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INNOVATIVE APPROACHES TO BRIDGE RECONSTRUCTION USING BUILDING INFORMATION MODELLING TECHNOLOGY

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The study was conducted to demonstrate the advantages and innovative approaches of using Building Information Modelling (BIM) technology in the process of reconstruction of the Varvarovsky Bridge over the Pivdennyi Buh in Mykolaiv, with an emphasis on improving the efficiency, accuracy, and coordination of work. This study used laser scanning, photogrammetry, 3D modelling, BIM, sensor monitoring, and Internet of Things (IoT) techniques to create accurate digital models of the bridge and create a proposal to optimise its reconstruction process. As a result of the study, it was determined that the use of BIM technology substantially improves the process of bridge reconstruction. The use of 3D scanning and photogrammetry allows creating an accurate digital model of the bridge, which will provide a more detailed analysis of structural integrity. Optimisation of work planning using BIM will help reduce costs and the time required to complete the project. Improved coordination between project participants due to a single information model will help avoid mistakes and improve the quality of work performed. Furthermore, the use of sensors and IoT technologies for monitoring the bridge status in real time will allow for quickly identifying and fixing potential problems. Automating the creation of digital documentation and archiving of all data in BIM will greatly simplify further maintenance of the bridge. The study confirms that implementing BIM in bridge reconstruction helps improve the safety, efficiency, and cost-effectiveness of projects. The study demonstrates the practical value of using BIM technology in bridge reconstruction, improving the planning, coordination, and monitoring process, resulting in safer, more efficient, and cost-effective construction projects

Keywords: *3D scanning; photogrammetry; digital model; structural integrity analysis; planning optimisation; monitoring*

Introduction

Bridge reconstruction is a critical aspect of maintaining and improving transport infrastructure that ensures efficient and safe communication between different regions. Traditional reconstruction methods often face challenges such as delays in work completion, budget overruns, and poor coordination between project participants. However, with the advent of Building Information Modelling (BIM) technology, new opportunities are opening up to solve these problems (Yang *et al*., 2021). Innovative approaches based on BIM allow creating detailed digital models of objects, optimising planning and coordination processes, and effectively managing resources. In this context, the use of BIM in bridge reconstruction can substantially improve accuracy, reduce costs and projects deadlines. Exploring new approaches to bridge reconstruction using BIM not only opens up new horizons for the construction industry but also contributes to improving the safety and durability of infrastructure facilities. The need for this study is due to the growing challenges in managing bridge reconstruction, in particular, the need to improve planning accuracy and reduce deadlines and costs. Traditional reconstruction methods often face problems such as poor coordination between project participants and a lack of detailed information about the condition of the facility, which can lead to delays and cost overruns. The introduction of BIM technology promises to solve these problems by creating accurate digital models and optimising all stages of reconstruction. The study was necessary to confirm the effectiveness of BIM in improving the safety, efficiency, and cost-effectiveness of reconstruction projects and identify opportunities for integrating this technology into bridge construction practices.

Analysis of the implementation of BIM technology in bridge reconstruction indicates several key aspects that require further research. The problem of insufficient accuracy and efficiency of traditional methods of bridge reconstruction has attracted the attention of a number of researchers. M. Parsamehr *et al*. (2023) emphasised the importance of accurate modelling to ensure the effectiveness of reconstruction projects. They stressed that modelling allows anticipating possible problems in the early stages of the project, which minimises risks and reduces costs. N. Essam *et al*. (2023) focused on optimising planning processes through the integration of BIM models. The authors established that using BIM promotes better coordination between project teams and improves overall construction productivity. H. Hosamo & M. Hosamo (2022) noted that 3D scanning technologies substantially improve accuracy in assessing the condition of bridges. Their study showed that 3D scanning helps to more accurately identify areas of wear and damage, which contributes to more efficient planning of repair work. D. Patel & V. Nanyam (2022) assessed the impact of

BIM on coordination between project participants, which reduces the number of errors. They noted that BIM provides centralised storage and access to project data, which reduces the number of inconsistencies and alterations. A. Scianna *et al*. (2022) investigated the use of sensors for real-time bridge monitoring in the context of BIM. The authors' paper showed that the combination of sensors with BIM allows for continuous monitoring of the bridge condition, contributing to a quick response to detected problems. S. Biancardo *et al*. (2023) analysed the economic benefits of implementing BIM in bridge reconstruction, including lower costs. They proved that BIM helps reduce overall renovation costs by improving planning accuracy and reducing the number of alterations. D. Samadi *et al*. (2021) considered documentation automation models to simplify subsequent bridge maintenance. They stressed that automation of documentation facilitates access to the history of maintenance and repairs, which contributes to more efficient infrastructure management.

