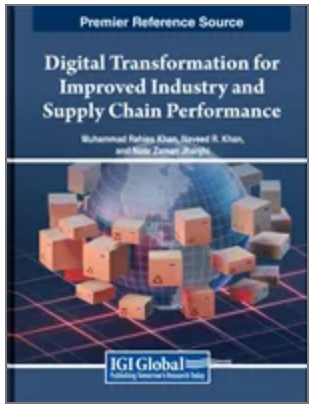

Digital Twins and Green Paths: A Sustainable Journey Through Industry 4.0

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Abstract

The contribution of digital twins to sustainability is explored in this chapter within the setting of Industry 4.0. It begins by providing concepts and definitions of digital twins by highlighting the significance of sustainability in contemporary industries. It subsequently investigates various types of digital twins and their interactions with other Industry 4.0 technologies representing their broad-ranging applications. The chapter then proceeds to examine sustainability, exemplifying how digital twins optimize resource utilization, efficiently manage energy, and promote eco-friendly practices in industrial settings, corroborated by empirical case studies. Additionally, it scrutinizes emerging technologies, global initiatives, and ethical considerations pertaining to the implementation of digital twins. Finally, it emphasizes the transformative potential of digital twins in driving sustainable industrial practices and advocates for ongoing research and collaboration to progress towards a more environmentally conscious future.

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Introduction

Definition of Digital Twins

Digital twins are virtual replicas that mimic the characteristics and behaviour of actual physical systems, processes, or objects. These replicas are used to facilitate the ongoing surveillance, data analysis, and simulation of different scenarios(Stavropoulos & Mourtzis, 2022). In healthcare domain, digital twins have the capacity to revolutionize patient care by creating virtual replicas of humans that comprise their tissues, organs, and physiological activities. The digital human twins (DHTs) may be used to monitor the development of illnesses, enhance treatment strategies, and streamline precise medicines and surgical preparations if required(Cinar, Nuhu, Zeeshan, & Korhan, 2020). The field of ecology may greatly benefit from the use of digital twins, which serve as a valuable tool for monitoring and understanding various systems and processes widespread in nature. The systems are explored through the integration of domain knowledge expertise, data and models (Korhan, 2020). Furthermore, in the field of commerce, there exists a digital twin of the digital world acronymized as DTDW which serves as a virtual replica that interacts with processes involved individuals, data, and technology to achieve desired business outcomes. The functions of these systems include the mechanization, prediction, surveillance, and enhancement of operations pertaining to commerce (Mateev, 2020; Redeker, Weskamp, Rössl, & Pethig, 2022).

- **Explanation of the concept of digital twins in the context of Industry 4.0.**

As depicted in Fig 1.0, Digital twins are a fundamental aspect of Industry 4.0, where physical products are replicated digitally to enable simulations, real-time analysis, and predictive maintenance (Dimitris, 2023; Waclawek, Schäfer, Binder, Hirsch, & Huber, 2023). The use of digital twins may enhance productivity in several sectors via the integration of smart manufacturing, Industry 4.0, and the Metaverse(Abdullahi Abdul, Olov, & Ulf, 2023). The Industrial Business Process Twin (IBPT) serves as an intermediate entity that enables the application of IT methodologies to operational technology (OT)(Eugenio, 2023). The IBPT serves as a channel between the realms of information technology (IT) and operational technology (OT), facilitating the incorporation of components from various manufacturers and platforms (Hannes, Georg, Christoph, Eduard, & Stefan, 2023). In cyber physical systems, the use of digital twins has played a crucial role in decreasing the expenses associated with establishing novel manufacturing methods thereby enhancing productivity and eliminating fluctuations in batch production process. Manufacturing benefits from its many uses, such as intelligent logistics and efficient supply chain management.

