A Survey on Information Managment in Digital Twins Across Industries

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***Abstract*—Efficient information management is a challenge that affects every industry attempting to create digital twins, making it one of the primary bottlenecks when adopting this technology. Additionally, each industry defines digital twins differently, resulting in very low interoperability of digital twin architecture across industries. However, despite the varying definitions, the core of digital twins are oftentimes processing large amounts of heterogeneous data. This study examines the degree to which the varying definitions of digital twins effect the information management requirements and methods in digital twin implementations. Furthermore, this study evaluates how well these methods can be adapted to different industries, identifying both open challenges with adapting these methods and future research directions.**

***Index Terms*—digital twin, information management**

I. Introduction

The concept of a digital twin, an accurate digital representation of a physical object, has recently become feasible due to advancements in enabling technologies. This technological progress has led to an exponential increase in digital twin research over the last decade. The original motivation behind the development of digital twins was to optimize product lifecycle management, primarily in the manufacturing industry, as a means to support the goals of Industry 4.0. However, through ongoing research, a wide range of applications across various industries have been discovered [1] [2] [3]. Digital twins rely on a bidirectional flow of information between the physical and virtual spaces, as illustrated in Figure 1. Changes in the virtual space lead to changes in the physical space, and vice versa. As a result, the basic architecture of a digital twin can be defined by three key components:

1) The physical object or space
2) A digital representation of the physical space
3) A communication channel that links these spaces together

One of the most significant challenges in implementing effective, high-fidelity digital twins is information management [4] [5]. Digital twins often need to collect and process large volumes of heterogeneous data from both physical and digital sources, making data fusion a critical aspect of their operation. Fusing physical and digital data is essential to leverage their dependencies and create a comprehensive view of the system. However, ensuring data quality can be challenging, as physical data may be incomplete or incorrect due to issues like power outages or faulty sensors. Efficient data storage is another crucial consideration, as data retention policies may require information to be stored for extended periods. Furthermore, depending on the application, high-speed data communication channels may be necessary to enable real-time monitoring and control. Finally, robust data security and governance practices are essential to protect the digital twin and its associated systems. All communication between the physical and virtual spaces must be secure to maintain the integrity and confidentiality of the data.

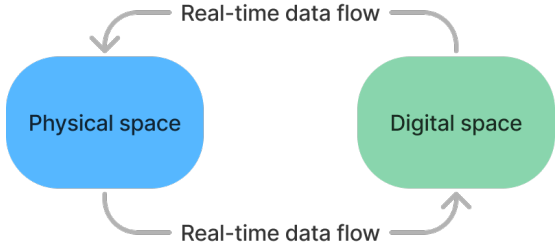

Fig. 1. digital twin concept overview

A. Related Surveys

This section provides an overview of recent digital twin surveys and their coverage of information management challenges. Table I summarizes the extent to which each survey addresses data fusion, data quality, data storage, data communication, and data security. The analysis reveals that while some surveys have partially or thoroughly addressed specific information management aspects, a comprehensive survey examining how different industries tackle these challenges has not been conducted. Such a survey could help identify information management practices that can be adapted across industries, facilitating the development of interoperable templates reduce the development time and cost of digital twin implementation.

✓✓- thorough coverage of the topic
✓- partial coverage of the topic
x - no coverage of the topic

B. Research Methodology

This survey attempts to answer the following research questions:

TABLE I
AN OVERVIEW OF DIGITAL TWIN SURVEYS SINCE 2022

reference	fusion	quality	storage	communication	security
[1]	x	✓	x	✓✓	✓✓
[2]	x	x	x	x	x
[3]	x	x	✓	✓	✓✓
[4]	✓✓	✓	x	x	x
[5]	x	✓	✓	✓	✓
This survey	✓✓	✓✓	✓✓	✓✓	✓✓

1) How do information management requirements change across industries?
2) What approaches are different industries currently applying to meet these requirements?
3) How can these methods be adapted across industries?

