Digital Twins and E-Learning: Navigating Challenges and Opportunities

# Digital Twins and E-Learning: Navigating Challenges and Opportunities

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**Abstract.** Digital Twin (DT) has gained significant traction over the last decade, and it has been defined many times from different perspectives by the academy and industry communities. Although DTs are widely used in e.g. manufacturing, healthcare, agriculture, their potential applications will soon extend and cover other domains. In this scenario, education is required to play a major role in building its own DT models for purposes ranging from academic to professional training. The DT technology in the education context is expected to enhance the outcomes and scopes of the standard digital e-learning approaches. A particular aspect of the research includes how the DT concept can be transferred over to e-learning and its technology adjusted for a virtual to virtual model. Furthermore, DT is a unique phenomenon, often misinterpreted, that need to be well-defined within a proper framework. In this work, we present the architecture of a Prototypical Digital Twin architecture and explain the importance of defining a framework for a DT-Learning concept.

**Keywords:** Digital Twin · E-Learning · Technology

## 1 Introduction

### 1.1 Background

In recent years, the rapid advances of technology has brought forth new paradigms that have the potential to revolutionize various industries and sectors. One such paradigm is the concept of Digital Twins (DT). A DT is a virtual replica of a physical object, system, or process that is synchronized in real-time with its physical counterpart. It enables monitoring, analysis, and simulation of the physical entity, providing valuable insights and opportunities for optimization and improvement.

NASA has defined a DT as "an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin." [21].

Michael Grieves has defined DT "as a set of virtual information constructs that fully describe a potential or actual physical manufactured product from the micro atomic level


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to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physically manufactured product can be obtained from a DT" [9].

If we look further, the CIRP Encyclopedia has defined DT as "a digital representation of an active unique product (real device, object, machine, service, or intangible asset) or unique product-service system (a system consisting of a product and a related service) that comprises its selected characteristics, properties, conditions, and behaviors by means of models, information, and data within a single or even across multiple life cycle phases" [6, 24].

The E-learning is a very broad and familiar to everyone, however, it is crucial to define it precisely. According to the Cambridge Dictionary, e-learning is "learning done by studying at home using computers and courses provided on the internet" [5]. According to Kumar Basak, Wotto, and Bélanger, 2018, "e-learning stands for electronic learning, which is a subset of digital learning. It refers to the use of electronic devices such as computers, tablets, and smartphones to access educational content and resources" [15]. As we can see e-learning has been well-defined and in the context of this article these interpretations will be used.

DT technology has gained significant attention and traction in recent years, particularly in the context of Industry 4.0 [15]. It has the potential to transform industries by enabling enhanced decision-making, predictive maintenance, improved productivity, and cost savings. By creating a digital replica that mirrors the behavior and characteristics of its physical counterpart, organizations can gain a deeper understanding of their assets and processes, leading to improved operational efficiency and competitive advantage.

Education itself has plenty of challenges that need to be addressed on a daily basis [12]. Back in 2012 Johnson et al. identified three main challenges: enabling people to learn more effectively, at a lower cost, and demonstrating success through an interdisciplinary education in complex systems science. Even at that time, authors were certain an individual and personalized approach to education was a must to suit each individual person.

### 1.2 Purpose of the Study

The purpose of this study is to explore the challenges and opportunities associated with DT technology in various sectors. By examining case studies and examples from manufacturing, healthcare, road infrastructure, city infrastructure, and other relevant domains, we aim to understand the potential of DT in transforming industries and driving innovation. Furthermore, this study seeks to answer to the research question of the specific challenges and opportunities of DT technology in the context of e-learning, considering its potential to revolutionize the education sector.

It delves into the specific applications and benefits of DT in manufacturing, healthcare, road infrastructure, city infrastructure, and other relevant domains. Additionally, it explores the potential of DT to revolutionize the education sector, examining how it can enhance e-learning experiences and transform traditional educational approaches.

### 1.3 Organization of the Research

This work is organized into three main sections. Section 1 provides an introduction to the study, presenting the background, purpose, scope. Section 2 delves into the challenges and opportunities of DT technology in various sectors, including manufacturing, healthcare, road infrastructure, and city infrastructure. It examines real-world examples and case studies to illustrate the transformative potential of DT. Section 3 focuses specifically on the challenges and opportunities of DT technology in the context of e-learning. It explores how DT can revolutionize the education sector, enhance practical learning experiences, and empower collaborative learning. Finally, the conclusion Sect. 4 summarizes the key findings and provides insights for future research in the field of DT technology.

