resource planning, cost forecasting, and risk minimisation (Shults & Annenkov, 2023). The use of these technologies is particularly relevant in conditions of unstable resource supply, where it is necessary to quickly adapt construction processes to changes in material supply, price fluctuations, and logistical constraints. The relevance of the research topic is driven by the increasing challenges in the construction sector related to the instability of material supplies, the rising cost of resources, and the need to ensure the resilience of construction processes. The implementation of digital solutions can significantly improve resource management, shorten construction times, and enhance the quality of work execution.

The development of digitalisation in the construction sector is actively being researched by academics. Analysis of academic studies allows for the identification of the main approaches and prospects for using digital technologies to optimise the construction process under conditions of unstable resource supply. For example, T. Goncharenko (2021) investigated how BIM affects resource management and the planning of construction projects. He noted that the implementation of BIM is capable of reducing material waste and improving the efficiency of building

resource supply. V. Shcheglov & O. Morozova (2022) analysed the use of IoT technologies for real-time monitoring of the condition of building materials, which is critically important under conditions of unstable supply. In their study, A. Kuzior *et al.* (2023) considered the role of AI in improving management decisions and optimising innovative processes. The authors emphasised that the application of artificial intelligence contributes to accelerating the development of new solutions, increasing the efficiency of collaboration between participants in innovative ecosystems, and reducing risks at the implementation stage. R. Krishnan *et al.* (2024) noted that intelligent algorithms of artificial intelligence help to improve logistics processes and enhance coordination in supply management.

In turn, W. Li *et al.* (2021) emphasised the role of cloud computing in ensuring flexible management of construction processes. They noted that the implementation of cloud platforms allows for the centralised management of resources and the integration of data from various sources, which is critically important in unstable supply conditions. The study by S.N. Pargoo & M. Ilbeigi (2022) focused on cybersecurity issues in the digitalisation of the construction sector, pointing out the risks of data leaks and potential attacks on automated management systems. They proposed the use of blockchain technologies to increase the security of data and transactions in construction management. In their research, K. Lavrukina *et al.* (2024) argued that the challenges of globalisation contribute to the accelerated development of innovative and information processes, which positively impact the competitiveness of the construction industry. S.V. Mhaskey (2024) pointed out the importance of integrating automated management systems with enterprise resource planning (ERP) systems for the effective allocation of resources and the monitoring of supply. He emphasised that digital solutions can reduce logistics and procurement costs. The study by N.H. Pan & N.N. Isnaeni (2024) considered the application of augmented reality



(AR) in construction, which allows engineers and project managers to make more accurate decisions regarding the use of materials and the optimisation of work processes. J.M.D. Delgado *et al.* (2019) focused on the use of autonomous robotic systems in construction, which can reduce dependence on the human factor and ensure the continuity of work even in difficult resource supply conditions.

Despite significant progress in the digitalisation of construction processes, several important aspects remain insufficiently studied. In particular, most research focuses on the implementation of individual technologies (BIM, IoT, AI), but comprehensive models for the integration of digital solutions under conditions of unstable resource supply are rarely considered. Furthermore, insufficient attention is paid to the analysis of the effectiveness of digitalisation in real-world projects, especially in the context of adaptive resource management and risk forecasting. The question of the economic feasibility and potential return on investment of digital technologies in the construction sector also requires further study. Considering these aspects, this study aimed to evaluate the effectiveness of the digitalisation of the construction process under conditions of unstable resource supply and to develop recommendations for optimising the use of digital technologies to enhance the flexibility and resilience of resource management. To achieve this aim, it was necessary to analyse existing digital technologies and their impact on the optimisation of the construction process and to investigate adaptive models of resource management based on digital solutions.

## MATERIALS AND METHODS

The research methodology was based on a comprehensive analysis of academic sources, specifically works focusing on the implementation of BIM in residential building projects, the use of digital twins in urban planning, and the application of virtual reality (VR) technologies to optimise costs in construction. Particular attention was paid to the case study of BIM implementation in the ASTON HALL residential complex project by the company DEHAUSS. This example was chosen due to its relevance to the Ukrainian context, the public availability of information, the presence of a digital strategy, and its execution in conditions of unstable resource supply, which allows for tracking the effectiveness of digitalisation in a real-world setting. The case study of BIM usage in the large-scale infrastructure project Crossrail in Great Britain was also analysed, where digital models significantly reduced errors, optimised change management, and accelerated implementation (BIM and GIS integration..., n.d.; Walker, 2023). Another important example was Singapore's practice of implementing digital twins for urban infrastructure management, demonstrating the effectiveness of digitalisation at the national planning level. A comparison of regulatory approaches in different countries, particularly Great Britain and Singapore, allowed for the identification of best practices, the assessment of the degree of regulatory readiness for digitalisation, and the determination of areas for improving national regulation.

The research encompassed an analysis of the functionalities of BIM 360, Revit, ArchiCAD, and Tekla Structures software, as well as energy efficiency calculation tools such as DesignBuilder and EnergyPlus. Particular attention was paid to a comparative analysis of digital technologies: BIM, IoT, AI, AR/VR, GIS, blockchain, cloud platforms, and automated control systems. Their application in the processes of design, logistics, energy management, monitoring, and cost control was considered. To assess the effectiveness of digital solutions, comparative analysis and case study analysis were used. This allowed for the comparison of different technologies based on criteria such as the reduction of design and implementation time, the decrease in the number of errors, the saving of financial and material resources, the improvement of calculation accuracy, as well as the enhancement of energy efficiency and the overall manageability of construction processes.

