PROSPECTS OF DIGITAL TWIN IMPLEMENTATION IN URBAN WATER SUPPLY AND WASTEWATER SYSTEMS IN UKRAINE

Kravchuk Oleksandr
Candidate of Technical Sciences, Associate Professor
Water Supply and Water Disposal Department
Lavrukhina Kateryna
Candidate of Economic Sciences, Associate Professor
Department of Construction Economics
Kyiv National University of Construction and Architecture, Ukraine

The full-scale war in Ukraine has caused extensive destruction of critical infrastructure facilities, in particular water supply and wastewater systems, which constitute a fundamental component of the life-support systems of cities and settlements. A significant part of water supply and sewerage networks has suffered direct damage, emergency shutdowns, or is operating under conditions of increased deterioration and limited resources [1, 2]. Under these circumstances, ensuring uninterrupted, safe, and energy-efficient water supply acquires not only engineering but also social and security significance.

The post-war reconstruction of Ukraine's municipal infrastructure requires a transition from the simple restoration of destroyed facilities to their systematic modernization based on the principles of sustainable development, digitalization, and compliance with European standards [3–5]. In this context, the implementation of modern digital management tools capable of ensuring transparency of the technical condition of networks, risk forecasting, and evidence-based investment planning becomes particularly relevant [6, 7].

One such tool is digital twin technology, which enables the creation of integrated digital models of urban water supply and wastewater systems that account for their actual condition, operating modes, and the influence of external factors. The use of digital twins opens new opportunities for rapid response to emergency situations, optimization of operation, and strategic planning of water infrastructure development under conditions of increased risk.

A digital twin is a dynamic digital model of a physical object, process, or system that reproduces its real state and behavior through the integration of design, spatial, and operational data. Unlike traditional static models, a digital twin operates in a continuous update mode, providing capabilities for analysis, forecasting, and decision-support in management processes [8].

In the context of urban water supply and wastewater systems, digital twins represent network structures, hydraulic parameters, the technical condition of equipment, operating modes of pumping stations and treatment facilities, as well as system responses to changes in demand, emergency situations, and climatic impacts.

Unlike individual BIM models or calculation schemes, a digital twin has an integrated and process-oriented nature, enabling scenario modeling and comprehensive analysis of the functioning of engineering systems [9, 10].

In the process of restoring Ukraine's municipal infrastructure, digital twins play an important role in assessing damage to engineering networks. Based on BIM and GIS data, results of technical inspections, and information from monitoring and dispatch systems, an up-to-date digital model is formed, allowing the identification of critical network sections, prioritization of recovery measures, and minimization of the risk of repeated failures.

An important function of digital twins is the modeling of recovery scenarios for municipal infrastructure facilities. Digital models make it possible to analyze various options for reconstruction or replacement of damaged elements, assess their technical, economic, and environmental impacts, and predict their influence on the overall system performance. This enables the selection of optimal recovery scenarios, taking into account limited financial resources and the principles of sustainable development.

The application of digital twins also contributes to improving the efficiency of planning repair and recovery works. The development of phased implementation plans, identification of resource requirements, and coordination between design, operational, and management units help reduce cost overruns and facilitate a transition from reactive to proactive infrastructure management.

Digital twins are an important instrument for implementing the principles of sustainable development in municipal infrastructure. Their use ensures the optimization of water, energy, and material resource consumption, reduction of operating costs and losses, and improvement of the energy efficiency of water supply and wastewater facilities. Modeling environmental parameters enables the assessment of the impact of engineering systems on the environment and supports the alignment of their operation with European environmental standards.

The social effect of digital twin implementation is reflected in improved reliability and quality of municipal services, reduced accident rates, and increased transparency of management processes, which contributes to greater public trust in local self-government authorities.