C. Survey Structure

The survey categorizes related works based on the following industries: (1) manufacturing, (2) aerospace, (3) automotive, (4) energy, (5) construction, (6) marine, (7) healthcare, and (8) education. For each category, relevant papers have been identified for discussion, and additional references will be included in the full submission.

For category (1), papers [6] [7] [8] [9] will be discussed
For category (2), papers [4] [10] [11] will be discussed
For category (3), papers [12] [13] [14] will be discussed
For category (4), papers [15] [16] [17] [18] will be discussed
For category (5), papers [19] [20] [21] will be discussed
For category (6), papers [22] [23] will be discussed
For category (7), papers [24] [25] [26] will be discussed
For category (8), papers [27] [28] will be discussed

D. Contributions

The primary contributions of this survey are:

1) A comprehensive analysis of information management methods employed by industries utilizing digital twin technology, focusing on (1) data fusion, (2) data fidelity, (3) data storage, (4) data communication, and (5) data security and governance.
2) An evaluation of how these methods can be adapted and applied across industries.
3) Identification of open challenges and future research directions in the field of information management for digital twins.

To the best of my knowledge, no comprehensive analysis of the aforementioned information management methods for digital twins across different industries currently exists.

REFERENCES

[1] S. Mihai, M. Yaqoob, D. V. Hung, W. Davis, P. Towakel, M. Raza, M. Karamanoglu, B. Barn, D. Shetve, R. V. Prasad, H. Venkataraman, R. Trestian, and H. X. Nguyen, "Digital Twins: A Survey on Enabling Technologies, Challenges, Trends and Future Prospects," *IEEE Communications Surveys & Tutorials*, vol. 24, no. 4, pp. 2255–2291, 2022, conference Name: IEEE Communications Surveys & Tutorials. [Online]. Available: https://ieeexplore.ieee.org/document/9899718

[2] M. Singh, R. Srivastava, E. Fuenmayor, V. Kuts, Y. Qiao, N. Murray, and D. Devine, "Applications of Digital Twin across Industries: A Review," *Applied Sciences*, vol. 12, no. 11, p. 5727, Jun. 2022. [Online]. Available: https://www.mdpi.com/2076-3417/12/11/5727

[3] J. B. Heluany and V. Gkioulos, "Survey on Digital Twins: from concepts to applications," in *Proceedings of the 18th International Conference on Availability, Reliability and Security*, ser. ARES '23. New York, NY, USA: Association for Computing Machinery, Aug. 2023, pp. 1–8. [Online]. Available: https://dl.acm.org/doi/10.1145/3600160.3605070

[4] M. Xiong and H. Wang, "Digital twin applications in aviation industry: A review," *The International Journal of Advanced Manufacturing Technology*, vol. 121, no. 9, pp. 5677–5692, Aug. 2022. [Online]. Available: https://doi.org/10.1007/s00170-022-09717-9

[5] H. Boyes and T. Watson, "Digital twins: An analysis framework and open issues," *Computers in Industry*, vol. 143, p. 103763, Dec. 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0166361522001609

[6] W. S. Lam, W. H. Lam, and P. F. Lee, "A Bibliometric Analysis of Digital Twin in the Supply Chain," *Mathematics*, vol. 11, no. 15, p. 3350, Jul. 2023. [Online]. Available: https://www.mdpi.com/2227-7390/11/15/3350

[7] N. Jyeniskhan, K. Shaimergenova, M. H. Ali, and E. Shehab, "Digital Twin for Additive Manufacturing: Challenges and Future Research Direction," in *2023 IEEE International Conference on Smart Information Systems and Technologies (SIST)*, May 2023, pp. 337–342. [Online]. Available: https://ieeexplore.ieee.org/document/10223556