Figure 1. Digital twin IR 4.0 features

(https://igiprodst.blob.core.windows.net:443/source-

content/9798369353752_339902/979-8-3693-5375-2.ch002.f01.png?sv=2015-12-11&sr=c&sig=w2gx8xs1h6jGj1sh8iu5VXiO1JtL17fPEK5aBQzvxRg%3D&se=2024-05-13T11%3A52%3A57Z&sp=r)
(Javaid & Haleem, 2023)

• **The role of digital twins in creating virtual representations of physical entities.**

Digital twins (DTs) have the potential to enhance every aspect of the operational process in intelligent networks within the framework of 6G mobile networks. They provide virtual models of physical systems, functioning as interactive equivalents for AI and ML algorithms. These systems provide flexibility and scalability features that enable them to incorporate new AI/ML algorithms efficiently and accurately (Apostolakis, Chatzieleftheriou, Bega, Gramaglia, & Banchs, 2023). In health domain, DTs provide remote health monitoring (RHM) by producing virtual copies that receive data from physical assets, mimicking their real-world behavior. Through the integration of robotics and the Internet of Things (IoT), Digital Twins (DTs) in the field of Internet of Robotic Things (IoRT) are capable of both navigating within a designated area and establishing connections with IoT devices, hence enhancing their capabilities(S. Khan, Ullah, Khan, & Rehman, 2023). In Industry 4.0 context, Digital twins (DTs) provide a viable alternative for the implementation of virtual models in smart manufacturing. They possess the ability to examine the interaction and impact among many elements and provide precise predictions about the conditions in electric drive applications(Ebadpour, Jamshidi, Talla, Hashemi-Dezaki, & Peroutka, 2023). Distributed technologies may enhance the administration of smart space devices and services by establishing a virtual representation that is connected to the actual environment (Motlagh et al., 2023). Networking support is essential for precise real-time synchronization between physical systems and their digital twins, facilitating the development and utilization of digital twin technology(Vaezi et al., 2022).

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References

Follow Reference

Abdullahi Abdul, A., Olov, S., & Ulf, B. (2023). *Digital Twin as a Proxy for Industrial Cyber-Physical Systems*. Springer. 10.1145/3585967.3585982

AIMultipleResearch. (2024). *15 Digital Twin Applications/ Use Cases by Industry in 2024*. AI Multiple Research. https://research.aimultiple.com/digital-twin-applications/ (https://research.aimultiple.com/digital-twin-applications/)

Follow Reference Alferidah, D. K., & Jhanjhi, N. (2020). Cybersecurity impact over bigdata and iot growth. Paper presented at the *2020 International Conference on Computational Intelligence (ICCI)*. IEEE. 10.1109/ICCI51257.2020.9247722

Follow Reference Alkhateeb A. Jiang S. Charan G. (2023). Real-time digital twins: Vision and research directions for 6G and beyond.IEEE Communications Magazine, 61(11), 128–134. 10.1109/MCOM.001.2200866

Follow Reference Almusaylim A. , Z., & Jhanjhi, N. (. (2020). Comprehensive review: Privacy protection of user in location-aware services of mobile cloud computing.Wireless Personal Communications, 111, 541–564. 10.1007/s11277-019-06872-3

Follow Reference Anandan R. Gopalakrishnan S. Pal S. Zaman N. (2022). Industrial Internet of Things (IIoT): Intelligent Analytics for Predictive Maintenance. John Wiley & Sons. 10.1002/9781119769026

Follow Reference Apostolakis N. Chatzieleftheriou L. E. Bega D. Gramaglia M. Banchs A. (2023). Digital Twins for Next-Generation Mobile Networks: Applications and Solutions.IEEE Communications Magazine, 61(11), 80–86. 10.1109/MCOM.001.2200854

Follow Reference Asad U. Khan M. Khalid A. Lughmani W. A. (2023). Human-Centric Digital Twins in Industry: A Comprehensive Review of Enabling Technologies and Implementation Strategies.Sensors (Basel), 23(8), 3938. 10.3390/s2308393837112279

Follow Reference Ashraf, H., Hanif, M., Ihsan, U., Al-Quayed, F., Humayun, M., & Jhanjhi, N. (2023). A Secure and Reliable Supply chain management approach integrated with IoT and Blockchain. Paper presented at the *2023 International Conference on Business Analytics for Technology and Security (ICBATS)*. IEEE. 10.1109/ICBATS57792.2023.10111371

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*.

