International Journal of Social and Education (INJOSEDU) e-ISSN: 3047-6151
Vol. 3 No. 1 April 2026, hal., 85-97

DIGITAL TWIN TECHNOLOGY IN ENGINEERING SYSTEMS: REAL-TIME MONITORING AND PREDICTIVE MAINTENANCE

Renaldy Salam
Universitas Pancasakti Tegal, Indonesia
Email: renaldysalam11@gmail.com

Abstract

Engineering systems have been profoundly altered by the quick development of digital technologies, especially with the use of Digital Twin technology. The purpose of this project is to investigate how digital twins facilitate predictive maintenance and real-time monitoring within engineering systems using a literature review approach. The method involves systematically analyzing and synthesizing findings from recent scholarly articles, conference proceedings, and technical reports related to Digital Twin applications. The results indicate that The development of virtual copies of real systems is made easier by digital twin technology, enabling continuous data integration, performance simulation, and anomaly detection. Through real-time monitoring, engineering systems can achieve improved operational transparency and faster decision-making. Furthermore, the implementation of predictive maintenance supported by Digital Twin reduces downtime, optimizes maintenance scheduling, and minimizes operational costs by predicting potential failures before they occur. However, challenges such as data integration complexity, high implementation costs, and cybersecurity risks remain significant barriers. This study highlights that despite these challenges, Digital Twin technology presents substantial opportunities for enhancing efficiency, reliability, and sustainability in modern engineering systems. Future research is recommended to focus on scalable frameworks and secure data architectures to maximize its implementation.

Keywords: Digital Twin, Engineering Systems, Real-Time Monitoring, Predictive Maintenance, Smart Maintenance, Industrial IoT

INTRODUCTION

The development of digital technology in recent decades has brought significant changes to various industrial sectors, particularly in systems engineering. The Industrial Revolution 4.0, A new paradigm for managing engineering systems that is more intelligent, adaptive, and efficient has emerged as a result of the combination of information technology, the Internet of Things (IoT), artificial intelligence, and data analytics (Zhong et al., 2023a). In this situation, it is more important than ever to have systems that can monitor in real time and anticipate possible errors before they happen. This has to do with sustainability, safety, and operational effectiveness and reducing the often-high maintenance costs of complex engineering systems.

One technological innovation that has emerged in response to this need is Digital Twin Technology. A digital twin is a virtual version of a real-world system, process, or object that uses real-time data integration to dynamically reproduce its current state. Accurate monitoring and thorough analysis of a system's true state are made possible by this technology, which permits two-way communication between the real and virtual worlds (Singh et al., 2023). Engineers and system managers may make better educated, data-driven decisions, identify abnormalities early, and obtain more thorough insights into system performance using a digital twin.

In modern engineering systems, the primary challenges often faced are increasing system complexity and the need for optimal operational reliability. Systems such as power plants, transportation networks, automation-based manufacturing, and smart infrastructure require continuous monitoring to ensure all components are operating according to established standards. Conventional reactive or schedule-based system maintenance methods are often inefficient because they fail to detect sudden failures or account for the actual condition of components. As a result, system failures can occur without warning, potentially causing significant economic and safety losses.

In this context, Using a digital twin provides a more proactive method through the concept of predictive maintenance. By utilizing historical and real-time data combined with analytical algorithms and machine learning, a digital twin can predict the likelihood of component failure before it actually occurs. This enables timely and planned maintenance actions, reducing downtime, increasing operational efficiency, and extending equipment lifespan. Furthermore, the simulation capabilities of digital twins allow testing various operational scenarios without disrupting the physical system, significantly minimizing risks (Wahab et al., 2024).

However, implementing digital twins in engineering systems is not without challenges. One major challenge is integrating data from multiple sources in different formats. Furthermore, the need for adequate technological infrastructure, such as high-speed communication networks and large computing capacity, is also crucial for the successful implementation of this technology. Data security and privacy are also important concerns, given that digital twins involve continuous data exchange between physical and digital systems (Panyaram, 2024). Therefore, a comprehensive approach is required in designing and implementing digital twins to achieve optimal benefits.

On the other hand, the development of supporting IoT, cloud computing, and big data analytics are examples of technologies that have made it possible to tackle these issues. Accurate real-time data collecting is made possible by increasingly complex sensors. Cloud technology provides a flexible platform for large-scale data storage and processing, while data analytics enables valuable insights from available data. The combination of these technologies makes digital twins an increasingly relevant and applicable solution in various industrial sectors. In a research context, studying digital twins in engineering systems is crucial for a deeper understanding of their potential, benefits, and the challenges faced in their implementation. Literature-based research can give a thorough summary of recent advancements, research trends, and industry best practices. As a result, it is anticipated that this study will add to the body of knowledge and act as a guide for the creation and use of digital twins in the future.