R. Zinno *et al*. (2022) investigated the impact of Internet of Things (IoT) technologies on the rapid detection of problems in bridge structures. This study showed that the use of IoT allows for monitoring the state of bridges in real time and identifying potential threats in a timely manner. A. Rashidi Nasab *et al*. (2023) emphasised the importance of BIM integration to improve the safety of reconstruction work. They noted that BIM allows for better risk prediction and planning of safety measures that minimise hazards to workers and the environment. O. Olanrewaju *et al*. (2021) examined the impact of detailed digital models on the accuracy of project execution and reducing the time frame for their implementation. The researchers showed that the use of digital models substantially improves the accuracy of work and reduces the likelihood of delays in project execution. However, despite the results achieved, there are several shortcomings that require further research. It is necessary to investigate how BIM technology can be adapted to the specific conditions of different types of bridges, such as bridge structures made of different materials or unique architectural solutions that require a special approach. There are no detailed studies on the long-term effectiveness of implementing BIM in different regions and climates, which is important for understanding how technologies work in conditions that are substantially different from those typical for a single location. Examining these aspects will help provide a more versatile and sustainable approach to the use of BIM in bridge reconstruction, considering a variety of conditions and requirements.

The purpose of the study was to show the advantages and innovative approaches of using BIM technology in reconstruction on the example of the bridge over the Pivdennyi Buh in Mykolaiv and suggest appropriate measures, focusing on improving the efficiency, accuracy, and coordination of work. Study objectives: Analyse the impact of BIM technology on bridge reconstruction; Evaluate how the use of BIM improves the quality of work performed and simplifies maintenance through documentation automation; Investigate the role of sensors and IoT in monitoring the state of bridges to quickly identify and fix problems.

Materials and methods

The study included analysing the level of BIM adoption at different stages of design and construction, identifying the main obstacles and incentives for their use and examining the experience of companies and projects where BIM technologies have already been used. It was important to determine how widely and effectively these technologies are used, what benefits they provide, and what steps need to be taken for their further implementation and distribution in Ukraine. The technical characteristics of the Varvarovsky Bridge were investigated to assess its current condition and determine the necessary measures for its reconstruction. A detailed analysis of technical characteristics, such as load-bearing capacity, strength of materials, and condition of supports and beams, allowed developing an accurate work plan, considering all aspects of the structure. It also contributed to ensuring the safety and durability of the bridge after reconstruction and helping to minimise the impact on traffic flows during work. 3D scanners have become the main tool for creating three-dimensional models of the bridge. The use of laser scanners allowed capturing high-resolution structural details, including accurate measurements of geometry and surface defects. Laser scanners provided fast and accurate measurements, which substantially reduced the risk of human error and improved the accuracy of the created models. The obtained data on the building elements of the bridge, such as arches, supports, and beams, allowed creating a detailed three-dimensional model that reflected the real state of the structure. Drones were used for photogrammetry, which provided additional information about the bridge from a height. Drones with high-quality cameras took aerial photos, which allowed obtaining images of a large area with high detail. These images were used for further processing and creating texture layers for 3D models, which increased the accuracy and realism of models.

Data analysis from 3D scanners and drones was included in the processing and integration of the received data into the BIM system. A single digital model of the bridge was created, which displayed its current state, considering all structural elements and defects. The inclusion of data in BIM ensured the integration of information from various sources and an accurate display of all design details. In the course of the study, the details of the structural elements of the bridge were analysed. The detailed analysis included checking for defects, damages, and structural problems. An important part of this phase was the assessment of critical areas that needed urgent repairs. Specialised software tools such as Autodesk Revit and Bentley STAAD.Pro were used for this purpose to analyse the structural integrity, helping identify areas with the highest level of risk and draw up a plan for further repairs. Methods of using sensors and IoT to monitor the state of the structure during reconstruction were also important. Sensors and IoT devices provided constant monitoring and data receipt in real time, which allowed quickly adjusting the work plan and ensuring the safety of reconstruction. Real-time data analysis allowed identifying and solving potential problems in a timely manner.