Follow Reference Broo D. G. Schooling J. (2023). Digital twins in infrastructure: Definitions, current practices, challenges and strategies.International Journal of Construction Management, 23(7), 1254–1263. 10.1080/15623599.2021.1966980

Follow Reference Cheng X. Chaw J. K. Goh K. M. Ting T. T. Sahrani S. Ahmad M. N. Abdul Kadir R. Ang M. C. (2022). Systematic literature review on visual analytics of predictive maintenance in the manufacturing industry.Sensors (Basel), 22(17), 6321. 10.3390/s2217632136080780

Follow Reference Choobineh M. Mohagheghi S. (2018). Sustainable Industrial Plants: Energy-Efficient, Asset-Aware, and Waste-Averse.IEEE Transactions on Industry Applications, 54(3), 1966–1974. 10.1109/TIA.2018.2797134

Cinar, Z. M., Nuhu, A. A., Zeeshan, Q., & Korhan, O. (2020). *Digital twins for industry 4.0: a review.* Paper presented at the Industrial Engineering in the Digital Disruption Era: Selected papers from the Global Joint Conference on Industrial Engineering and Its Application Areas, Gazimagusa, North Cyprus, Turkey.

Follow Reference Defraeye T. Shrivastava C. Berry T. Verboven P. Onwude D. Schudel S. Bühlmann A. Cronje P. Rossi R. M. (2021). Digital twins are coming: Will we need them in supply chains of fresh horticultural produce? Trends in Food Science & Technology, 109, 245–258. 10.1016/j.tifs.2021.01.025

Follow Reference Dimitris M. (2023). Digital twin inception in the Era of industrial metaverse.Frontiers in Manufacturing Technology, 3, 1155735. 10.3389/fmtec.2023.1155735

Follow Reference Ebadpour M. Jamshidi M. Talla J. Hashemi-Dezaki H. Peroutka Z. (2023). Digital Twin Model of Electric Drives Empowered by EKF.Sensors (Basel), 23(4), 2006. 10.3390/s2304200636850601

Follow Reference Elkefi S. Asan O. (2022). Digital Twins for Managing Health Care Systems: Rapid Literature Review.Journal of Medical Internet Research, 24(8), e37641. 10.2196/3764135972776

Follow Reference Eugenio, F. (2023). *3D Real Time Digital Twin*. OnePetro. 10.2118/213115-MS

Follow Reference Farsi M. Daneshkhah A. Hosseinian-Far A. Jahankhani H. (2020). Digital twin technologies and smart cities. Springer. 10.1007/978-3-030-18732-3

Fernando, J., & Ganesh, E. (2022). Digital Twin for Processes and Products. *Technoarete Transactions on Internet of Things and Cloud Computing Research, 2*(10.36647).

Follow Reference Gaur L. Rana J. Jhanjhi N. (2023). Digital Twin and Healthcare: Trends, Techniques, and Challenges. IGI Global., 10.

Gaur, L., Rana, J., & Jhanjhi, N. Z. (2023). Digital Twin and Healthcare Research Agenda and Bibliometric Analysis. *Digital Twins and Healthcare: Trends, Techniques, and Challenges*, 1-19.

Gill, S. H., Razzaq, M. A., Ahmad, M., Almansour, F. M., Haq, I. U., Jhanjhi, N., & Masud, M. (2020). *Security and privacy aspects of cloud computing: a smart campus case study*.

Follow Reference Hannes, W., Georg, S., Christoph, B., Eduard, H., & Stefan, H. (2023). Digital Twins of Business Processes as Enablers for IT / OT Integration. *arXiv.org, abs/2305.06001*. doi:/arXiv.2305.0600110.48550

Hawkinson, E. (2022). Automation in Education with Digital Twins: Trends and Issues. *International Journal on Open and Distance e-Learning, 8*(2).