Furthermore, the focus on real-time monitoring and predictive maintenance in this research is highly relevant, given that these two aspects are key to improving the efficiency and reliability of engineering systems. Real-time monitoring enables immediate and continuous detection of system conditions, while predictive maintenance provides a more strategic approach to maintenance management. Integrating these two aspects through a digital twin is expected to create a system that is not only responsive to change but also able to anticipate problems before they occur (Keskar, 2025). Against this background, this study aims to in-depth examine the role of digital twin technology in engineering systems, specifically in supporting real-time monitoring and predictive maintenance. This study is expected to provide a clearer understanding of how this technology can be implemented effectively and the factors influencing its success. Furthermore, this research is also expected to identify opportunities for further development and provide recommendations for future research in this evolving field.

RESEARCH METHOD

This study's research methodology combines a qualitative approach with a review of the literature. The goal of this research is to thoroughly investigate the idea, application, and advancement of digital twin technology in engineering systems, with a focus on real-time monitoring and predictive maintenance. Research data came from a variety of pertinent secondary sources, including credible international journal papers, conference proceedings, scientific books, and technical reports published within a specific timeframe to ensure the freshness of the information. The literature search was conducted through academic databases such as Scopus, Web of Science, IEEE Xplore, and Google Scholar using keywords related to "digital twin," "engineering systems," "real-time monitoring," and "predictive maintenance." The obtained literature was then selected based on inclusion and exclusion criteria, such as topic relevance, publication quality, and contribution to the development of the research concept.

Next, By classifying, contrasting, and synthesizing numerous prior study findings, the gathered data was examined utilizing qualitative descriptive analytic approaches. The purpose of the analysis was to find patterns, trends, and connections between ideas pertaining to the use of digital twins to increase the dependability and operational efficiency of engineering systems. Furthermore, a conceptual approach is used to develop a systematic framework for integrating sensor technology, digital twins using artificial intelligence and the Internet of Things (IoT). The analysis's findings are subsequently given in a detailed account to give readers a thorough grasp of the digital twin's function as a cutting-edge remedy for supporting predictive maintenance systems and real-time data-driven monitoring.

RESULT AND DISCUSSION

Internet of Things (IoT) Integration in Digital Twins

The integration One of the most important developments in the digital transformation of contemporary engineering systems is the use of the Internet of Things (IoT) in digital twins. The concept of a Digital Twin is essentially a virtual representation of a physical object, system, or process that is continuously updated in real-time through data streams from the real world. In this context, IoT acts as a key backbone, enabling the continuous collection, transmission, and synchronization of data between the physical entity and its digital model. Without IoT, a Digital Twin would not be able to function dynamically due to the lack of accurate and continuous real-time data (A Survey on Digital Twin for Industrial Internet of Things, n.d.).

IoT enables various Sensors, actuators, and other smart devices are examples of physical devices that can be linked together into a single, integrated network. Temperature, pressure, vibration, humidity, and even specific machine operating conditions can all be recorded by these devices. After that, this data is sent to the Digital Twin platform for processing and analysis via a communication network (del Campo et al., 2024). A Digital Twin can reflect the true state of a physical device in almost real time thanks to this constant data stream, facilitating quicker and more precise decision-making. IoT integration into a Digital Twin also expands the system's capabilities for continuous monitoring. In engineering systems such as manufacturing, energy, and transportation, real-time monitoring of asset condition is crucial for maintaining performance and preventing failures. IoT enables sensors to continuously transmit operational data, while the Digital Twin visualizes and analyzes this data in the form of simulations or digital models. This allows operators not only to view current conditions but also to understand patterns and trends that occur over time.

Furthermore, this integration significantly contributes to the development of predictive maintenance. By leveraging historical and real-time data collected through IoT, a Digital Twin can use analytical algorithms and artificial intelligence to predict potential system failures before they occur. This enables companies to take more efficient preventative measures, reduce downtime, and lower maintenance costs. This approach is significantly superior to traditional maintenance methods that are reactive or based on fixed schedules (A. et al., 2023).