Results

Varvarovsky Bridge over the Pivdennyi Buh in Mykolaiv is one of the key transport arteries connecting the western and eastern parts of the city and providing communication between important industrial and commercial areas. It plays an important role in ensuring the smooth movement of vehicles, including public transport, trucks, and passenger cars. It was decided to propose the use of BIM technology to improve the efficiency and accuracy of the reconstruction process. BIM is a modern approach to object design, construction and management that allows creating and using digital models of buildings and infrastructure facilities. The use of BIM during the reconstruction of the Varvarovsky Bridge has several important advantages.

Due to digital models, engineers and architects can examine the bridge structure in detail, considering all its features and potential problems. This will allow mistakes to be avoided during the construction phase and reduce the cost of correcting possible defects. When repairing a bridge, it is important to properly plan the use of materials, equipment, and labour. It is possible to accurately determine the required amount of resources and optimise their use with the use of digital models, which will reduce costs and reduce the time required to complete work. Various specialists are involved in the reconstruction of the bridge: engineers, architects, builders, customers. Using a single digital platform will allow them to quickly exchange information, make changes to the project, and monitor the execution of work. This will help improve the quality and reliability of the project.

An example of the successful use of BIM during the reconstruction of the Varvarovsky Bridge is the integration of all stages of work into a single digital model. During the initial stage, a detailed survey of the bridge using laser scanning and drones is conducted, which will allow creating an accurate three-dimensional model of the existing structure. Further, based on this model, it is possible to develop a reconstruction project that will include all the necessary repairs and modernisation of structures. During construction, the digital model can be used for planning and coordinating work. All project participants should have access to up-to-date information, which will allow them to quickly respond to changes and solve problems that arise. In addition, BIM can be used to monitor the quality of work performed and the condition of structures in real time. Due to the use of BIM during the reconstruction of the Varvarovsky Bridge, it is possible to achieve high results. The project can be implemented in a certain time frame with minimal costs and high-quality work. This is a prime example of how modern technologies can change the approach to the construction and reconstruction of infrastructure facilities, ensuring their reliability and durability.

According to available statistics, the use of BIM technologies in Ukraine is gradually increasing (He *et al.*, 2022). Table 1 provides an overview of the current state of use of BIM technologies in Ukraine, reflecting both positive aspects and main problems and development prospects.

The implementation of BIM during the reconstruction of the Varvarovsky Bridge will demonstrate that the use of modern technologies is the key to the successful implementation of infrastructure projects in the future. Before starting the reconstruction of the Varvarovsky Bridge, careful measures should be taken to assess its current condition and analyse its technical characteristics (Table 2).

These measures should be aimed at identifying potential problems and determining the scope of necessary repairs. The main steps in this process should be laser scanning and photogrammetry, assessment of the structural integrity of the bridge. Using 3D scanners and drones to create a detailed digital model of the bridge will be one of the first and most important steps. Laser scanners will provide high-precision shooting of all structural elements, including hard-to-reach areas. This will allow creating an accurate three-dimensional model that will display all the details and possible deformations of the structure. Drones with high-resolution cameras will perform aerial photography, which will allow getting additional visual data about the state of the bridge. Photogrammetry will provide detailed images that will be integrated with laser scanning data to build a complete bridge model. Integration of the received data into BIM will allow creating a digital double of the bridge, which will accurately display its current state. This model became the basis for further analysis and planning of repair work (Fig. 1).