Follow Reference Hopfstock A. Knöfel P. Lindl F. (2022). Digital Twin Germany–a digital replica for simulation and analysis build on geospatial data.Abstracts of the ICA*, 5*, 1-2. 10.5194/ica-abs-5-119-2022

Follow Reference Hossain, S. M., Saha, S. K., Banik, S., & Banik, T. (2023). A new era of mobility: Exploring digital twin applications in autonomous vehicular systems. Paper presented at the *2023 IEEE World AI IoT Congress (AIIoT).* IEEE. 10.1109/AIIoT58121.2023.10174376

Humayun M. Jhanjhi N. Talib M. Shah M. H. Suseendran G. (2021). Cybersecurity for Data Science: Issues, Opportunities, and Challenges. *Intelligent Computing and Innovation on Data Science:*Proceedings of ICTIDS 2021, (pp. 435-444). IEEE.

Follow Reference Jacoby M. Usländer T. (2020). Digital twin and internet of things—Current standards landscape.Applied Sciences (Basel, Switzerland), 10(18), 6519. 10.3390/app10186519

Javaid, M., & Haleem, A. (2023). Digital Twin applications toward Industry 4.0: A Review. *Cognitive Robotics*. kbvresearch. https://www.kbvresearch.com/digital-twin-market/ (https://www.kbvresearch.com/digital-twin-market/)

Follow Reference Kerin M. Pham D. T. Huang J. Hadall J. (2023). A generic asset model for implementing product digital twins in smart remanufacturing.International Journal of Advanced Manufacturing Technology, 124(9), 3021–3038. 10.1007/s00170-022-09295-w

Follow Reference Khalaj O. Jamshidi M. Hassas P. Mašek B. Štadler C. Svoboda J. (2023). Digital Twinning of a Magnetic Forging Holder to Enhance Productivity for Industry 4.0 and Metaverse.Processes (Basel, Switzerland), 11(6), 1703. 10.3390/pr11061703

Follow Reference Khalyasmaa A. I. Stepanova A. I. Eroshenko S. A. Matrenin P. V. (2023). Review of the Digital Twin Technology Applications for Electrical Equipment Lifecycle Management.Mathematics, 11(6), 1315. 10.3390/math11061315

Khan, A., Jhanjhi, N. Z., & Sujatha, R. (2022). Emerging Industry Revolution IR 4.0 Issues and Challenges. In *Cyber Security Applications for Industry 4.0* (pp. 151-169): Chapman and Hall/CRC.

Khan, S., Ullah, S., Khan, H. U., & Rehman, I. U. (2023). Digital Twins-Based Internet of Robotic Things for Remote Health Monitoring of COVID-19 Patients. *IEEE Internet of Things Journal.* IEEE.

Follow Reference

Konatham, B. R., Simra, T., Ghimire, A., Amsaad, F., Ibrahem, M. I., & Jhanjhi, N. (2023). ML-assisted Security for Anomaly Detection in Industrial IoT (IIoT) Applications. *Paper presented at the2023 Second International Conference On Smart Technologies For Smart Nation (SmartTechCon).* IEEE. 10.1109/SmartTechCon57526.2023.10391331

Korhan, O. (2020). Digital Twins for Industry 4.0: A Review. *Industrial Engineering in the Digital Disruption Era*, 193.