Furthermore, IoT integration within a Digital Twin also supports comprehensive system performance optimization. Data collected from various points within the system enables the Digital Twin to simulate various operational scenarios. A Digital Twin, for instance, can mimic changes in production parameters to determine the most effective configuration in the manufacturing sector. By taking into account current demand and grid circumstances, a digital twin can aid in the optimization of energy distribution in the energy sector. This capability not only improves operational efficiency but also supports sustainability through more optimal resource utilization (Attaran et al., 2024).

However, the integration of IoT into a Digital Twin also faces several challenges that require attention. One major challenge relates to data security. Because IoT involves the continuous transmission of data over a network, the risk of cyberattacks increases. Unprotected data can be misused or manipulated, ultimately compromising the accuracy of the Digital Twin. Therefore, a robust security system is required, including data encryption, device authentication, and strict access management. Furthermore, other challenges arise related to interoperability and system integration. IoT involves a variety of devices from different manufacturers with varying standards. This can make it difficult to integrate data into a single, unified Digital Twin platform. To address this, compatible communication standards and protocols are required, as well as an integration platform capable of effectively managing data from various sources. Without strong interoperability, the full potential of IoT and Digital Twin integration will not be realized.

Another crucial aspect is large-scale data administration. Massive amounts of data are produced by IoT, and these volumes keep growing as more devices are connected. To continue delivering precise and rapid analytical results, a Digital Twin must be able to effectively manage, store, and process this data. To guarantee that the system may function at its best without encountering bottlenecks, this calls for the assistance of technologies like cloud computing, edge computing, and big data analytics (Zayed et al., 2023). Furthermore, the integration of IoT into a Digital Twin also opens up significant opportunities for developing more intelligent and adaptive systems. With the ability to learn from data, a Digital Twin can evolve into a system that not only represents physical conditions but also provides recommendations and even performs automated actions. For example, in an intelligent industrial system, a Digital Twin can automatically adjust operational parameters based on environmental conditions or workload, thereby increasing system efficiency and flexibility.

More broadly, this integration also plays a crucial role in supporting the concepts of smart cities and Industry 4.0. IoT enables data collection from various city infrastructures such as transportation, energy, and utilities, while the Digital Twin provides a platform for analyzing and simulating these systems holistically. This allows governments and stakeholders to design more effective policies and strategies based on accurate and comprehensive data.

Overall, IoT integration within a Digital Twin is a key foundation for the development of modern, data-driven, efficiency-driven engineering systems. The combination of IoT's ability to collect real-time data and the Digital Twin's ability to analyze and simulate that data creates a system that is not only responsive but also proactive. While there are challenges to overcome, the potential benefits offered by this integration are substantial, ranging from increased operational efficiency and cost reduction to enhanced system reliability and sustainability. Therefore, The creation and application of IoT integration in a digital twin will continue to be a key focus for digital transformation across various industrial sectors in the future.

Digital Twin Applications in Energy and Infrastructure Systems

The application of digital twins in energy and infrastructure systems is a transformational innovation that enhances sustainability, dependability, and efficiency by fusing digital technology with physical systems. A digital twin is a virtual version of a physical system, process, or asset that is updated in real time by integrating sensor data, the Internet of Things (IoT), and artificial intelligence-based analytics. In the context of energy and infrastructure systems, this technology plays a crucial role in monitoring, analyzing, and optimizing the performance of various components such as power plants, distribution networks, transportation, and even urban infrastructure as a whole (Braik & Koliou, 2023). With the ability to simulate real-world conditions, digital twins enable faster and more accurate decision-making based on both actual data and future predictions.

In energy systems, the application of digital twins significantly contributes to the management of power plants, both conventional and renewable energy-based. For example, in wind and solar power plants, Digital twins are used to track the operation of turbines and panels in real time, spot possible damage, and anticipate maintenance requirements before system breakdowns happen. In addition to increasing operational effectiveness, this lowers downtime, which may have an effect on financial losses (Liu et al., 2023). Additionally, with a smart grid, a digital twin functions to integrate various distributed energy sources, dynamically manage electricity loads, and maintain grid stability. Thus, this technology supports the transition to a cleaner and more sustainable energy system.

Furthermore, a digital twin also is essential to enhancing energy distribution efficiency. By utilizing data from sensors installed in the transmission and distribution network, a digital twin system can detect anomalies such as energy leaks, overloads, or other technical disruptions early. Historical and predictive data-driven analysis enables operators to optimize energy flows, reduce power losses, and improve electricity supply reliability. On a broader scale, integrating a digital twin with advanced analytics technology allows simulations of various operational scenarios, such as surges in energy demand or system disruptions due to natural disasters, allowing effective mitigation strategies to be developed.