By examining the challenges and opportunities of DT technology across different sectors, this study aims to contribute to the existing knowledge base and shed light on the transformative potential of DT in industry and education. Through a comprehensive exploration of real-world examples and case studies, we seek to provide valuable insights that can inform organizations, policymakers, and educators in harnessing the power of DT for innovation, efficiency, and enhanced learning experiences.

## 2 Main Sectors of Adoption of Digital Twin Technologies

DT technology has emerged as a powerful tool for transforming industries and optimizing processes in various sectors [13, 18]. Before entering the core discussions of this article whose main topic is DT technology in e-learning, we will provide a few examples of everyday use of DT. In this section, we explore the main examples of applications associated with DT technology across different domains, including manufacturing, healthcare, road infrastructure, city infrastructure, and more. By examining real-world examples and case studies, we aim to highlight the transformative potential of DT and shed light on the key factors that contribute to their successful implementation. We provide below a short list of prominent sectors where DT can be adopted:

**Manufacturing**
The manufacturing sector has witnessed significant advancements with the adoption of DT technology which enables manufacturers to create virtual replicas of their production systems, allowing for real-time monitoring, predictive maintenance, optimization, fault identification, etc. [27]. One of the key challenges in implementing DT in manufacturing is the integration of data from various sources and systems to create a comprehensive digital representation [26]. Additionally, ensuring data accuracy and security throughout the DT lifecycle poses a significant challenge. However, the opportunities offered by DT in terms of improved efficiency, reduced downtime, and enhanced product quality make them an attractive investment for manufacturers.

**Healthcare**
In the healthcare sector, DT has the potential to revolutionize patient care, medical research, and personalized medicine [19]. By creating virtual replicas of individual patients, healthcare providers can simulate and analyze different treatment scenarios, optimizing care plans and improving outcomes. However, challenges such as data privacy and security, interoperability of healthcare systems, and the integration of real-time patient data into DT need to be addressed. The opportunities offered by DT in healthcare include personalized treatment strategies, remote patient monitoring, and the advancement of medical research through virtual simulations and predictive models [17].

**Transport Infrastructures**
DT technology can significantly benefit the road infrastructure sector by enabling real-time monitoring, predictive maintenance, and optimized traffic management. DT of road networks can simulate traffic flow, identify bottlenecks, and suggest optimal routing strategies [10]. Challenges in this domain include the integration of data from various sources, such as sensors, traffic cameras, and weather systems, to create an accurate representation of the transportation system. Additionally, ensuring the scalability and interoperability of DT across different road networks presents a challenge. The opportunities of DT application in road infrastructure lie in improved traffic management, reduced congestion, and enhanced safety for drivers and pedestrians.

**Urban Infrastructures**
DT has the potential to transform the planning, design, and management of city infrastructure [7]. By creating virtual replicas of cities, urban planners and policymakers can simulate and analyze different scenarios, optimizing resource allocation and improving sustainability. Challenges in implementing DTs for city infrastructure include data integration from diverse sources, ensuring data accuracy and quality, and addressing privacy concerns [28]. The opportunities offered by DT in this domain include improved urban planning, efficient resource management, and enhanced citizen engagement.

**Agriculture**
It can be a complex challenge to model DT for Eco-Cyber-Physical Systems (ECPS) in smart agriculture, advocating the use of Enterprise Modelling as the foundational framework and the Living Lab methodology for iterative refinement [16]. The authors have utilized historical records from Latvia's robust potato production history and modern soil moisture sensor data, and the research emphasizes the significance of Digital Twins (DTs) in guiding decisions and interventions within Eco-Cyber-Physical Systems (ECPS). The 4EM Enterprise Modelling methodology assumes a pivotal role, concurrently endorsing an ecosystem-oriented strategy for agriculture, thus illuminating the modeling and system-thinking advantages inherent in the ECPS paradigm. Validation

of this approach stems from real-world field experiments and exhaustive literature analysis. Nonetheless, the persistence of challenges in accurately depicting ECPS dynamics necessitates future enhancement via field trials and technological innovations.