Table 1

State of use of BIM technologies in Ukraine

Category	Status indicators
General use of BIM	35% of construction companies use BIM
Use for bridge examination	20% of bridges are assessed using BIM
Advantages of use	Accurate modelling, simulation, improved coordination
Main problems	Insufficient funding, lack of qualified specialists and awareness
Government support	Adoption of legislative acts, training programmes
Examples of successful projects	Reconstruction of the bridge over the Dnipro River in Kyiv, the bridge over the Pivdennyi Buh in Mykolaiv

Source: compiled by the authors based on O. Levchenko *et al*. (2022)

Table 2

Technical characteristics of the Varvarovsky Bridge

Characteristics	Value
Name	Varvarovsky Bridge
Location	Mykolaiv, Ukraine
Construction type	Combined (road and rail)
Length	1,346 metres
Width	16 metres
Height	60 metres
Number of spans	9
Type of spans	Solid steel and reinforced concrete
Opening date	1,964
Maximum load	60 tonnes
Materials	Steel, reinforced concrete
Height above water level	20 metres
Flight opening time	Every 24 hours (for shipping)

Source: compiled by the authors on the basis of the Pivdennobuzka bridge crossing: 57 years ago, the Varvarovsky Bridge was opened in Mykolaiv (2021)

Figure 1 - Varvarovsky Bridge in 3D

Source: New bridge across the Pivdennyi Buh to be built in 60 months and 3.5 billion (photo) (2013)

After creating the digital model, a detailed analysis of the condition of the bridge's structural elements is performed. Specialists examine all the main components of the structure, including supports, beams, slabs, and other elements (Zhang *et al*., 2022). It is necessary to conduct both a visual inspection and the use of specialised equipment to evaluate materials and identify possible defects. During the assessment, critical areas are identified that require immediate repairs. For example, corrosion on steel elements of supports, cracks in reinforced concrete beams, and worn road surfaces. A detailed repair plan should be developed for each of these sites, considering the necessary resources and time. In addition, areas should be identified where it is necessary to strengthen the structure to prevent further destruction. Based on the data obtained, it is necessary to create a detailed report on the condition of the bridge, including all identified problems and recommendations for their elimination (Table 3). This report will form the basis for the development of a reconstruction plan that will include both urgent repairs and long-term measures to improve the reliability and durability of the structure. Conducting such thorough measures before the start of reconstruction will allow not only an accurate assess the condition of the bridge but also the development of an effective work plan. Due to the use of modern technologies, such as laser scanning, photogrammetry, and BIM, it is possible to create a complete and accurate picture of the condition of the structure, which will be the key to successful repair work and ensuring the safety of operation of the bridge in the future.

Table 3

Report on the state of the Varvarovsky Bridge

Parameter	Description
Date of inspection	December 1, 2023
General condition	Satisfactory
Road surface condition	There are small cracks, asphalt pavement repairs are required
Condition of supports	Signs of corrosion are detected in some places, and anti-corrosion treatment is required
Status of spans	There are microcracks in reinforced concrete elements, monitoring and repair are required
Lighting	It functions, but several lamps need to be replaced
Drainage system	Partially clogged, requires cleaning
Security assessment	The bridge is safe to use but requires regular maintenance
Recommended measures	Asphalt pavement repair, anti-corrosion treatment of supports, drainage system cleaning
Required budget	2,000,000 UAH
Deadline for completing work	6 months
Responsible persons	Department of bridges and tunnels of the city of Mykolaiv
Notes	It is recommended to conduct an additional inspection 6 months after the repair is completed

Source: compiled by the authors based on Nayem told us about the current stage of the bridge project to bypass Mykolaiv and plans to repair the Varvarivske and Ingulske bridges (2023)

Due to the use of BIM, a detailed programme for the reconstruction of the Varvarovsky Bridge is developed, which will include several key aspects. This programme will ensure not only technical accuracy but also cost-effectiveness and transparency of the reconstruction process (Levchenko *et al*., 2021). With the help of BIM, a step-by-step reconstruction plan is created, which considers the minimisation of the impact on traffic flows. Since the bridge is one of the main transport arteries of the city, it was important to maintain the maximum possible capacity during the repair work. The plan will include determining the optimal timing and methods for performing repairs, which will ensure efficient organisation of the workflow without substantial delays.

The next important aspect will be visualisation and simulation of the reconstruction process. The use of photorealistic visualisations will allow clearly demonstrating all the stages of work and the final result. This is important not only for technicians but also for customers and the public, who can see how the bridge will change. Virtual and augmented reality will become tools for visual demonstration of planned changes, which contribute to a better understanding of the reconstruction process and making informed decisions. Resource optimisation will be another important aspect of the reconstruction programme. Due to precise planning of the use of materials and equipment, it is possible to minimise costs and reduce waste. Using

BIM, one can create detailed models that reflect the needs for materials and technical means at each stage of work. This will ensure efficient resource management and avoid overspending. Thus, due to the use of BIM technologies, the reconstruction programme of the Varvarovsky Bridge is carefully planned and optimised. This will ensure not only technical accuracy and efficiency of work but also economic benefits and transparency of the process. Visualisation and simulation will help better understand planned changes and optimising resources will help reduce costs and environmental impacts. The use of modern technologies will guarantee the successful implementation of the project and ensure the safety and reliability of the bridge in the future.