The focus was on evaluating the challenges and prospects for the development of digital technologies in construction. Key barriers were identified, such as the high cost of implementation, the need to adapt the regulatory framework, the complexity of integrating digital solutions with traditional construction methods, and the insufficient level of digital competence among specialists. Possible ways to overcome these barriers were analysed, including the updating of regulatory documents, the stimulation of investment in digital technologies, the development of training programmes, and the international exchange of experience. The prospects for the development of digitalisation in the context of global trends in sustainable construction, increased efficiency of resource use, and the automation of construction process management were also investigated.

## RESULTS

The digitalisation of construction is the process of implementing digital technologies across all stages of the life-cycle of building projects, aimed at increasing efficiency, reducing costs, and minimising risks. It encompasses the use of automated control systems, artificial intelligence, the Internet of Things, cloud computing, and other digital solutions that allow for the optimisation of the planning, construction, and operational processes of buildings. One of the key technologies of digitalisation is BIM – Building Information Modelling – which involves creating a digital three-dimensional representation of a building with all its characteristics. BIM enables the integration of all stages of design, construction, and operation into a single system, which reduces errors, shortens project implementation time, and improves the accuracy of material calculations. The use of BIM ensures better coordination between contractors, clients, and engineers, which is critically important in conditions of unstable resource supply.

The implementation of BIM allows for a significant increase in the accuracy and speed of drawing coordination by creating a single digital model of the building that integrates all necessary data in one place. This enables all project participants (architects, engineers, contractors) to



work with up-to-date data in real time, which minimises the risk of errors and simplifies the process of approving design decisions. Thanks to the ability to integrate different disciplinary models (architectural, structural, building services, etc.), all changes are automatically reflected in all relevant parts of the documentation. This means that any changes made to one element of the model instantly update the linked drawings, ensuring their synchronisation.

Thus, the process of drawing coordination becomes significantly faster and more accurate, as the need for manual document updates and making changes in different files is eliminated. Thanks to model integration and automatic data updates, the number of repeated checks and adjustments is reduced, which also shortens the time spent on coordinating project documentation. This ensures a faster transition to the construction phase, which is critical when projects have tight deadlines. Within BIM, each stage of design automatically integrates changes into all other elements of the model and the corresponding drawings. This allows for maintaining the relevance of documentation without the need to manually make changes in different files. For example, changing the dimensions of doors or windows in the 3D model immediately updates all related drawings, which significantly reduces the time spent on correcting errors and coordinating changes between different project participants.

Furthermore, automatic updating helps to reduce the likelihood of errors when manually transferring changes between different parts of the project, which, in turn, improves the overall quality of the documentation and lowers the risks associated with inconsistencies in the building's elements. Revit and ArchiCAD are among the most popular platforms for BIM, widely used in the construction industry. Revit is a leading platform for Building Information Modelling. This software integrates various design disciplines (architecture, structural engineering, and building services) into a single digital model, ensuring effective collaboration between different project participants. A key advantage of Revit is its ability to automatically update all project components when model parameters are changed. This helps to reduce the likelihood of errors and simplifies the process of coordinating drawings. ArchiCAD, in turn, also offers a wide range of features for model integration and automatic updating, but with a greater emphasis on flexible work with 2D and 3D elements. This platform allows for more convenient work with drawings, has a large set of tools for creating detailed plans, and enables users to customise them according to project requirements. Both programs, Revit and ArchiCAD, offer powerful capabilities for automatically updating documentation and integrating changes into the BIM model. They have similar features for collaboration and error reduction; however, Revit is more geared towards integration with other engineering disciplines, while ArchiCAD offers a more user-friendly and intuitive workflow for architects and designers. The choice between these platforms often depends on the specific needs of the project, the budget, and the existing expertise of the team.

In any case, both systems significantly enhance the speed and accuracy of creating and coordinating project documentation in the process of digitalisation in construction.

The IoT allows for the use of network-connected devices to collect and process data in real time. IoT sensors can monitor the condition of equipment, the level of construction material stocks, environmental conditions, and the safety level on the construction site. This enables automatic adjustments to workflows, helps to avoid downtime, and increases the efficiency of resource management. The application of AI and machine learning in the construction sector helps to predict potential delays, analyse risks, and optimise logistical processes (Shults *et al.*, 2023). AI algorithms are capable of analysing large volumes of data obtained from IoT devices and BIM models to ensure effective resource planning. Furthermore, AI is used to control the quality of construction and automate routine processes, which helps to reduce the impact of human error. Digital Twin technology is a virtual representation of a physical object or process that allows for the analysis, simulation, and optimisation of the construction process. The use of digital twins allows for the testing of different construction scenarios, predicting the behaviour of structures and optimising the use of resources. Cloud technologies provide centralised data storage and simplify access to information for all participants in the construction process. This enables real-time updating of documents, tracking of changes in projects, and ensuring management transparency (Visartsakul & Damrianant, 2023). Blockchain technologies are used to enhance the security and transparency of transactions in construction, ensuring the reliability of financial operations and control over the execution of contracts. Thus, the digitalisation of construction is based on the implementation of comprehensive technological solutions that allow for the automation of processes, the improvement of resource management, and the enhancement of the efficiency of construction projects, especially in conditions of unstable resource supply (Kim *et al.*, 2020).