The implementation of digital twins in Ukraine's municipal sector offers several advantages, including increased reliability and safety of engineering systems, transparency in the management of municipal assets, and data-driven decision-making support. At the same time, this process is accompanied by challenges related to the insufficient level of digital maturity of municipal enterprises, a shortage of qualified personnel, and limited regulatory and financial support.

Further development of digital twins in Ukraine should be pursued through the adaptation of European experience, particularly in the context of post-war reconstruction of municipal infrastructure and integration with Smart City and digital community concepts. This creates the prerequisites for forming a modern, resilient, and efficient system for managing urban engineering networks.

Thus, the application of digital twin technology in Ukraine's water supply and wastewater systems is an effective tool for post-war recovery and sustainable

development of municipal infrastructure. Digital twins provide comprehensive assessment of the technical condition of engineering networks, support scenario-based modeling of recovery measures, and enable evidence-based investment planning, thereby enhancing the reliability, energy efficiency, and environmental safety of municipal systems. At the same time, further advancement of digital twins in Ukraine requires overcoming digital maturity barriers, developing human capital, and establishing appropriate regulatory and financial frameworks in line with European experience and Smart City principles.

References

1. Kravchenko, O., Khoruzhy, V., & Kanibolotsky, V. (2022). Peculiarities of operation of drinking water supply systems in wartime. Problems of Water Supply, Sewerage and Hydraulic, 38, 18–37. https://doi.org/10.32347/2524-0021.2022.38.18-37
2. Kravchuk, O., Andriiashchenko, O., Levitin, V., Yeremchenko, L., & Lavrukhina, K. (2024). Recommendations regarding the operation features of water supply and sewerage pumping stations during military actions. Urban Development and Spatial Planning, 85, 268–276. https://doi.org/10.32347/2076-815x.2024.85.268-276
3. Levchenko, O., Mykhailenko, A., & Cherevatyi, A. (2025). BIM for the sustainable reconstruction of Ukraine. Current Problems of Architecture and Urban Planning, 72, 82–102. https://doi.org/10.32347/2077-3455.2025.72.82-102
4. Lavrukhina, K., Tytok, V., & Kravchuk, O. (2024). Innovative approaches and solutions of domestic construction companies for the reconstruction of post-war Ukraine. Building Production, 77, 85–91. https://doi.org/10.36750/2524-2555.77.85-91
5. Kravchuk, O., & Lavrukhina, K. (2025). Applying clusters to improve the reliability of water supply and wastewater systems in Ukraine. Proceedings of the International Scientific and Practical Conference, Sumy, June 13–14, 2025 / edited by Karintseva O. and Kubatko O. Sumy: Sumy State University, 2025. 76–78.
6. Kravchenko, O., Khoruzhy, V., Lyubenko, V., & Nedashkovsky, I. (2023). BIM technologies in engineering network design. Problems of Water Supply, Sewerage and Hydraulic, 42, 29–34. https://doi.org/10.32347/2524-0021.2023.42.29-34
7. Кравчук, О., & Лаврухіна, К. (2025). Перспективи застосування BIM-технологій у міських системах водопостачання та водовідведення в Україні. Збірник наукових праць XVIII Міжнародної науково-практичної конференції «Академічна й університетська наука: результати та перспективи», 09–12 грудня 2025 року. Полтава: Полтавська політехніка, 2025. 265–267.
8. Tao, F., Xiao, B., Qi, Q., Cheng, J., & Ji, P. (2022). Digital twin modeling. Journal of Manufacturing Systems, 64, 372-389. https://doi.org/10.1016/j.jmsy.2022.06.015
9. Shen, Y. (2025). Integration of IoT and digital twin for intelligent management of urban underground pipe galleries in smart cities. Informatica, 49(15). https://doi.org/10.31449/inf.v49i15.7903
10. Iancu, G., Ciolofan, S. N., & Drăgoicea, M. (2024). Real-time IoT architecture for water management in smart cities. Discover Applied Sciences, 6(4), 191. https://doi.org/10.1007/s42452-024-05855-9