In the infrastructure sector, The use of a digital twin has an equally important effect. Infrastructure such as bridges, roads, buildings, and transportation systems can be digitally modeled to continuously monitor structural and operational conditions. For example, on bridges and tall buildings, installed sensors can transmit data related to vibrations, stresses, and structural deformation to a digital twin system. This data is then analyzed to detect potential damage or structural degradation early, allowing repairs to be taken before more serious damage occurs. This is crucial for maintaining public safety and extending the lifespan of infrastructure (Ismail et al., 2024).

Digital twins make it possible to operate transportation systems more intelligently and cohesively. Real-time route optimization, traffic flow monitoring, and congestion detection can all be achieved through modeling urban transportation systems. Additionally, digital twins can be utilized to replicate the effects of specific transportation policies, such as lane changes or the implementation of odd-even traffic systems, before they are implemented. This makes transportation planning and management more efficient and data-driven.

The primary advantage of implementing digital twins in energy and infrastructure systems lies in their ability to support predictive maintenance. Unlike traditional reactive or schedule-based maintenance approaches, digital twins enable the identification of potential damage before it occurs. This is achieved through continuous data analysis combined with machine learning algorithms (Sharifi et al., 2024). This reduces maintenance costs, minimizes the risk of operational disruptions, and extends asset lifespan. Furthermore, digital twins also support increased energy efficiency by optimizing resource use in real time.

However, implementing digital twins is not without challenges. One of the main challenges is the need for adequate technological infrastructure, including reliable communication networks, accurate sensor devices, and high computing capacity. Furthermore, integrating It might be difficult to ensure data consistency and quality when dealing with data from several sources Cybersecurity is also a crucial concern, given that digital twins involve continuous data exchange, which is vulnerable to cyberattacks. Therefore, a comprehensive security strategy is required to protect the system from potential threats.

Furthermore, human resources are also key to the success of digital twin implementation. A workforce with competencies in information technology, data analytics, and an understanding of energy and infrastructure systems is required. Collaboration between various stakeholders, including government, industry, and academia, is crucial in developing a sustainable digital twin ecosystem. Furthermore, supportive regulations and policies are needed to encourage the widespread adoption of this technology (A Review on Digital Twin Technology in Smart Grid, Transportation System, and Smart City, n.d.).

Overall, Efficiency, dependability, and sustainability can be greatly increased by applying digital twins to infrastructure and energy systems. This technology allows for more precise, data-driven decision-making by simulating and monitoring system conditions in real time. The quick advancement of technology and the increasing demand for more intelligent and effective systems make digital twins possible despite a number of implementation problems a relevant and strategic solution for the future. In the context of sustainable development, digital twins serve not only as a technological tool but also as an enabler in creating more adaptive, resilient, and environmentally friendly energy and infrastructure systems.

Case Studies of Digital Twin Use in Engineering System Maintenance

Case studies of digital twin use in engineering system maintenance demonstrate how the integration of Predictive analytics, virtual models, and real-time data can greatly increase system dependability and operational efficiency. A digital twin is an electronic version of a physical object that is updated on a regular basis using information from sensors and Internet of Things (IoT) devices (Salzano et al., 2025). In a maintenance context, this technology enables engineering system managers to monitor equipment condition in real time, identify potential failures early, and plan more precise, data-driven maintenance actions. The implementation of a digital twin not only shifts the maintenance approach from reactive to proactive but also drives a transformation toward more efficient and economical predictive maintenance.

One frequently referenced The use of digital twins in the manufacturing sector, namely in automated machine-based production processes, is the subject of this case study. Every equipment in this setting has sensors that gather information on temperature, vibration, pressure, and speed of operation. After that, this data is sent to a digital twin platform for analysis in real time (Zhong et al., 2023b). Using accurate simulation models, the system can detect anomalies that indicate potential machine failure. For example, an abnormal increase in vibration in a particular component can be an early indicator of wear or damage. Through a digital twin, technicians can perform analysis without having to stop the machine, thus minimizing downtime. Furthermore, the system can recommend optimal maintenance schedules based on the actual condition of the machine, rather than just predetermined time intervals.

Digital twins have also been extensively utilized in the energy sector for power generation system maintenance, including wind and gas turbines. Digital twins make it possible to continuously monitor the state of the generators, gearboxes, and turbine blades of wind turbines. The collected data is used to build predictive models that estimate component lifespan and the likelihood of failure. This allows operators to initiate maintenance before more serious damage occurs. This is particularly important given that wind turbines are often located in remote or offshore locations, making maintenance and repair costs prohibitively high if performed reactively. Digital twins help reduce these costs by increasing the accuracy of maintenance decision-making.