The digitalisation of the construction process offers significant advantages; however, its implementation is accompanied by several challenges, particularly in conditions of unstable resource supply. The main focus is on the key challenges and benefits associated with the practical aspects of construction activities – specifically, the processes of preparing project documentation, conducting geodetic surveys, using specialised software for creating drawings and visualisations, as well as performing calculations of material loads and assessing their energy efficiency. Challenges in implementing digital solutions in construction include the high cost of implementation and staff training, as the use of modern software for creating project documentation, geodetic and geological surveys, calculating material loads, and assessing their energy efficiency requires significant financial expenditure. Additionally, staff must undergo training, which increases the timeframes for technology implementation (Demirkesen & Tezel, 2021). The alignment of data formats between these systems is a



complex task, especially when it comes to integrating load calculations, energy efficiency assessments, and geodetic surveys. Insufficient digital literacy within the industry is also a significant obstacle, as many construction companies are slow to adopt digital technologies due to resistance to change. Traditional management methods, paper-based documentation, and manual calculations are still widely used, which complicates the transition to automated processes. Furthermore, reliance on stable resource provision and infrastructure becomes an issue, as digital solutions require reliable electricity supply, internet connectivity, and computing power, and in conditions of unstable resource supply, such as when building in remote or crisis regions, this becomes a significant problem. Cybersecurity and data protection are also important, as the use of cloud technologies and digital platforms for project management increases the risks of unauthorised data access. This is particularly important when storing geodetic surveys, structural calculations, and drawings, which can be critical for the safety of structures.

The successful implementation of digital technologies in the construction industry is only possible with a strategic approach and the integration of innovative solutions at all stages of a project. Digital methods, such as Light Identification, Detection and Ranging (LIDAR), drones, and GIS, have significantly changed approaches to geodetic and geological surveys in construction. These technologies allow for the collection of data with high accuracy and in shorter timeframes compared to traditional methods. LIDAR is one of the most effective technologies for mapping and measuring the Earth's surface, using laser beams to create detailed three-dimensional models. This makes it possible to measure distances to objects more accurately, as well as to determine surface characteristics with an accuracy of up to a few centimetres. Due to its high scanning speed, LIDAR can quickly cover large areas, making it ideal for use in geodesy and geology, particularly for studying landscapes, construction sites and for investigations in areas where traditional measurements are not feasible.

The accuracy of measurements obtained using LIDAR can reach a few centimetres, ensuring high data reliability. In the case of drones, the accuracy of measurements depends on the type of camera and sensors used, but it typically also amounts to a few centimetres for height and a metre for horizontal distances, making them highly accurate for mapping. GIS, in turn, allows for the integration of data from various sources and provides their spatial analysis with an accuracy of up to a few metres, depending on the input data (Golinko & Nedosnovanyi, 2024). Overall, these digital methods provide a high level of accuracy and efficiency in geodetic and geological surveys, which is important for the successful planning and implementation of construction projects. The use of drones in geodesy also allows for obtaining high-precision images and maps of the terrain. With the help of drones, aerial photography can be carried out from altitude, which enables effective mapping of large areas, as well as obtaining 3D models of

the terrain for further analysis. The application of drones in combination with the Global Positioning System and geodetic instruments allows for achieving high accuracy in measurements, which is important for design and engineering. Drone technology makes it possible to conduct investigations in hard-to-reach places, such as mountainous terrains or marshy areas, where traditional methods are impractical or extremely expensive.

The advantages of implementing digital solutions in construction include the optimisation of project documentation creation, as the use of digital platforms such as BIM significantly reduces the time for developing and approving documentation. Automated drawing updates and instant access to information ensure more effective project management. Increased accuracy in geodetic and geological surveys is also an important advantage, as drones, LIDAR, satellite technologies, and GIS allow for the highly accurate determination of topographical features of the terrain, which reduces the likelihood of errors during construction. The automation of material load calculations and energy efficiency analysis is also a significant advantage, as specialised software (e.g., SCAD Office, Tekla, ETABS) allows for the quick and accurate calculation of loads, optimising the use of materials (Abdelalim *et al.*, 2025). Energy efficiency analysis tools (EnergyPlus, DesignBuilder) help to assess the effectiveness of insulation materials and predict the energy consumption of buildings. The optimisation of resource provision and supply chain management allows for the use of digital technologies to control material costs and minimise downtime due to unstable supply. IoT sensors can track the status of warehouses in real time, and artificial intelligence algorithms can predict optimal delivery routes. Improved visualisation and project coordination through 3D modelling, AR, and VR allow clients, architects, and contractors to view the future building at a real scale even before construction begins, minimising the risks of discrepancies between expectations and actual execution. Waste reduction and improved environmental safety are further advantages, as digital resource management helps to optimise the use of materials and reduce construction waste. Automated planning enables a decrease in surplus material orders and, consequently, their wastage (Anh & Pásztor, 2021). The use of software for creating drawings and visualisations has significantly transformed the construction process, particularly through the integration of the latest VR and AR technologies. These technologies allow for a significant increase in the efficiency of project coordination, as they provide the opportunity to visualise the future construction project in a real-world environment. In VR, using special headsets and devices, the user can immerse themselves in a virtual environment where they can fully explore the building project or structure, viewing it from different angles and scales. This significantly improves the understanding of the project and also helps to identify potential problems at the coordination stage that might not be noticed in 2D drawings. AR, in turn, allows for the superimposition of virtual models onto the real world,



making it possible to see how the future project will look in a specific location. This is particularly useful for planning construction work, as it allows for a comparison of the project with the actual parameters of the site in real-time, live conditions. This use of technologies helps to reduce the number of errors in design and decreases the need for expensive and labour-intensive adjustments at later stages.