**Other Domains**
Apart from manufacturing, healthcare, road infrastructure, and city infrastructure, DT technology finds applications in various other sectors. For example, in the energy sector, DT can optimize energy generation, distribution, and consumption [23]. In the aerospace industry, DT enables predictive maintenance and enhances aircraft performance [20]. Furthermore, DT of the Earth for Green Transition is another ambitious project that stumbles upon the challenge of designing the DT that allows its users to intervene, extract information, and influence system trajectory across time and space [4]. The challenges and opportunities in these domains vary but often revolve around data integration, security, and scalability.

## 3 Challenges and Opportunities of Digital Twin in E-learning

In this section, we explore the challenges and opportunities of implementing DT in e-learning. Given the broad range of applications of DT technology as described in the previous section, we discuss here how the DT technology has the potential to revolutionize the field of education by transforming traditional learning environments into interactive and immersive experiences. Given the diversity of application areas development of a discipline aimed at the DT learning system will require a multidisciplinary context or ecosystem where sector-specific knowledge would match to the knowledge and expertise in computer science, communication technology and pedagogical knowledge.

By leveraging the capabilities of DT, educators can create virtual replicas of physical setups, laboratories, and experiments, providing students with a realistic and engaging learning experience [11]. Additionally, DT in e-learning will enhance collaboration by enabling remote access to DT resources, and accelerate the learning process [8]. This section aims to highlight the transformative potential of DT in e-learning and discuss the key challenges that need to be addressed for successful implementation.

### 3.1 Enhanced Learning

One of the significant opportunities presented by DT in e-learning is the ability to enhance learning experiences [1]. By creating virtual replicas of physical setups, students can engage in realistic simulations and experiments. DT provides a hands-on learning environment, allowing students to interact with the virtual models, manipulate variables, and observe the system evolution in real-time [20]. This experiential learning approach fosters deeper understanding, critical thinking, and problem-solving skills [25].

Furthermore, emerging technologies and pedagogical innovations are a huge part of the learning experience students get. By integrating interactive digital platforms, personalized learning pathways, and immersive virtual environments educators can create dynamic and engaging lessons that cater to diverse learning styles. DT technology is one of the technological advancements that can further deepen the student's learning experience.

### 3.2 Personalized Learning

DT also enables personalized learning experiences. This pedagogical approach can tailor education to meet the individual student's needs, preferences, and abilities. By creating individualized virtual replicas of students, educators can tailor the content and pace of instruction to meet each student's specific needs and learning style [2]. DT can track students' progress, identify areas of strength and weakness, and provide targeted feedback and support. Adaptive learning algorithms can be integrated into DT to dynamically adjust the learning path based on the student's performance and learning goals, ensuring optimal learning outcomes.

### 3.3 Collaborative Learning

DT facilitates collaborative learning by enabling students to work together in virtual environments. Students can collaborate on complex projects, conduct virtual experiments, and solve problems collectively, regardless of their physical locations. DT supports real-time communication, information sharing, and joint decision-making, fostering teamwork and collaboration skills [8]. This collaborative learning approach prepares students for the collaborative nature of the modern workplace and encourages the exchange of ideas and perspectives [7].

### 3.4 Remote Access to Digital Twin Resources

One of the challenges in traditional education is limited access to resources, especially for students in remote areas or those with physical disabilities [22]. DT Learning should address the additional challenge of providing remote access to replica of complex physical or technological objects and their representation. Students should be able to access virtual replicas of systems of roads, agriculture, etc., equipment's, and resources from anywhere, anytime, by using internet-connected devices. The DT Learning will extend the current potential of today's inclusive education, expands educational opportunities, and reduces barriers.

### 3.5 Challenges in Implementing Digital Twin in E-Learning

While the potential of DT in e-learning is significant, several challenges must be addressed for successful implementation.

1. The development of high-quality and accurate virtual replicas. Creating realistic and dynamic digital models that accurately mimic the physical environment requires expertise in modeling, simulation, and data integration.
2. Ensuring the security and privacy of personal data (students, citizens, employees) and protecting intellectual property rights are critical considerations.
3. Integration with existing platforms and systems. DT in e-learning platforms should seamlessly integrate with management systems, content repositories, and assessment tools to provide a unified and coherent learning experience. Interoperability standards and protocols need to be established to enable seamless data exchange and integration across different platforms and technologies [14].