Follow Reference

Krupitzer C. Noack T. Borsum C. (2022). Digital Food Twins Combining Data Science and Food Science: System Model, Applications, and Challenges.Processes (Basel, Switzerland), 10(9), 1781. 10.3390/pr10091781

Follow Reference

Kumar T. Pandey B. Mussavi S. Zaman N. (2015). CTHS based energy efficient thermal aware image ALU design on FPGA.Wireless Personal Communications, 85(3), 671–696. 10.1007/s11277-015-2801-8

Follow Reference

Kumari N. Sharma A. Tran B. Chilamkurti N. Alahakoon D. (2023). A Comprehensive Review of Digital Twin Technology for Grid-Connected Microgrid Systems: State of the Art, Potential and Challenges Faced.Energies, 16(14), 5525. 10.3390/en16145525

Follow Reference

Leng J. Wang D. Shen W. Li X. Liu Q. Chen X. (2021). Digital twins-based smart manufacturing system design in Industry 4.0: A review.Journal of Manufacturing Systems, 60, 119–137. 10.1016/j.jmsy.2021.05.011

Follow Reference

Lexman R. R. Baral R. (2023). Digital twins in MOOCs: Exploring ways to enhance interactivity.Development and Learning in Organizations. 10.1108/DLO-04-2023-0091

Follow Reference

Li L. Lei B. Mao C. (2022). Digital twin in smart manufacturing.Journal of Industrial Information Integration, 26, 100289. 10.1016/j.jii.2021.100289

Follow Reference

Maheshwari P. Kamble S. Kumar S. Belhadi A. Gupta S. (2023). Digital twin-based warehouse management system: A theoretical toolbox for future research and applications.International Journal of Logistics Management. 10.1108/IJLM-01-2023-0030

Follow Reference

Maksimović, M. (2023). *A faster path to sustainability: the use of Digital Twins.* Paper presented at the 2023 22nd International Symposium INFOTEH-JAHORINA (INFOTEH). 10.1109/INFOTEH57020.2023.10094074

Follow Reference

Mateev, M. (2020). Industry 4.0 and the digital twin for building industry. *Industry 4.0, 5*(1), 29-32.

Follow Reference

Mendi A. F. (2022). A Digital Twin Case Study on Automotive Production Line.Sensors (Basel), 22(18), 6963. 10.3390/s2218696336146313

Follow Reference

Mihai S. Yaqoob M. Hung D. V. Davis W. Towakel P. Raza M. Prasad R. V. (2022). Digital twins: A survey on enabling technologies, challenges, trends and future prospects.IEEE Communications Surveys and Tutorials, 24(4), 2255–2291. 10.1109/COMST.2022.3208773

Follow Reference

Motlagh N. H. Zaidan M. A. Lovén L. Fung P. L. Hänninen T. Morabito R. Tarkoma S. (2023). Digital Twins for Smart Spaces-Beyond IoT Analytics.IEEE Internet of Things Journal.

Follow Reference

Mourtzis D. (2023). Digital twin inception in the Era of industrial metaverse.Frontiers in Manufacturing Technology, 3, 1155735. 10.3389/fmtec.2023.1155735

Follow Reference

Nayak, C. K., Karunakaran, S., Yamunaa, P., Kayalvili, S., Tiwari, M., & Unni, M. V. (2023). Analysis of Digital Twins Implementation in Smart City using Big Data and Deep Learning. *Paper presented at the 2023 7th International Conference on Intelligent Computing and Control Systems (ICICCS).* IEEE. 10.1109/ICICCS56967.2023.10142813

Follow Reference

O'Connell, E., O'Brien, W., Bhattacharya, M., Moore, D., & Penica, M. (2023). *Digital Twins: Enabling Interoperability in Smart Manufacturing Networks.* Paper presented at the Telecom. 10.3390/telecom4020016

Follow Reference

Pesapane F. Rotili A. Penco S. Nicosia L. Cassano E. (2022). Digital twins in radiology.Journal of Clinical Medicine, 11(21), 6553. 10.3390/jcm1121655336362781

Follow Reference

Piromalis D. Kantaros A. (2022). Digital twins in the automotive industry: The road toward physical-digital convergence.Applied System Innovation, 5(4), 65. 10.3390/asi5040065

