Advances in Reliability, Safety and Security

ESREL 2024
Monograph Book Series

Digital Twin For Maintenance: Overview And Trends

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Keywords: Digital Twin, maintenance, overview, trends, Industry 4.0

This article examines the evolution of Digital Twin (DT) technology from 2017 to 2023, highlighting its increasing importance and diversified application, especially in maintenance. A significant advancement is the integration of Augmented Reality (AR) and Virtual Reality (VR) technologies since 2021, significantly improving the DT experience. Research, predominantly conducted in Europe and Asia, shows a diversification of DT applications beyond the industrial sector, encompassing civil engineering, healthcare, energy, and transportation. The article emphasizes the transformative impact of DTs in maintenance strategies, anticipating their continuous evolution and growing relevance across various sectors.

As the industrial landscape continuously evolves, Digital Twin (DT) technology has emerged as a game-changer. Building upon insights from the 2020 study, "Digital Twin for Maintenance: A Literature Review," our article delves into the transformative period from 2017 to 2023. We meticulously analyzed 272 articles sourced from Google Scholar, focusing on titles with specific keywords to uncover the latest trends and breakthroughs in DT technology. A noteworthy development since 2021 is the seamless integration of Augmented Reality (AR)/Virtual Reality (VR) and Multiple-Criteria Decision Analysis (MCDA) technologies, significantly enhancing DT applications.

Post-2017, we've witnessed an exponential increase in digital twin research, highlighting its escalating significance across multiple sectors. This trend is not merely in quantity but also in the quality and sophistication of the solutions. The integration of VR technologies (Heuser et al., 2022) and AR technologies (Wei et al, 2021) since 2021 marks a significant leap, transforming digital twins into more intuitive and user-friendly tools. These advancements in visualization and interaction capabilities are revolutionizing monitoring and maintenance strategies. The adoption of MCDA methodologies also signifies a shift toward more complex and multi-dimensional decision-making in maintenance management (Yu et al., 2021).

Geographically, the majority of digital twin research originates from Europe and Asia, accounting for an astounding 84% of total publications. China's substantial contribution, representing 34% of the total, underscores the technological prowess and commitment of these regions to advance DT applications in maintenance. The European research landscape is notably diverse, with significant contributions from the UK, Germany, Italy, and France, demonstrating their robust approach to DT research and development (Table 1). Sector-wise, the industrial domain remains the primary beneficiary of DT technology. However, there's an emerging trend of diversification.

The rise in applications within civil engineering, which now accounts for 7% of the studies, signals DT's expansion beyond traditional manufacturing realms to include maintenance of infrastructure, buildings, and bridges. Moreover, the technology is steadily penetrating sectors like healthcare, energy, and transportation, collectively comprising 6% of the literature. This diversification underscores the versatile utility of digital twins and their potential to revolutionize maintenance strategies across various industries.

Digital twins in maintenance have transcended predictive maintenance, becoming integral to various strategies including condition-based, reliability-oriented, and proactive maintenance. These models are pivotal not just in forecasting potential issues, but in actively shaping maintenance schedules and activities through real-time data and risk assessments. In advanced applications, digital twins are even recommending or autonomously implementing solutions to mitigate risks and prevent failures, showcasing their adaptability and transformative impact across sectors. The incorporation of AR and VR technologies since 2021 represents a significant advancement in the digital twin arena (Figure 1). These immersive tools offer more intuitive and interactive platforms for maintenance, facilitating a deeper understanding and more effective management of complex systems. This technological progression isn't just a testament to innovation in digital twin applications but also hints at the future trajectory of this field, promising enhanced efficiency and continued progress.

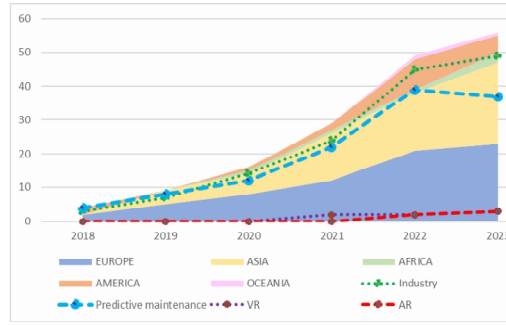

Fig. 1. Digital Twins and related technologies trends in different continents.

Table 1. Summary of the selected papers for the study and their classifications.

	2018	2019	2020	2021	2022	2023	Total	%
EUROPE	2	5	8	12	21	23	71	44%
ASIA	0	4	6	14	17	24	65	40%
AFRICA	0	0	1	1	1	3	6	4%
AMERICA	2	0	1	2	9	5	19	12%
OCEANIA	0	0	0	0	1	1	2	1%
	4	9	16	29	49	56	163	100%
Industry	3	7	14	24	45	49	142	87%
Civil Engineering	1	2	1	3	2	3	12	7%
Other	0	0	1	2	2	4	9	6%
	4	9	16	29	49	56	163	100%
Predictive maintenance	4	8	12	22	39	37	122	75%
Preventive maintenance	0	0	2	4	7	9	22	13%
Systematic maintenance	0	1	1	2	1	5	10	6%
Conditional preventive maintenance	0	0	1	1	2	5	9	6%
	4	9	16	29	49	56	163	100%
VR	0	0	0	2	2	3	7	4%
AR	0	0	0	0	2	3	5	3%

In conclusion, our study not only reaffirms but also expands upon the findings of previous literature, emphasizing the evolution of the digital twin as an indispensable tool in maintenance. The post-2017 era is marked by a diversification in application and a broadening of scope, with digital twins becoming increasingly essential in varied maintenance strategies. The integration of technologies like AR and VR has enriched the digital twin experience, elevating decision-making within maintenance practices. While our focused research approach has narrowed the scope to a subset of available studies, it has effectively captured the essence of this transformative technology. The industrial sector continues as the primary beneficiary, especially in manufacturing with the rapid adoption of Industry 4.0 innovations. Nevertheless, the escalating relevance of digital twins in civil engineering and other sectors is undeniable. This study not only corroborates foundational ideas from earlier literature but also illuminates the evolving utility of digital twins as a comprehensive tool for advanced maintenance strategies across diverse industries.

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