4. The availability of infrastructure and access to reliable internet connectivity is essential for students to access and utilize DT effectively. Bridging the digital divide and ensuring equitable access to technology and connectivity for all students is crucial for the widespread adoption of DT in e-learning.
5. Understanding of the DT term and the technological advancement it can offer is crucial so the technology is not misinterpreted with other technological options available. Furthermore, DT technology is a complex system that requires a thorough understanding of the automatic data flow and how it can be set up so DT is applied correctly.

### 3.6 Data Security and Privacy

In 2022, Banaeian Far and Imani Rad have focused on the intricate security and privacy hurdles entailed in the deployment of Digital Twins (DTs) within the Metaverse, a concept dating back to 1992 [3]. These challenges encompass safeguarding the integrity and individuality of DTs within the digital realm, with proposed solutions involving the implementation of blockchain-based data auditing protocols. Additionally, the paper highlights the imperative of fortifying DT security against cyber threats within the Metaverse's decentralized landscape, while concurrently addressing trust establishment issues in the absence of trusted third parties. Ensuring ownership verification, preventing theft, ensuring continuous DT availability, and validating the authenticity of DTs and Metaverse-based services are among the overarching concerns.

Furthermore, the authors underscore the intricacies of central management in a decentralized Metaverse environment and the necessity of effectively managing identities within this digital realm. These multifaceted challenges must be effectively surmounted to guarantee the secure and privacy-preserving utilization of DTs within the Metaverse. Authors have outlined a three-layer architecture linking the physical world with the Metaverse, emphasizing the potential applications of DTs in this context. The significance of these security and privacy challenges in the realm of DTs and the Metaverse suggests avenues for future research. These avenues include solutions for cyber threats, privacy concerns, ethical, legal, and societal issues, data management, as well as predictability and signal processing challenges.

## 4 Discussion and Conclusions

In the above sections, we have explored the challenges and opportunities associated with DT technology in the learning sector. From manufacturing to healthcare, road infrastructure to city planning, DT offers transformative potential by enabling real-time monitoring, simulation, and optimization. While challenges related to data integration, privacy, and scalability exist, the opportunities presented by DT in terms of improved efficiency, reduced costs, and enhanced decision-making make them compelling solutions for industries and organizations.

By understanding of DT technology works across different domains, stakeholders can make informed decisions and develop strategies to leverage its potential effectively. This context delves into the challenges and opportunities of DT in the context of learning which is the main objective of our work. We explored how this technology can revolutionize the education sector and enhance the learning experiences of students.

DT concept has the potential to transform e-learning by providing realistic and interactive learning experiences, personalized instruction, collaborative learning opportunities, and remote access to educational resources. While challenges related to virtual model development, integration, and infrastructure exist, addressing these challenges can pave the way for the widespread implementation of DT in e-learning. By harnessing the power of this technology, educators can create engaging and immersive learning environments that empower students and prepare them for the demands of the digital age.

However, it is crucial to teach DT technology to the stakeholders and industry experts to the extent that DT is not confused with the Digital Model or Digital Shadow [29]. This means to teach the DT phenomenon it is required to develop a well-defined protocol and framework that we call "DT-learning". DT-learning would allow us to teach the DT phenomenon to industry experts, stakeholders, academic staff, and the young generation. Furthermore, it would explain the difference between Digital Model, Digital Shadow, and Digital Twin so that whenever someone develops a new system, they do not have to misinterpret any of the terms and the protocol would be clear.

To comply with the DT definition and apply it to e-learning we are introducing a new term that would allow us to use DT technology in a virtual to-virtual environment - "Virtual AI Twin". We present e-learning platform layout for this concept in the Fig. 1.

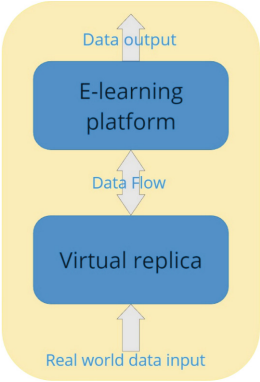


**Fig. 1.** E-learning platform layout concept. Data exchange between E-learning platform and it's virtual replica, created by authors (2023).

We also present our first prototypical DT architecture in e-learning in Fig. 2.