Follow Reference

Ponnusamy V. Humayun M. Jhanjhi N. Yichiet A. Almufareh M. F. (2022). Intrusion Detection Systems in Internet of Things and Mobile Ad-Hoc Networks.Computer Systems Science and Engineering, 40(3). 10.32604/csse.2022.018518

Follow Reference

Qiu C. Zhou S. Liu Z. Gao Q. Tan J. (2019). Digital assembly technology based on augmented reality and digital twins: A review.Virtual Reality & Intelligent Hardware, 1(6), 597–610. 10.1016/j.vrih.2019.10.002

Follow Reference Rathore M. M. Shah S. A. Shukla D. Bentafat E. Bakiras S. (2021). The role of ai, machine learning, and big data in digital twinning: A systematic literature review, challenges, and opportunities.IEEE Access : Practical Innovations, Open Solutions, 9, 32030–32052. 10.1109/ACCESS.2021.3060863

Redeker, M., Weskamp, J. N., Rössl, B., & Pethig, F. (2022). A digital twin platform for industrie 4.0. In *Data Spaces: Design, Deployment and Future Directions* (pp. 173-200): Springer International Publishing Cham.

Follow Reference Saeed M. M. A. Saeed R. A. Ahmed Z. E. (2024). Data Security and Privacy in the Age of AI and Digital Twins. In Digital Twin Technology and AI Implementations in Future-Focused Businesses (pp. 99–124). IGI Global. 10.4018/979-8-3693-1818-8.ch008

Follow Reference Sama, N. U., Jhanjhi, N., Humayun, M., & Rahman, A. U. (2024). Digital twin evolution, application areas and enabling technology. Paper presented at the *AIP Conference Proceedings*. AIP. 10.1063/5.0168361

Follow Reference Seungjin L. Abdullah A. Jhanjhi N. Z. (2020). A review on honeypot-based botnet detection models for smart factory.International Journal of Advanced Computer Science and Applications, 11(6), 418–435. 10.14569/IJACSA.2020.0110654

Follow Reference Shafiq, D. A., Jhanjhi, N., & Abdullah, A. (2021). Machine learning approaches for load balancing in cloud computing services. *Paper presented at the2021 National Computing Colleges Conference (NCCC).* IEEE. 10.1109/NCCC49330.2021.9428825

Follow Reference Shafiq D. A. Jhanjhi N. Abdullah A. (2022). Load balancing techniques in cloud computing environment: A review.Journal of King Saud University. Computer and Information Sciences, 34(7), 3910–3933. 10.1016/j.jksuci.2021.02.007

Follow Reference Shah I. A. Jhanjhi N. Ray S. K. (2024). Artificial Intelligence Applications in the Context of the Security Framework for the Logistics Industry. In Advances in Explainable AI Applications for Smart Cities (pp. 297–316). IGI Global. 10.4018/978-1-6684-6361-1.ch011

Shah, I. A., Sial, Q., Jhanjhi, N., & Gaur, L. (2023). Use Cases for Digital Twin. In *Digital Twins and Healthcare: Trends, Techniques, and Challenges,* (pp. 102-118). IGI Global.

Shah, I. A., Sial, Q., Jhanjhi, N. Z., & Gaur, L. (2023). The role of the iot and digital twin in the healthcare digitalization process: Iot and digital twin in the healthcare digitalization process. In *Digital Twins and Healthcare: Trends, Techniques, and Challenges* (pp. 20-34): IGI Global.

Follow Reference Shen T. Li B. (2024). Digital twins in additive manufacturing: A state-of-the-art review.International Journal of Advanced Manufacturing Technology, 131(1), 1–30. 10.1007/s00170-024-13092-y

Follow Reference Shirowzhan S. Tan W. Sepasgozar S. M. (2020). Digital twin and CyberGIS for improving connectivity and measuring the impact of infrastructure construction planning in smart cities (Vol. 9). MDPI.