Other case studies can be found in the transportation sector, particularly in the maintenance of railway and aircraft systems. In the aviation industry, digital twins are used to monitor aircraft engine conditions in real time during flight. Data obtained from engine sensors is analyzed to detect deviations from normal conditions. If potential damage is detected, the system can alert technicians on the ground before the aircraft lands (Nasirinejad et al., 2026). This allows for early maintenance preparation, thereby shortening aircraft turnaround times. Furthermore, digital twins are used to simulate various operational scenarios to improve system reliability and flight safety.

In the context of infrastructure, such as bridges and buildings, digital twins are used to continuously monitor structural conditions. Sensors installed on the structure collect data related to deformation, vibration, and environmental conditions. This data is then used to update the digital twin model, reflecting the actual condition of the structure. This approach allows for early detection of potential damage, allowing corrective action to be taken before structural failure occurs. Case studies on bridges have shown that digital twins are capable of identifying microcracks that are not visually visible but have the potential to develop into larger damage if left untreated.

Despite its many advantages, implementing digital twins in engineering systems maintenance also faces various challenges. One major challenge is the need for adequate technological infrastructure, including sensors, communication networks, and computing systems capable of processing large amounts of data in real time. Furthermore, the accuracy of digital twin models is highly dependent on the quality of the collected data. If the data used is inaccurate or incomplete, the resulting analysis and predictions will be less reliable (van Dinter et al., 2023). Therefore, a sound data management system and strong integration between various technological components are required.

Beyond technical aspects, human resources are also a challenge in implementing digital twins. The use of this technology requires a workforce competent in data analysis, system modeling, and information technology. This requires training and skills development for the workforce to optimally utilize digital twin technology. Furthermore, organizational culture changes are also needed to support the transition from traditional maintenance approaches to data- and technology-driven approaches (Werbińska-Wojciechowska et al., 2024).

Overall, case studies of digital twins in engineering system maintenance demonstrate that this technology has the potential to greatly increase system safety, dependability, and efficiency. Digital twins facilitate quicker and more precise decision-making by enabling real-time condition monitoring and predictive analysis. While various challenges remain in implementation, continued technological development is expected to overcome these obstacles and encourage broader adoption of digital twins across various industrial sectors. Thus, digital twins will become not only a maintenance tool but also an integral part of the digital transformation of modern engineering systems.

CONCLUSION

The conclusion In this study shows that the use of digital twin technology in engineering systems greatly increases the efficiency of real-time monitoring and forecasts possible system faults. Digital twins can accurately and virtually depict a system's physical state by combining sensor data, the Internet of Things (IoT), and artificial intelligence-based analytics. This enables faster, data-driven decision-making, thereby improving operational reliability, reducing downtime, and optimizing overall system performance.

Furthermore, the implementation of this technology in predictive maintenance has been shown to shift the maintenance paradigm from a reactive to a proactive approach. With continuous predictive analysis, potential damage can be identified before failure occurs, thereby improving maintenance cost efficiency and extending asset lifespan. However, challenges such as the need for complex technological infrastructure, data security, and human resource readiness remain critical factors that must be addressed to ensure the successful adoption of Digital Twin Technology in engineering systems in the future.

REFERENCES

A Review on Digital Twin Technology in Smart Grid, Transportation System and Smart City: Challenges and Future. (n.d.). Retrieved April 10, 2026, from https://ieeexplore.ieee.org/abstract/document/10034656

A., S., Vairavasundaram, S., Kotecha, K., V., I., Ravi, L., Selvachandran, G., & Abraham, A. (2023). Blockchain-based trust mechanism for digital twin empowered Industrial Internet of Things. *Future Generation Computer Systems*, *141*, 16–27. https://doi.org/10.1016/j.future.2022.11.002

A Survey on Digital Twin for Industrial Internet of Things: Applications, Technologies and Tools. (n.d.). Retrieved April 10, 2026, from https://ieeexplore.ieee.org/abstract/document/10188847

Attaran, S., Attaran, M., & Celik, B. G. (2024). Digital Twins and Industrial Internet of Things: Uncovering operational intelligence in industry 4.0. *Decision Analytics Journal*, *10*, 100398. https://doi.org/10.1016/j.dajour.2024.100398