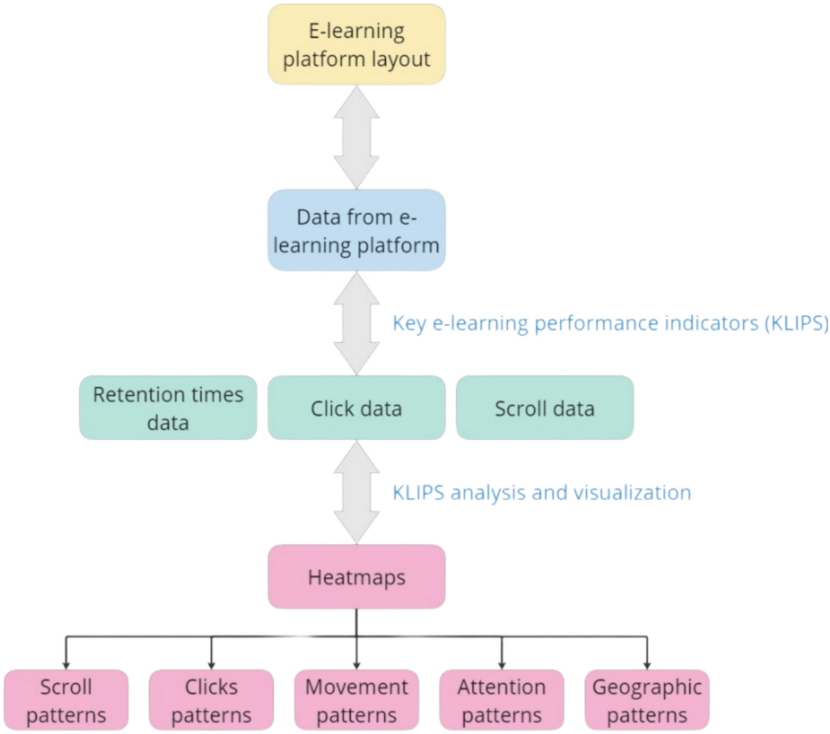


**Fig. 2.** Prototypical DT architecture for e-learning. We have E-learning platform layout (layer 1) that can change based on the data (layer 2) that can be collected from E-learning platforms virtual replica using various data (layer 3) that different heatmaps patterns (layer 4) can provide from the E-learning platform, created by authors (2023).

## 5 Future Research Directions

In this manuscript, a review of the current DT deployment has been presented with the main aim to argue on the need to develop a proper framework for the DT-Learning experience. It has to be defined in a way the industry experts and users can rely on it and not misinterpret Digital Twin's meaning and usability. Furthermore, it is required to deep dive into our proposed prototype in e-learning and to understand the meaning and necessity of its elements and how to integrate the architecture in a new or existing e-learning management system.