[8] W. Zhao, C. Zhang, J. Wang, S. Wang, D. Lv, and F. Qin, "Research on Digital Twin Driven Rolling Bearing Model-Data Fusion Life Prediction Method," *IEEE Access*, vol. 11, pp. 48 611–48 627, 2023, conference Name: IEEE Access. [Online]. Available: https://ieeexplore.ieee.org/document/10127969

[9] D. Chen, C. Zhou, H. Yang, M. Li, and L. Lu, "The Data Domain Construction of Digital Twin Network," in *2023 IEEE 3rd International Conference on Digital Twins and Parallel Intelligence (DTPI)*, Nov. 2023, pp. 1–5. [Online]. Available: https://ieeexplore.ieee.org/document/10365474

[10] E. Y. Hua and L. M. Boan, "Leveraging Digital Twins to Support a Sustained Human Presence on the Lunar Surface," in *2023 Winter Simulation Conference (WSC)*, Dec. 2023, pp. 3190–3201, iSSN: 1558-4305. [Online]. Available: https://ieeexplore.ieee.org/document/10407136

[11] S. Diange and N. Haiyun, "Research on the Construction of Civil Airport Safety Management System Based on Digital Twin Technology," in *2022 IEEE 13th International Conference on Software Engineering and Service Science (ICSESS)*, Oct. 2022, pp. 203–208, iSSN: 2327-0594. [Online]. Available: https://ieeexplore.ieee.org/document/9930186

[12] G. K. S, S. R. Kakarlapudi, and R. Sultana, "Design of Digital Twin for Safety Systems in Electric Vehicles," in *2023 International Conference on Next Generation Electronics (NEleX)*, Dec. 2023, pp. 1–6. [Online]. Available: https://ieeexplore.ieee.org/document/10421634

[13] G. Xie, K. Yang, C. Xu, R. Li, and S. Hu, "Digital Twinning Based Adaptive Development Environment for Automotive Cyber-Physical Systems," *IEEE Transactions on Industrial Informatics*, vol. 18, no. 2, pp. 1387–1396, Feb. 2022, conference Name: IEEE Transactions on Industrial Informatics. [Online]. Available: https://ieeexplore.ieee.org/document/9372842

[14] N. I. Gross and P. Svasta, "Transition to Digital Twin for Automotive Sensor Interfaces Test Equipment," in *2023 46th International Spring Seminar on Electronics Technology (ISSE)*, May 2023, pp. 1–5, iSSN: 2161-2536. [Online]. Available: https://ieeexplore.ieee.org/document/10168449

[15] Y. Gu, F. Wang, M. Li, L. Zhang, and W. Gong, "A Digital Load Forecasting Method Based on Digital Twin and Improved GRU," in *2022 Asian Conference on Frontiers of Power and Energy (ACFPE)*, Oct. 2022, pp. 462–466. [Online]. Available: https://ieeexplore.ieee.org/document/9952254

[16] Z. Zhifeng, M. Qingzheng, C. Xiao, K. Jinhui, Z. Zhe, and S. Tong, "Distribution Room Modeling Based on Digital Twin," in *2023 International Conference on Computer Applications Technology (CCAT)*, Sep. 2023, pp. 7–12. [Online]. Available: https://ieeexplore.ieee.org/document/10410333

[17] J. Nwoke, M. Milanesi, J. Viola, and Y. Chen, "FPGA-Based Digital Twin Implementation for Power Converter System Monitoring," in *2023 IEEE 3rd International Conference on Digital Twins and*

Parallel Intelligence (DTPI), Nov. 2023, pp. 1–6. [Online]. Available: https://ieeexplore.ieee.org/document/10365466

[18] J. Qiao, L. Peng, A. Zhou, Z. Ou, Y. Mao, and S. Pan, "Research and Implementation of Multi Fusion Data Model Construction Technology for Distribution Network Digital Twins," in *2023 5th International Conference on Decision Science & Management (ICDSM)*, Mar. 2023, pp. 258–262. [Online]. Available: https://ieeexplore.ieee.org/document/10314058