In the context of 3D visualisation, programs like Navisworks, Unity, and Unreal Engine have powerful capabilities for creating detailed building models and their visualisations. Navisworks provides the integration of different data types and allows for the creation of complex models that help to identify potential clashes between structural elements before work begins on site. This program allows not only for viewing 3D models but also for checking how different construction phases will look in practice. Unity and Unreal Engine offer even greater possibilities for creating interactive visualisations. Unity allows for the development of interactive applications where the user can navigate through 3D models, explore different work execution scenarios, and interact with building elements. Unreal Engine provides high-quality graphics and realistic

visualisations, enabling the creation of impressive visual effects for presentations and real-time project testing. The use of these platforms allows not only for demonstrating projects but also for conducting simulations, analysing various aspects of energy efficiency, and even testing the building's interaction with the surrounding environment (lighting, weather, etc.). These technologies create new opportunities for project development and coordination, as they provide interactivity and realism, allowing all participants in the construction process (from architects to clients) to gain a complete understanding of the future building. This significantly reduces the risk of misunderstandings at the design stage and allows for more effective planning and execution of construction work. Modern construction is actively implementing digital technologies to increase efficiency, reduce costs, and optimise resource provision. The adoption of BIM, GIS, automated control systems, and other digital solutions allows for a significant improvement in the quality of planning, construction control, and facility operation. Table 1 demonstrates the main digital technologies in construction, their areas of application, advantages, and challenges.

**Table 1.** Impact of digital technologies on construction processes: areas of application, advantages, and challenges

Digital technology	Area of application	Main advantages	Implementation challenges	Software examples
BIM	Design, construction management, cost optimisation	Accurate modelling, automatic drawing updates, coordination between project participants, error reduction	High software costs, need for staff training, difficulty transitioning from traditional methods	Autodesk Revit, ArchiCAD, Tekla Structures, Navisworks
LIDAR scanning and 3D scanning	Geodetic surveys, object condition assessment, reconstruction	High measurement accuracy, possibility of creating digital twins of buildings	Expensive equipment, need for specialised software, large data volumes	Leica Cyclone, Faro Scene, Autodesk Recap
GIS	Site analysis, construction planning, infrastructure management	Visualisation of spatial data, integration with geodetic surveys	Need for high-quality input data, the complexity of analysing large volumes of information	ArcGIS, QGIS, Bentley Map
IoT	Monitoring the condition of construction sites, resource control, safety	Real-time control, cost reduction, prediction of material wear	High dependence on a stable internet connection, risks of cyberattacks	Smart Construction Dashboard, Trimble Connect, Autodesk Forge
VR/AR	Project visualisation, staff training, construction monitoring	Improved client coordination, error detection at the design stage	High equipment costs, content adaptation is required	Unity, Unreal Engine, Fuzor, IrisVR
Cloud platforms for document storage	Project documentation management, team collaboration	Access to data from any location, fast information exchange, protection against data loss	Risks of cyberattacks, stable internet connection is required	BIM 360, Procore, Aconex
Automated construction management systems	Monitoring work progress, logistics, resource planning	Increased efficiency, accurate cost forecasting, minimisation of delays	Need for integration with other systems, need for staff training	Primavera P6, Buildertrend, PlanGrid, Microsoft Project
Automated systems for calculating loads and energy efficiency	Assessment of structural strength, optimisation of energy costs	High accuracy, reduction of calculation time, decrease in energy consumption	Complexity of modelling, need for high-performance equipment	SCAD Office, ETABS, EnergyPlus, DesignBuilder
Drones (UAVs) in construction	Construction site monitoring, geodetic surveys, safety assessment	Reduction of geodesy costs, speed of data acquisition	Need for qualified operators, legislative restrictions	DroneDeploy, Pix4D, Propeller Aero
3D printing in construction	Printing of building elements, construction of low-rise buildings	Reduction of construction time, decrease in material costs	Need for qualified operators, legislative restrictions	COBOD, ICON, WASP

**Source:** compiled by the authors based on L.D.H. Anh & Z. Pásztor (2021), A. Yasinska et al. (2023), D. Bondarenko & K. Kalashnikova (2024)

The development of digital technologies significantly impacts the efficiency of the construction process, reducing risks, optimising costs, and promoting the sustainable development of the industry. However, the implementation of digital solutions requires significant investment in staff training, equipment modernisation, and data protection. Despite these challenges, the use of digital technologies in construction is key to increasing the productivity and resilience of the construction industry. The methodology for implementing digitalisation in construction involves a comprehensive approach that includes several key stages. First, there is an analysis of the current state and the definition of digitalisation goals. This involves assessing existing business processes, and technological provision, identifying key problems, and formulating specific goals, such as optimising load calculations, automating geodetic surveys, or improving document management. The next step is the selection of appropriate technologies and tools, which may include BIM modelling for accurate design, GIS and LIDAR scanning for spatial analysis, software packages for creating drawings and visualisations, automated construction management systems for process monitoring, as well as energy efficiency analysis systems for assessing the impact of materials and structural solutions on energy consumption.