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## References


1. Azeta, A., et al.: A Digital Twin Framework for Analysing Students' Behaviours Using Educational Process Mining, PREPRINT (Version 1) available at Research Square (2020)
2. Bucchiarone, A.: Gamification and virtual reality for digital twin learning and training: architecture and challenges. Virtual Real. Intell. Hardw. **4**(6), 471–486 (2022)
3. Banaeian Far, S., Imani Rad, A.: Applying digital twins in metaverse: user interface, security and privacy challenges. J. Metaverse **2**(1), 8–15 (2022)
4. Bauer, P., Stevens, B., Hazeleger, W.: A digital twin of Earth for the green transition. Nat. Clim. Chang. **11**(2), 80–83 (2021)
5. Cambridge Dictionary. https://dictionary.cambridge.org/dictionary/english/e-learning. Accessed 23 July 2023
6. Chatti, S., Tolio, T.: CIRP Encyclopedia of Production Engineering. Springer, Berlin, Heidelberg (2019). https://doi.org/10.1007/978-3-662-53120-4
7. Dembski, F., Wössner, U., Letzgus, M.: The digital twin tackling urban challenges with models, spatial analysis and numerical simulations in immersive virtual environments. In: Proceedings of the 23rd International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA)/Doctoral Students Track, pp. 334–343 (2019)
8. Georgakopoulos, I., Piromalis, D., Ntanos, S., Zakopoulos, V., Makrygiannis, P.: A prediction model for remote lab courses designed upon the principles of education for sustainable development. Sustainability **15**(6), 5473 (2023)
9. Grieves, M., Vickers, J.: Origins of the digital twin concept. Fla. Inst. Technol. **8**, 3–20 (2016)
10. Jiang, F., Ma, L., Broyd, T., Chen, W., Luo, H.: Building digital twins of existing highways using map data based on engineering expertise. Autom. Constr. **134**, 104081 (2022)
11. Johra, H., Petrova, E. A., Rohde, L., Pomianowski, M. Z.: Digital twins of building physics experimental laboratory setups for effective e-learning. In: Journal of Physics: Conference Series, vol. 2069, no. 1, pp. 012190. IOP Publishing (2021)
12. Johnson, J., Buckingham Shum, S., Willis, A., et al.: The FuturICT education accelerator. Eur. Phys. J. Spec. Top. **214**, 215–243 (2012)
13. Jones, D., Snider, C., Nassehi, A., Yon, J., Hicks, B.: Characterising the digital twin: a systematic literature review. CIRP J. Manuf. Sci. Technol. **29**, 36–52 (2020)
14. Kuts, V., Otto, T., Caldarola, E.G., Modoni, G., Sacco, M.: Enabling the teaching factory leveraging a virtual reality system based on the digital twin (2018)
15. Kumar Basak, S., Wotto, M., Bélanger, P.: E-learning, M-learning and D-learning: conceptual definition and comparative analysis. E-Learn. Digit. Media **15**(4), 191–216 (2018)
16. Majore, G., Majors, I.: Digital twin modelling for eco-cyber-physical systems: In the case of A smart agriculture living lab. In: Proceedings of PoEM Forum, vol. 22, pp. 98–112 (2022)
17. Mashaly, M.: Connecting the twins: a review on digital twin technology & its networking requirements. Procedia Comput. Sci. **184**, 299–305 (2021)
18. Müller-Zhang, Z., Kuhn, T., Antonino, P.O.: Towards live decision-making for service-based production: Integrated process planning and scheduling with digital twins and Deep-Q-Learning. Comput. Ind. **149**, 103933 (2023)
19. Qi, Q., et al.: Enabling technologies and tools for digital twin. J. Manuf. Syst. **58**, 3–21 (2021)
20. Sepasgozar, S.M.: Digital twin and web-based virtual gaming technologies for online education: a case of construction management and engineering. Appl. Sci. **10**(13), 4678 (2020)
21. Shafto, M., Conroy, M., Doyle, R., Glaessgen, E., Kemp, C., LeMoigne, J., et al.: Modeling, simulation, information technology & processing roadmap. Natl. Aeronaut. Space Adm. **32**, 1 (2012)

22. Smajic, H., Stekolschik, A., Byiringiro, J.B.: Digital twins for online training of automation techniques. In: The International Conference on E-Learning in the Workplace (2020)
23. Soliman, A., et al.: AI-based UAV navigation framework with digital twin technology for mobile target visitation. Eng. Appl. Artif. Intell. **123**, 106318 (2023)
24. Stark, R., Damerau, T.: Digital twin. In: Chatti, S., Tolio, T. (eds.) CIRP Encyclopedia of Production Engineering. Springer, Berlin Heidelberg (2019). https://doi.org/10.1007/978-3-642-20617-7
25. Tagliabue, L.C., Cecconi, F.R., Maltese, S., Rinaldi, S., Ciribini, A.L., Flammini, A.: Leveraging Digital Twin for Sustainability Assessment of an Educational Building. Sustainability **13**(2), 480 (2021)
26. Tao, F., Xiao, B., Qi, Q., Cheng, J., Ji, P.: Digital twin modeling. J. Manuf. Syst. **64**, 372–389 (2022)
27. Wang, J., Zhang, Z., Liu, Z., Han, B., Bao, H., Ji, S.: Digital twin aided adversarial transfer learning method for domain adaptation fault diagnosis. Reliab. Eng. Syst. Saf. **234**, 109152 (2023)
28. Wan L., Nochta T., Schooling J.M.: International Conference on Smart Infrastructure and Construction 2019 (ICSIC), pp. 187–194 (2019)
29. Wright, L., Davidson, S.: How to tell the difference between a model and a digital twin. Adv. Model. Simul. Eng. Sci. **7**, 13 (2020)