[19] S. Sabri, K. Alexandridis, M. Koohikamali, S. Zhang, and H. E. Ozkaya, "Designing a Spatially-explicit Urban Digital Twin Framework for Smart Water Infrastructure and Flood Management," in *2023 IEEE 3rd International Conference on Digital Twins and Parallel Intelligence (DTPI)*, Nov. 2023, pp. 1–9. [Online]. Available: https://ieeexplore.ieee.org/document/10365478

[20] G. Xinying, B. Liang, Y. Bolati, P. Xudong, and G. Aizaizi, "Digital Twin Smart Computer Room Management Method based on BIM Technology," in *2023 2nd International Conference on Data Analytics, Computing and Artificial Intelligence (ICDACAI)*, Oct. 2023, pp. 652–657. [Online]. Available: https://ieeexplore.ieee.org/document/10361193

[21] S. Furuta, J. Nakazato, and M. Tsukada, "Web-Based BIM Platform for Building Digital Twin," in *2023 IEEE 3rd International Conference on Digital Twins and Parallel Intelligence (DTPI)*, Nov. 2023, pp. 1–6. [Online]. Available: https://ieeexplore.ieee.org/document/10365476

[22] V. Bartolucci, N. Ciuccoli, F. Prendi, L. Screpanti, and D. Scaradozzi, "A digital twin infrastructure for designing an underwater survey with a professional DPV," in *2022 30th Mediterranean Conference on Control and Automation (MED)*, Jun. 2022, pp. 829–834, iSSN: 2473-3504. [Online]. Available: https://ieeexplore.ieee.org/document/9837286

[23] Z. Lv, H. Lv, and M. Fridenfalk, "Digital Twins in the Marine Industry," *Electronics*, vol. 12, no. 9, p. 2025, Jan. 2023, number: 9 Publisher: Multidisciplinary Digital Publishing Institute. [Online]. Available: https://www.mdpi.com/2079-9292/12/9/2025

[24] M. Shrivastava, R. Chugh, S. Gochhait, and A. B. Jibril, "A Review on Digital Twin Technology in Healthcare," in *2023 International Conference on Innovative Data Communication Technologies and Application (ICIDCA)*, Mar. 2023, pp. 741–745. [Online]. Available: https://ieeexplore.ieee.org/document/10099646

[25] M. Viceconti, M. De Vos, S. Mellone, and L. Geris, "Position Paper From the Digital Twins in Healthcare to the Virtual Human Twin: A Moon-Shot Project for Digital Health Research," *IEEE Journal of Biomedical and Health Informatics*, vol. 28, no. 1, pp. 491–501, Jan. 2024, conference Name: IEEE Journal of Biomedical and Health Informatics. [Online]. Available: https://ieeexplore.ieee.org/document/10278402

[26] S. Pirbhulal, H. Abie, and A. Shukla, "Towards a Novel Framework for Reinforcing Cybersecurity using Digital Twins in IoT-based Healthcare Applications," in *2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring)*, Jun. 2022, pp. 1–5, iSSN: 2577-2465. [Online]. Available: https://ieeexplore.ieee.org/document/9860581

[27] G. Tabunshchyk, P. Arras, and C. Wolff, "Digital Twins in Engineering Education, Preparing Students for Industrial Digital Transformation," in *2023 IEEE 12th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS)*, vol. 1, Sep. 2023, pp. 271–274, iSSN: 2770-4254. [Online]. Available: https://ieeexplore.ieee.org/document/10348648

[28] N. A. Fashal, G. A. Elkhayat, and S. A. Elmorsy, "Review and Proposed Digital Twin Model for Sustainable Smart University Asset Management," in *2023 IEEE Afro-Mediterranean Conference on Artificial Intelligence (AMCAI)*, Dec. 2023, pp. 1–8. [Online]. Available: https://ieeexplore.ieee.org/document/10431490