There is also staff preparation and training, which involves conducting training sessions for designers, engineers, geodetic surveyors, and managers, familiarising specialists with the use of digital tools and providing consultancy support. This is followed by pilot implementation and testing on a specific project, which allows for the identification of potential problems, the assessment of the economic efficiency of the technologies, and the adjustment of the integration of new tools with existing systems (Hasegawa *et al.*, 2020). After successful testing, digital solutions are integrated into the overall construction process,

covering all its stages: design and documentation preparation, execution of geodetic and geological surveys, logistics optimisation, calculation of material needs, control of energy efficiency, and operational characteristics of building structures. The final stage is the monitoring of effectiveness and the adjustment of strategy, which includes assessing cost reductions, increasing the speed of project execution, and improving the quality of construction and the level of integration of new technologies into work processes. Thus, the implementation of digitalisation in construction requires careful planning, the adaptation of staff to new technologies, and the continuous analysis of results to increase the efficiency of the construction process in conditions of unstable resource supply (Nikmehr *et al.*, 2021).

In modern construction, the implementation of digital technologies is becoming not just a trend but a necessity, driven by increased demands for the quality, speed, and efficiency of construction work. Traditional methods, based on paper documentation, manual calculations, and physical inspections, are gradually being replaced by digital tools that provide greater accuracy, reduce the risks of human error, and significantly speed up processes. The use of BIM modelling, automated resource management systems, laser scanning, sensor technologies, and other digital tools allows construction companies to manage projects more effectively, minimise costs, and improve quality control (Turner *et al.*, 2020). At the same time, the digitalisation of the construction process is associated with certain challenges, such as the need for staff training, high initial investments, and the integration of new technologies into existing workflows. However, the experience of many companies demonstrates that the long-term benefits of digital solutions significantly outweigh the costs of their implementation. To better understand the differences between traditional and digital methods in construction, comparative Table 2 highlights the key aspects of these two approaches.

**Table 2.** Comparison of the effectiveness of traditional and digital methods in the construction process

Stage of the construction process	Traditional methods	Digital methods
Design and documentation	Manual drawing, paper-based documentation, complex process for making changes	Use of BIM, AutoCAD, Revit, rapid drawing adjustments, and centralised document storage
Geodetic surveys	Manual measurements, traditional theodolites, high probability of errors	LIDAR scanning, drones, GIS systems, high data accuracy
Geological surveys	Costly and time-consuming process, physical sampling	Digital soil modelling, automated data analysis
Load calculations	Use of standard calculation tables, risk of errors	Software for engineering calculations (SAP2000, ANSYS, SCAD), automation of processes
Cost estimation and cost management	Manual cost estimation, difficulty in accounting for changes in material costs	Automated cost estimation systems (ABC 4, AVK-5), integration with supplier databases
Construction work	Lack of centralised control, paper-based reports	Use of digital construction logs, quality control sensors
Logistics and resource management	Manual supply planning, risk of delays	Intelligent resource management systems, IoT for monitoring material status
Quality and safety control	Visual inspection, risk of human error	Digital monitoring, drones for inspections, AI image analysis
Energy efficiency of buildings	Limited methods for calculating heat loss, reliance on standard designs	Software modelling of energy efficiency, digital sensors for energy consumption
Operation and maintenance	Manual record-keeping, difficult access to data about the building	Digital building logbooks, predictive maintenance using IoT

**Source:** compiled by the authors based on O. Bashynskiy (2018), V.V. Vapnichna (2020), C.J. Turner *et al.* (2020)



An equally important aspect is quality and safety control. Traditional methods are often limited to visual inspections and periodic checks, whereas digital solutions, such as monitoring sensors and augmented reality, allow for the detection of deviations in real time. This is particularly relevant in conditions of unstable resource supply, where it is important to respond promptly to changes in material costs, workforce availability, and logistical difficulties. Despite the significant advantages of digitalisation, its implementation requires substantial initial investments, the adaptation of work processes, and the training of qualified specialists. However, in the long term, digital methods provide significant cost savings, increased productivity, and reduced project completion times (Urbach *et al.*, 2018).

The Crossrail project, the largest infrastructure project in the United Kingdom, is a prime example of the use of BIM technology for coordinating construction processes (Elizabeth Line, n.d.). For this project, a single digital model of the entire rail transport system was created, including tunnels, stations, and infrastructure. The implementation of BIM allowed for the reduction of errors, the simplification of communication between project participants, and ensured accuracy in the execution of drawings and calculations. Thanks to BIM, effective management of changes that arose during construction was ensured, as well as improved integration with other digital tools. This made it possible to shorten construction time and reduce costs.

In Singapore, digital twins have become a key tool for managing infrastructure projects. By using digital copies of the city's infrastructure, the Singaporean authorities have been able to optimise resource use, monitor the condition of engineering networks, and plan urban development. Digital twins allow for the real-time monitoring of the condition of construction sites, the prediction of resource needs, and the early detection of potential problems. This has helped not only to increase the efficiency of the construction process but also to ensure the sustainability of infrastructure in the long term, which is particularly important in the context of urbanisation and climate change (Muruganandan *et al.*, 2022).

Analysis of the implementation of digital technologies in construction in Ukraine also shows significant potential for increasing the efficiency and quality of construction projects. The company DEHAUSS (2017) actively implements BIM in its projects in Ukraine, which allows for a significant increase in the efficiency of design and construction. Thanks to the use of BIM 360, transparent control of the construction process has been ensured, the quality of work execution has been improved, and logistics have been optimised. However, to achieve wider adoption of BIM, state support, the development of appropriate standards, and the encouragement of the use of these technologies at all levels of the construction sector are necessary. One of the key projects is the ASTON HALL residential complex, located in Odesa. DEHAUSS carried out the conversion of the project from 2D to BIM, covering all stages of the life-cycle: design, construction, and operation. The implementation of BIM allowed for the identification and elimination of design errors and clashes even before the start of construction, which helped to avoid rework, material overruns, and additional work, as well as ensuring adherence to construction completion deadlines.