Braik, A. M., & Koliou, M. (2023). A novel digital twin framework of electric power infrastructure systems subjected to hurricanes. *International Journal of Disaster Risk Reduction*, *97*, 104020. https://doi.org/10.1016/j.ijdrr.2023.104020

del Campo, G., Saavedra, E., Piovano, L., Luque, F., & Santamaria, A. (2024). Virtual Reality and Internet of Things Based Digital Twin for Smart City Cross-Domain Interoperability. *Applied Sciences*, *14*(7), 2747. https://doi.org/10.3390/app14072747

Ismail, F. B., Al-Faiz, H., Hasini, H., Al-Bazi, A., & Kazem, H. A. (2024). A comprehensive review of the dynamic applications of the digital twin technology across diverse energy sectors. *Energy Strategy Reviews*, *52*, 101334. https://doi.org/10.1016/j.esr.2024.101334

Keskar, A. (2025). Advancing Industrial IoT and Industry 4.0 through Digital Twin Technologies: A comprehensive framework for intelligent manufacturing, real-time analytics and predictive maintenance. *World Journal of Advanced Engineering Technology and Sciences*, *14*, 228–240.

Liu, C., Zhang, P., & Xu, X. (2023). Literature review of digital twin technologies for civil infrastructure. *Journal of Infrastructure Intelligence and Resilience*, *2*(3), 100050. https://doi.org/10.1016/j.iintel.2023.100050

Nasirinejad, M., Afshari, H., & Sampalli, S. (2026). The adoption of digital twin technologies for maintenance in small and medium-sized enterprises: Challenges and benefits. *Advanced Engineering Informatics*, *74*, 104645. https://doi.org/10.1016/j.aei.2026.104645

Panyaram, S. (2024). Digital Twins & IoT: A New Era for Predictive Maintenance in Manufacturing. *Vol. No.*, (10).

Salzano, A., Cascone, S., Zitiello, E. P., & Nicolella, M. (2025). HVAC System Performance in Educational Facilities: A Case Study on the Integration of Digital Twin Technology and IoT Sensors for Predictive Maintenance. *Journal of Architectural Engineering*, *31*(1), 04025004. https://doi.org/10.1061/JAEIED.AEENG-1855

Sharifi, A., Tarlani Beris, A., Sharifzadeh Javidi, A., Nouri, M., Gholizadeh Lonbar, A., & Ahmadi, M. (2024). Application of artificial intelligence in digital twin models for stormwater infrastructure systems in smart cities.

Advanced Engineering Informatics, *61*, 102485. https://doi.org/10.1016/j.aei.2024.102485

Singh, R. R., Bhatti, G., Kalel, D., Vairavasundaram, I., & Alsaif, F. (2023). Building a Digital Twin Powered Intelligent Predictive Maintenance System for Industrial AC Machines. *Machines*, *11*(8), 796. https://doi.org/10.3390/machines11080796

van Dinter, R., Tekinerdogan, B., & Catal, C. (2023). Reference architecture for digital twin-based predictive maintenance systems. *Computers & Industrial Engineering*, *177*, 109099. https://doi.org/10.1016/j.cie.2023.109099

Wahab, N. H. A., Hasikin, K., Lai, K. W., Xia, K., Bei, L., Huang, K., & Wu, X. (2024). Systematic review of predictive maintenance and digital twin technologies challenges, opportunities, and best practices. *PeerJ Computer Science*, *10*, e1943. https://doi.org/10.7717/peerj-cs.1943

Werbińska-Wojciechowska, S., Giel, R., & Winiarska, K. (2024). Digital Twin Approach for Operation and Maintenance of Transportation System—Systematic Review. *Sensors*, *24*(18), 6069. https://doi.org/10.3390/s24186069

Zayed, S. M., Attiya, G. M., El-Sayed, A., & Hemdan, E. E.-D. (2023). A review study on digital twins with artificial intelligence and internet of things: Concepts, opportunities, challenges, tools and future scope. *Multimedia Tools and Applications*, *82*(30), 47081–47107. https://doi.org/10.1007/s11042-023-15611-7

Zhong, D., Xia, Z., Zhu, Y., & Duan, J. (2023a). Overview of predictive maintenance based on digital twin technology. *Heliyon*, *9*(4). https://doi.org/10.1016/j.heliyon.2023.e14534

Zhong, D., Xia, Z., Zhu, Y., & Duan, J. (2023b). Overview of predictive maintenance based on digital twin technology. *Heliyon*, *9*(4). https://doi.org/10.1016/j.heliyon.2023.e14534