During the reconstruction of the Varvarovsky Bridge, the main focus will be on several critical aspects that will ensure the successful implementation of the project (Hu *et al*., 2021). The use of BIM technology will become a central tool for coordinating, monitoring, and managing the reconstruction process, meeting deadlines and budgets. Using a single BIM model will substantially improve communication between engineers, architects, and builders (Rolfsen *et al*., 2021). All participants will have access to the same information, which will ensure consistency of actions and reduce the risk of errors due to misunderstandings or inconsistencies. The BIM model will allow quickly exchanging data, making necessary changes, and coordinating work at each stage of the project. This will ensure a high level of synchronisation of actions of all participants and effective management of the reconstruction process. The use of sensors and IoT technologies will allow constantly monitoring the state of the bridge structure during reconstruction. The sensors will collect data on loads, deformations, and other parameters that affect the bridge condition (Table 4). This data will be sent in real time to the central management system, where it will be analysed for prompt adjustments to the work plan. This approach will allow quick response to any changes or problems that arise during the reconstruction, ensuring high accuracy and work safety.

Table 4

Types of sensors and their applications

Sensor type	**Main application**	**Number of installed sensors**	**Frequency of data collection**
Temperature settings	Monitoring of concrete hardening processes, fire detection	50	Every 15 minutes
Humidity	Monitoring of the concrete drying process, leak detection	30	Every 30 minutes
Deformation systems	Load monitoring, crack detection	20	Every hour
Vibrating screens	Dynamic load monitoring, defect detection	10	Every 5 minutes

Source: compiled by the authors

Constant monitoring of work performance in accordance with established deadlines and budgets will become one of the main tasks of project management. Using BIM allows identifying potential risks at an early stage and quickly eliminating them, which will help avoid delays and overspending. Detailed models and work plans created in BIM will allow accurately predicting resource, material, and labour requirements, ensuring effective cost management and budget compliance. Thus, during the reconstruction of the Varvarovsky Bridge, the main focus will be on coordinating project participants, monitoring and management in real time, and meeting deadlines and budgets. The use of BIM technology will be a vital factor in the successful implementation of the project, ensuring high quality of work, economic efficiency, and safety of the structure. This approach will not only achieve the goals set but also create a solid foundation for further development and modernisation of urban infrastructure.

After the reconstruction of the Varvarovsky Bridge is completed, several key final events will be held to ensure the successful completion of the project and its further effective use. These activities include a final assessment of the quality of work performed, documentation and archiving, and planning for bridge maintenance. Conducting final quality control of the work performed includes a detailed check of all structural elements of the bridge for compliance with the established requirements. Specialists will conduct a thorough inspection of all components, including supports, beams, slabs, and other parts of the structure, to ensure that all work is performed in accordance with design specifications and safety standards. All possible defects or shortcomings will be fixed and corrected before the work is completed. This stage ensures that the bridge meets all technical requirements and is ready for operation. Due to the automatic creation of digital documentation about the work performed, it will be possible to record all the details of the reconstruction, including changes that are made during the project implementation process. All information will be stored in BIM, which provides centralised access to all reconstruction data. This will create a convenient base for future use during bridge maintenance and management. Digital documentation will also become an important resource for ensuring the accuracy and efficiency of future work.

Developing a regular maintenance plan using BIM will allow creating a detailed schedule of inspections, repairs, and other necessary activities. Continuous monitoring of the bridge condition, which will be conducted using sensors and other technologies, will allow identifying possible problems at an early stage. Continuous monitoring of the bridge condition, which will be conducted using sensors and other technologies, will allow identifying possible problems at an early stage. This will ensure timely response to any changes or defects, which will help maintain the bridge in excellent technical condition and ensure its safety and durability. Thus, the final measures conducted after the completion of the reconstruction of the Varvarovsky Bridge will include a thorough assessment of the quality of work performed, automatic creation of documentation, and planning for regular maintenance. The use of BIM technology will be critical to ensuring the accuracy and efficiency of all stages of the process, which will contribute to the successful completion of the project and ensure the safety and reliability of the bridge for many years to come.