The implementation of information technologies in construction varies significantly depending on the country, the level of development of digital infrastructure, and the availability of government support. In the United Kingdom, digital solutions, particularly BIM and IoT, are actively used to improve coordination between contractors and optimise the management of construction processes, as evidenced by the experience of the Crossrail project. In Singapore, digital twins and artificial intelligence are used at the level of public administration, which allows for the effective monitoring of urban infrastructure. In Ukraine, the digitalisation of construction is still in its early stages: the company DEHAUSS, in the ASTON HALL project, demonstrated the effectiveness of BIM in reducing costs and increasing design accuracy. However, the widespread adoption of digital technologies is hindered by the lack of unified standards and financial barriers. A comparison of these approaches is presented in Table 3.

**Table 3.** Comparison of the implementation of information technologies in construction in the United Kingdom, Singapore, and Ukraine

Criterion	United Kingdom (Crossrail)	Singapore (Digital Towns)	Ukraine (ASTON HALL, DEHAUSS)
Key technologies	BIM, IoT, digital twins	Digital twins, IoT, AI	BIM, design automation
Main advantages	Coordination between contractors, change control, optimisation of construction processes	Management of urban resources, forecasting infrastructure loads	Cost reduction, error minimisation, reduction of construction timeframes
Use of IoT	Real-time monitoring of construction processes	Monitoring the condition of urban infrastructure and loads	Limited use (focus on BIM)
Use of AI	Risk analysis, forecasting potential deviations	Automated management of urban processes, adaptive planning	Initial stage of development, used for design optimisation
Level of digitalisation	High, widespread adoption of BIM standards	Very high integration of digital twins at the state level	Partial implementation, lack of unified national standards
Main challenges	High complexity of data integration between contractors	Large data volumes, powerful computing infrastructure is required	Lack of regulatory framework, need for staff training, financial constraints
Economic effect	Cost reduction of 10-15% due to process optimisation	Effective management of urban resources, minimisation of accidents and failures	Cost savings due to the elimination of errors at the design stage

Source: compiled by the authors

The experience of the United Kingdom and Singapore demonstrates a high level of implementation of information technologies in construction, which contributes to resource optimisation, increased forecast accuracy, and cost reduction. In the United Kingdom, the emphasis is on BIM and IoT to improve construction management, while in Singapore, digital twins are used at the state level for comprehensive urban infrastructure management. In Ukraine, digitalisation is only gaining momentum: individual companies, such as DEHAUSS, actively implement BIM to minimise errors and reduce costs, but the overall level of digitalisation remains fragmented due to the lack of unified standards and financial constraints. For the successful development of digital technologies in construction, Ukraine needs to adopt international experience, introduce state support, and standardise processes.

## DISCUSSION

The digitalisation of construction is becoming a key factor for the optimisation and efficiency of construction processes, particularly in conditions of unstable resource supply. Digital twin technologies offer significant advantages in the planning, execution, and operation of construction projects. At the same time, this process is accompanied by several challenges related to high implementation costs, the need for staff training, software compatibility, and dependence on a stable resource supply. M. Wang *et al.* (2020) noted that the digitalisation of construction has played an important role in increasing the efficiency and optimisation of construction processes, especially in conditions of unstable resource supply. The authors emphasised the importance of integrating technologies such as BIM, IoT, AI, and digital twins to improve all stages of construction projects. However, the authors also pointed out the existing challenges related to high implementation costs, the need for staff training, software compatibility issues, and dependence on a stable resource supply.

One of the main advantages of digitalisation is the significant reduction in the time taken to develop project documentation and the increased accuracy of calculations. The use of BIM allows for the integration of all stages of the construction process into a single model, which significantly improves coordination between project participants and reduces the number of errors. The implementation of automated construction management systems allows for the optimisation of resource allocation, which is critical when there are unstable material supplies (Kuznetsov, 2024). Furthermore, IoT systems provide the ability to monitor the condition of construction sites in real time, which allows for a quick response to unforeseen situations and the minimisation of risks. Y. Zheng *et al.* (2021) highlighted the advantages of digitalisation, such as the reduction in time for developing project documentation and improved coordination through BIM, which aligns with the findings here, where the importance of these technologies for increasing accuracy and efficiency is also noted. However, unlike this study, the authors did not focus on challenges such as the

need for staff training and resource supply issues. Their emphasis on automated management systems for optimising resources in unstable conditions partially coincides with this study, although this study focuses more on the integration of IoT for site monitoring. Overall, the authors' results confirm most of the conclusions in this study but differ in their focus on certain aspects of technological implementation.

M. Tetik *et al.* (2019) emphasised in their research that a key factor in the successful digitalisation of construction is the integration of digital technologies at all stages of a project – from design to operation. They noted that while the implementation of digital solutions is accompanied by challenges such as high costs and the need for qualified specialists, the long-term benefits in terms of increased efficiency and reduced costs significantly outweigh these. Their conclusions generally align with this study, particularly regarding the importance of a strategic approach to digitalisation. At the same time, the authors placed a greater emphasis on the management aspects of digital transformations in construction, whereas the current study focuses more on the technical tools and methods of their application in conditions of unstable resource supply.