Follow Reference Spanedda F. (2023). Post_production. architectural design and the landscape of de-industrialisation. *City*. Territory and Architecture, 10(1), 17. 10.1186/s40410-023-00199-0

Follow Reference Stavropoulos P. Mourtzis D. (2022). Digital twins in industry 4.0. In Design and operation of production networks for mass personalization in the era of cloud technology (pp. 277–316). Elsevier. 10.1016/B978-0-12-823657-4.00010-5

Follow Reference Stefanova-Stoyanova, V., Stankov, I., & Danov, P. (2022). Technology for Multiplication and Analysis of Results Using Classes of Digital Twins in the Process of Designing Business Process Management Systems. Paper presented at the *2022 XXXI International Scientific Conference Electronics (ET).* IEEE. 10.1109/ET55967.2022.9920316

Follow Reference Su S. Zhong R. Y. Jiang Y. Song J. Fu Y. Cao H. (2023). Digital twin and its potential applications in construction industry: State-of-art review and a conceptual framework.Advanced Engineering Informatics, 57, 102030. 10.1016/j.aei.2023.102030

Follow Reference Sun T. He X. Li Z. (2023). Digital twin in healthcare: Recent updates and challenges.Digital Health, 9, 20552076221149651. 10.1177/20552076221149651366367 29

Follow Reference Sutherland J. W. Skerlos S. J. Haapala K. R. Cooper D. Zhao F. Huang A. (2020). Industrial sustainability: Reviewing the past and envisioning the future.Journal of Manufacturing Science and Engineering, 142(11), 110806. 10.1115/1.4047620

Follow Reference Talla A. McIlwaine S. (2024). Industry 4.0 and the circular economy: Using design-stage digital technology to reduce construction waste.Smart and Sustainable Built Environment, 13(1), 179–198. 10.1108/SASBE-03-2022-0050

Follow Reference Testasecca, T., Lazzaro, M., & Sirchia, A. (2023). Towards Digital Twins of buildings and smart energy networks: Current and future trends.*Paper presented at the2023 IEEE International Workshop on Metrology for Living Environment (MetroLivEnv).* IEEE. 10.1109/MetroLivEnv56897.2023.10164035

Follow Reference Vaezi M. Noroozi K. Todd T. D. Zhao D. Karakostas G. Wu H. Shen X. (2022). Digital twins from a networking perspective.IEEE Internet of Things Journal, 9(23), 23525–23544. 10.1109/JIOT.2022.3200327

Vasumathi, M., Khan, A., Sadasivan, M., & Ramamoorthy, U. (2022). Digital Twins—A Futuristic Trend in Data Science, Its Scope, Importance, and Applications. Paper presented at the *International Conference on Expert Clouds and Applications*. IEEE.

Follow Reference Waclawek, H., Schäfer, G., Binder, C., Hirsch, E., & Huber, S. (2023). Digital Twins of Business Processes as Enablers for IT/OT Integration. *arXiv preprint arXiv:2305.06001*. 10.1109/INDIN51400.2023.10217905

Follow Reference Wu, Y., & Liu, Y. (2023). Transforming Industrial Waterfronts into Inclusive Landscapes: A Project Method and Investigation of Landscape as a Medium for Sustainable Revitalization.Sustainability (Basel), 15(6), 5060. 10.3390/su15065060

Follow Reference Zaman S. K. U. Jehangiri A. I. Maqsood T. Umar A. I. Khan M. A. Jhanjhi N. Z. Shorfuzzaman M. Masud M. (2022). COME-UP: Computation offloading in mobile edge computing with LSTM based user direction prediction.Applied Sciences (Basel, Switzerland), 12(7), 3312. 10.3390/app12073312

Follow Reference Zhong, Y., Marteau, B., Hornback, A., Zhu, Y., Shi, W., Giuste, F., & Wang, M. D. (2022). IDTVR: A Novel Cloud Framework for an Interactive Digital Twin in Virtual Reality. Paper presented at the *2022 IEEE 2nd International Conference on Intelligent Reality (ICIR)*. IEEE. 10.1109/ICIR55739.2022.00020