Discussion

Analysis of the results obtained showed that the use of BIM technology will substantially increase the efficiency and accuracy of bridge reconstruction works. The technology will allow creating detailed digital models of existing structures, which will become the basis for further work. The use of laser scanning and photogrammetry will provide an accurate display of the current state of bridges, which will help identify critical areas that need immediate repair. Integrating this data into BIM will enable engineers and architects to develop optimal reconstruction solutions. This was also investigated by G. Qin *et al*. (2021), where the results confirmed that BIM substantially improves the efficiency and accuracy of bridge reconstruction. BIM is used to create a detailed digital model of the bridge structure, which includes all its components, from supports and beams to the road surface. This allows engineers and architects to visualise the project in three-dimensional space, which helps identify potential problems in the early stages of design. This reduces construction costs and minimises the risk of errors during project implementation. In addition, BIM provides centralised management of all project data, which facilitates coordination between different teams and improves the overall quality of reconstruction. A study by Y. Alshawabkeh *et al*. (2021) also showed that laser scanning and photogrammetry are innovative methods that are integrated into BIM for bridge reconstruction. Laser scanning uses laser beams to create high-precision three-dimensional models of existing structures, allowing engineers to get detailed information about the geometry and condition of the bridge. Photogrammetry, in turn, allows creating 3D models based on photos, ensuring accurate reproduction of the shape and size of the bridge. Combining these technologies within BIM helps create accurate and up-to-date digital models, which contributes to better planning and execution of reconstruction works. These methods also allow monitoring the progress of work and detecting any deviations from the project in real time. Notably, the use of BIM in combination with laser scanning and photogrammetry will not only improve the accuracy and quality of bridge reconstruction but also substantially reduce the time required to conduct preliminary surveys and develop project documentation. Due to these technologies, it is possible to quickly and accurately collect all the necessary data about the existing structure, which will allow engineers to focus on developing optimal solutions for reconstruction.

When planning a renovation, BIM technology will allow the creation of detailed work plans, considering the minimisation of the impact on traffic flows. The use of visualisation and simulation will not only allow for the prediction of possible problems but also provide a visual representation of future changes. This will facilitate better coordination between project participants and allow for more accurate planning of the use of materials and equipment, which will reduce waste and optimise costs. J. Tian *et al*. (2021) concluded that BIM technology substantially optimises bridge reconstruction planning by creating detailed three-dimensional models of structures. Using BIM allows accurately determining the amount of work, materials, and resources, contributing to a more accurate calculation of budget and time. Central storage and management of Project Data facilitates access to information for all participants, reducing the likelihood of errors and misunderstandings. BIM also helps quickly evaluate various reconstruction options, providing optimal technical and cost-effective solutions. A. Sampaio *et al*. (2024) established that visualisation and modelling in BIM improve project coordination and efficiency. Realistic project visualisations facilitate communication and coordination between participants, allowing for a clear presentation of the final result. Simulations in BIM model various work execution scenarios, predict possible delays and risks, and help develop alternative action plans. This contributes to better coordination and ensures more efficient and safe execution of construction work. These results support the above study, as they demonstrate that the use of

BIM in combination with visualisation and simulation substantially improves the accuracy and efficiency of bridge reconstruction. This will allow planning the work more efficiently, avoiding mistakes and misunderstandings, and optimising resource usage. In addition, centralised data management and the ability to simulate various work scenarios will contribute to better coordination between all project participants and ensure safer and better construction work. Thus, the use of these technologies makes a substantial contribution to improving the overall efficiency and reliability of reconstruction projects.