Through the use of digital technologies, such as LIDAR laser scanning and GIS, it has become possible to conduct geodetic and geological surveys more accurately. This enables the determination of site characteristics and the selection of the most optimal construction materials, taking energy efficiency into account. For example, energy efficiency calculation programs such as EnergyPlus and DesignBuilder allow for the prediction of the energy consumption of buildings, as well as the selection of materials that maximally reduce energy costs during the operation of the facility (Sukhodub & Serdechnyi, 2024). L. Jones & P. Hobbs (2021) emphasised the importance of using LIDAR laser scanning and GIS for geodetic and geological surveys, which aligns with this study regarding the application of digital technologies in these processes. However, the authors focused on the selection of materials for energy efficiency using programs such as EnergyPlus and DesignBuilder, which is not present in the current study. Overall, the authors' ideas are consistent with the current ones but include additional specific examples of software.

However, the implementation of digital technologies in construction is associated with several challenges. One of the biggest is the high cost of software and equipment. The expenses for licences for BIM, LIDAR scanners, or specialised load calculation programs significantly exceed the budget of traditional methods. In addition, there is a need for staff training to effectively use these tools, which further increases time and financial expenses. On the other hand, even after the implementation of technologies, problems arise with their integration and compatibility with other platforms, such as AutoCAD or Revit. In the absence of a unified standardised platform for storing and exchanging data, working with different systems can complicate interaction between the various participants in the construction



process. S.A. Hendrawan *et al.* (2024) noted that the main problems with the implementation of digital technologies are the high costs of software and equipment, as well as the need for staff training for the effective use of tools, which aligns with this study. However, this study did not raise the issue of compatibility between different software platforms such as AutoCAD or Revit, unlike this author, who considered the integration of different systems in detail. Overall, the authors' results confirm the findings here regarding financial and training challenges but add specifics regarding software compatibility.

Another significant challenge is the dependence on a stable resource supply. Digital solutions require a reliable electricity supply and internet access, which can be a serious problem for construction in remote or crisis-stricken regions. Power outages or low internet speeds can lead to delays in the execution of work and disable digital monitoring and management systems. J. Wang *et al.* (2022) emphasised the importance of a stable resource supply for the effective implementation of digital technologies, noting that a reliable electricity supply and internet access are critical factors for working with digital systems. These results align with the findings of this study, as this study also highlights the dependence on a stable resource supply as one of the main problems of construction digitalisation. However, the authors described the potential consequences of low internet speeds or power outages in more detail, which was not emphasised in this study.

Furthermore, data security is an important aspect of implementing digital technologies. The use of cloud platforms for storing documentation and managing projects increases the risks of unauthorised access to critical data, such as drawings, load calculations, and geodetic surveys. In this regard, it is necessary to develop and implement strategies to protect data from cyber threats. S. Somanathan (2023) noted that with the development of digital technologies in construction, there is a need to ensure data security. The use of cloud platforms for storing project documentation and managing projects can increase the likelihood of unauthorised access to important data, such as drawings, calculations, and research results. In this regard, it is important to develop measures to protect data from cyber threats and ensure reliable information security. This aligns with the findings of this study, which also addressed data protection in the context of digitalising construction, although it did not focus on cloud technologies and cybersecurity aspects, which emerge as critical in the research by this author.

Despite the challenges, the digitalisation of construction offers significant advantages in increasing efficiency, reducing costs, and improving the quality of construction work. Through the integration of the latest technologies, it is possible to significantly shorten construction time, increase the accuracy of work execution, and optimise resource expenditure. In particular, the ability to carry out automatic documentation updates, real-time monitoring of the construction status, and accurate energy efficiency calculations allows for the creation of more sustainable

and economical buildings (Schults *et al.*, 2016). J. Berlak *et al.* (2020) investigated the impact of digitalisation on construction efficiency, focusing on increasing the accuracy and speed of work execution. Their article noted that the integration of new technologies allows for a significant reduction in construction time, an increase in the accuracy of design calculations, and the optimisation of costs. Particular attention was paid to monitoring and the automatic updating of documentation, which allows for more effective project management at all stages. The results of the authors' study align with this research in certain aspects, particularly in highlighting the advantages of digitalisation for increasing efficiency, reducing construction time, and improving the quality of work through the integration of the latest technologies. However, their article places more emphasis on the automatic updating of documentation and the real-time monitoring of the construction status, while this study focuses more on the use of specific tools for energy efficiency calculations and resource allocation. Also, the authors paid less attention to the challenges associated with digitalisation than in this study.

For the successful digitalisation of construction, it is necessary to address several problems, particularly those related to cost, training, and ensuring data security. However, provided there is a strategic approach and the integration of innovations at all stages of construction, digital technologies can significantly improve resource management and ensure high efficiency of construction processes, even in challenging conditions of unstable resource supply. In their study, F. Elghaish *et al.* (2021) noted that for the successful digitalisation of construction, it is necessary to address several key problems, such as the high cost of technologies, the need for staff training, and data security issues. At the same time, they indicated that with a strategic approach and the integration of innovations at all stages of construction, digital technologies are capable of significantly improving the efficiency of resource management and ensuring high performance of construction processes, even in challenging conditions of unstable resource supply. These conclusions correspond to the results of this study, as it is also noted that for the implementation of technologies, it is important to address issues of funding, security, and staff training. However, the authors placed more emphasis on strategy and the integration of innovations into the overall process, while this study also considered specific aspects of using the latest technologies for energy resource management and the monitoring of building conditions.