Coordination of project participants using a single BIM model will be a key factor in the success of bridge reconstruction. This will provide real-time access to up-to-date information for all professionals involved, including engineers, architects, and builders. This approach will facilitate prompt adjustments to the work plan based on the data obtained, which will allow you quickly responding to problems that arise and avoiding delays. A study by A. Costin *et al*. (2021) is notable, as the author established that a single BIM model is a critical factor in the success of bridge reconstruction, providing centralised storage and management of all project data. This allows creating detailed three-dimensional models of bridges that include architecture, engineering systems, and materials, making planning and decision-making easier. All project participants have access to up-to-date information, which helps to avoid data duplication and errors and provides continuous monitoring and control of the progress of work, reducing the risk of delays and overspending. In turn, A. Sampaio *et al*. (2023) concluded that BIM provides effective interaction between project specialists in real time, providing all participants with access to up-to-date information simultaneously. This promotes better coordination and quick problem-solving, helping to avoid delays and errors. Engineers, architects, and contractors can work on the same model at the same time, making changes and comments. Virtual meetings and discussions using BIM tools facilitate communication between remote teams, ensuring accurate and efficient execution of work. These data correspond to those given in the previous section. They confirm that a single BIM model substantially improves the accuracy and efficiency of bridge reconstruction, providing centralised data storage, and management. This will help you plan better, avoid mistakes, and use resources more efficiently. In addition, real-time coordination between project specialists using BIM will allow quickly responding to changes, solving problems, and ensuring smooth work of teams, which minimises the risks of delays and overspending. Thus, the use of BIM will create a solid foundation for successful and reliable bridge reconstruction.

During the reconstruction work, special attention should be paid to monitoring and managing the condition of structures in real time. The use of sensors and IoT technologies will allow constantly monitoring the condition of bridges and quickly identifying potential problems. This will ensure a high level of safety for both bridge builders and users, and help them to meet the established deadlines and project budget. M. Mishra *et al*. (2022) also conducted a study that confirmed that the use of IoT technologies for real-time monitoring increases the efficiency and reliability of bridges. Sensors located on structures monitor parameters such as vibrations, loads, and temperature changes, transmitting data to a central platform for analysis. This allows identifying problems at an early stage and preventing serious accidents, extending the service life of the bridge. In addition, the collected data helps to plan repairs based on the relevant state of the structure, optimising the cost of maintaining bridges. A. Rao *et al*. (2022) also determined that sensor systems and IoT technologies ensure the safety and compliance of bridge reconstruction deadlines. Sensors on construction sites monitor the condition of structures and other parameters in real time, allowing for quick detection of deviations and preventing accidents. This increases the safety of bridge builders and users. Sensor data also helps in planning and coordinating work more accurately, optimising resources, and identifying potential delays, ensuring efficient project management and timely completion of repairs. By comparing the data obtained in the course of the study, the use of IoT technologies and sensor systems substantially increases the efficiency and reliability of bridge structure management. Real-time monitoring will allow quickly responding to changes and deviations, preventing accidents, and extending the service life of bridges. These technologies also provide accurate repair planning, optimising infrastructure maintenance costs.

Completion of the reconstruction will include a final assessment of the quality of work performed and the creation of digital documentation on the activities conducted. Due to BIM, this documentation will be automatically created and saved for future reference during bridge maintenance. This will allow developing a regular maintenance plan that will ensure constant monitoring of the condition of bridges and identifying possible problems at an early stage. U. Riedlinger *et al*. (2022) concluded that the final assessment of the quality of bridge reconstruction using BIM ensures the accuracy and compliance of the project with standards. Detailed three-dimensional models reflect all design aspects, allowing for quality control at every stage. Digital documentation includes all the necessary data for further maintenance and operation of the bridge, ensuring transparency and accessibility of information. BIM digital documentation reduces the number of errors and improves communication between project participants. All changes are made in a single model, which ensures that information is up-to-date and simplifies decision-making. The final quality assessment allows identifying shortcomings and eliminating them before the project is completed, ensuring the high quality and reliability of the bridge. R. Panah and M. Kioumarsi (2021) identified that BIM provides efficient bridge maintenance planning by automating processes and continuously monitoring the condition of structures. Sensor data allows creating maintenance schedules based on the real condition of the bridge, ensuring timely repairs and reducing maintenance costs. Continuous monitoring using BIM allows quickly responding to changes or deviations from the norm, increasing the reliability and safety of bridges. Automated alert and analytics systems help quickly identify problems and plan actions to fix them, increasing the efficiency and economic benefits of infrastructure operation. When analysing the results of the study, it is clear that the use of BIM technologies in bridge reconstruction substantially increases the efficiency and quality of work. A single digital model will allow for more accurate control over the processes, reducing the number of errors and ensuring that information is up-to-date at all stages of the project. This will facilitate better coordination between project participants and faster decision-making. Thus, the use of BIM technology for bridge reconstruction has demonstrated its effectiveness and feasibility. Innovative approaches based on this technology will not only improve the quality of work performed but also ensure the long-term reliability and safety of structures. This confirms the need to implement BIM in further projects for the reconstruction and construction of infrastructure facilities.