In their study, K. Guo & L. Zhang (2022) noted that the digitalisation of construction can significantly improve resource management and optimise construction processes. However, the successful implementation of technologies requires a comprehensive solution to problems associated with the high cost of software, the need for staff training, and ensuring cybersecurity. They emphasised that a strategic approach to the integration of digital solutions allows for the minimisation of risks and the increase of efficiency, even in challenging conditions. Their conclusions partially



align with the findings presented here, as this study also emphasises the importance of addressing these challenges. However, unlike this study, the authors focused more on cybersecurity issues and the organisational aspects of digital transformation, while this study places a greater emphasis on the technical aspects of resource management and the application of specific digital technologies in construction. Thus, the results of the conducted research not only confirm the key conclusions obtained by other researchers but also supplement them with new details, particularly in the context of the technical implementation of digital solutions in construction under conditions of unstable resource supply.

## CONCLUSIONS

This study conducted a comprehensive analysis of the digitalisation of construction, examining key technologies, their advantages, challenges, and implementation methods. The research confirmed that digitalisation encompasses the entire lifecycle of construction projects, from design to operation, using BIM, IoT, AI, digital twins, cloud technologies, and blockchain. It was demonstrated that BIM allows for the reduction of errors, the optimisation of resource management, and the increased accuracy of material calculations, while the integration of IoT provides real-time monitoring of sites, promoting the efficient use of resources. The use of AI in construction helps to analyse risks, predict delays, and optimise logistical processes, while digital twins allow for simulations and the prediction of structural behaviour. It was determined that cloud technologies simplify document management, and blockchain promotes the transparency of financial transactions and ensures data security. Within the scope of the study, real-world case studies of the implementation of digital technologies in construction were analysed. Specifically, in the DEHAUSS project, BIM technologies ensured effective coordination between contractors, and digital twins were used for the management of urban resources. In the United Kingdom, in the Crossrail project, BIM facilitated smooth coordination between different contractors and the

optimisation of construction, reducing risks and delays. In Singapore, digital twins are actively used for monitoring and managing urban resources, increasing infrastructure efficiency and improving city development planning.

The practical construction aspects of digitalisation were considered separately, including documentation development, the execution of geodetic and geological surveys, and the use of software for drawings, load calculations, and the assessment of material energy efficiency. It was determined that digital technologies allow for a significant increase in the accuracy of geodetic surveying, improved project modelling using 3D scanning, as well as the automation of design and engineering calculation processes. At the same time, several challenges were identified, including the high cost of implementing digital solutions, the need for staff training, software compatibility issues, and the complexity of data integration between different systems. The problem of an unstable resource supply, which affects the stability of digital solutions, especially in remote or crisis-stricken regions, was also investigated. The results of the study confirmed that the digitalisation of construction is a key factor in increasing the efficiency of the industry. However, its successful implementation requires a comprehensive approach, investment, and the resolution of several technical and organisational challenges. Promising directions for further research include the development of adaptive digital solutions for conditions of unstable resource supply, the improvement of methods for integrating BIM and IoT, as well as the evaluation of the effectiveness of artificial intelligence in predicting risks in construction projects.

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## **Оптимізація будівельного процесу за допомогою цифровізації на прикладах проєктів в умовах нестійкого ресурсозабезпечення**

**Анотація.** Метою роботи було дослідити вплив цифрових технологій на оптимізацію будівельного процесу за умов нестійкого ресурсозабезпечення та сформулювати практичні рекомендації для їх ефективного впровадження. Методологія дослідження включала аналіз сучасних тенденцій у сфері цифрових рішень, зокрема інформаційного моделювання будівель, технологій Інтернету речей, штучного інтелекту, цифрових двійників та хмарних платформ. Було розглянуто можливості інтеграції цих технологій для покращення планування, будівництва та експлуатації об'єктів, а також їхній вплив на підвищення ефективності управління ресурсами. Проведений аналіз реальних кейсів, зокрема впровадження інформаційного моделювання будівель у проєкті ASTON HALL компанії DEHAUSS, який підтвердив значний потенціал цифрових технологій. Також розглянуто проєкт Crossrail, де BIM-технології забезпечили ефективну координацію між підрядниками, і використання цифрових двійників у Сінгапурі, які використовуються для управління міськими ресурсами. Дослідження показало, що інформаційне моделювання будівель сприяє зменшенню помилок у проєктуванні та будівництві, покращенню координації між учасниками проєкту та зниженню витрат. Технології Інтернету речей забезпечують моніторинг стану будівельних матеріалів та обладнання у реальному часі, що підвищує рівень безпеки та зменшує ризики простоїв. Використання штучного інтелекту дає змогу прогнозувати можливі затримки, оптимізувати логістику та автоматизувати процеси управління. Цифрові двійники дозволяють тестувати різні сценарії будівельного процесу, що позитивно впливає на якість кінцевого результату. Основними викликами цифровізації будівництва залишаються висока вартість впровадження технологій, необхідність навчання персоналу, складнощі інтеграції програмних платформ та питання кібербезпеки. Водночас переваги, такі як автоматизація процесів, підвищена точність розрахунків навантажень та енергоефективності, оптимізація ресурсозабезпечення та вдосконалений контроль за будівельними проєктами, підтверджують стратегічну важливість цифрових рішень у розвитку будівельної галузі. Результати дослідження продемонстрували, що комплексний підхід до впровадження цифрових технологій, адаптація будівельних процесів та ефективна інтеграція цифрових платформ можуть суттєво підвищити продуктивність будівельних проєктів, особливо в умовах нестійкого ресурсозабезпечення.

**Ключові слова:** блокчейн; інформаційне моделювання будівель; геоінформаційні технології; хмарні обчислення; дистанційне зондування