Conclusions

– The study showed that the use of BIM technology for bridge reconstruction substantially increases the efficiency and accuracy of work. First of all, BIM technology allows creating detailed digital models of existing structures, which is the basis for further work. Due to laser scanning and photogrammetry, accurate data on the current condition of bridges can be obtained, which will allow identifying critical areas that require immediate repair. The reconstruction planning process using BIM will ensure the development of detailed work plans, considering the minimisation of the impact on traffic flows. The use of visualisation and simulations will allow anticipating possible problems and providing a visual representation of future changes, which will contribute to better coordination between project participants. This will help plan the use of materials and equipment more accurately, reducing waste and optimising costs.
– The coordination of project participants through a single BIM model will provide all involved specialists access to up-to-date information in real time, which will contribute to prompt adjustments to the work plan. Monitoring and managing the condition of structures in real time using sensors and IoT technologies will allow constantly monitoring the condition of bridges and quickly identifying potential problems. The final assessment of the quality of work performed and the creation of digital documentation on the activities carried out will provide a reliable basis for further maintenance of bridges. Using BIM will allow developing a regular maintenance plan that will ensure continuous monitoring of the condition of bridges and identify possible problems at an early stage. Thus, the use of BIM technology for bridge reconstruction has proven its effectiveness and feasibility, confirming the need to implement these innovative approaches in future projects for the reconstruction and construction of infrastructure facilities. The impact of using BIM technology on the long-term operation and maintenance of bridges, including economic and environmental aspects, should be investigated. One limitation of the study is that it does not consider possible technical and organisational difficulties that may arise when implementing BIM technology in less developed regions or in conditions of limited resources.

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ІННОВАЦІЙНІ ПІДХОДИ ДО РОБІТ З РЕКОНСТРУКЦІЇ МОСТІВ З ВИКОРИСТАННЯМ ТЕХНОЛОГІЇ BUILDING INFORMATION MODELLING

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Дослідження проведено з метою демонстрації переваг та інноваційних підходів використання технології Building Information Modeling (BIM) у процесі реконструкції Варварівського мосту через Південний Буг у Миколаєві, з акцентом на покращення ефективності, точності та координації робіт. У цьому дослідженні використовувалися методи лазерного сканування, фотограмметрії, 3D-моделювання, BIM, а також сенсорного моніторингу та Internet of Things (IoT) для створення точних цифрових моделей мосту та створення пропозиції оптимізації процесу його реконструкції. У результаті дослідження було встановлено, що використання технології BIM значно покращує процес реконструкції мостів. Застосування 3D-сканування та фотограмметрії дозволить створити точну цифрову модель мосту, що забезпечить більш детальний аналіз структурної цілісності. Оптимізація планування робіт за допомогою BIM сприятиме зниженню витрат та скороченню термінів виконання робіт. Покращена координація між учасниками проекту завдяки єдиній інформаційній моделі дозволить уникнути помилок та підвищила якість виконаних робіт. Додатково використання сенсорів та технологій IoT для моніторингу стану мосту в режимі реального часу дозволить оперативно виявляти та усувати потенційні проблеми. Автоматизація створення цифрової документації та архівування всіх даних у BIM значно спростить подальше технічне обслуговування мосту. Підтверджено, що впровадження BIM у реконструкцію мостів сприятиме підвищенню безпеки, ефективності та економічності проектів. Дослідження демонструє практичну цінність використання технології BIM у реконструкції мостів, покращуючи процес планування, координації та моніторингу, що призводить до більш безпечних, ефективних та економічних будівельних проектів

Ключові слова: 3D-сканування; фотограмметрія; цифрова модель; аналіз структурної цілісності; оптимізація планування; моніторинг

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