

Digital Twins in Industrial Transformation: A PRISMA-Based Review with Human Resource Implications

Manisha Gupta¹ and Mamta Singh²

¹School of Management Sciences, Lucknow, India

²Chandragupt Institute of Management Patna, Patna, India

herezmanisha@gmail.com

mamtakumar7@gmail.com

Abstract: The rapid advancement of Industry 4.0 technologies has transformed traditional industrial systems into intelligent, data-driven ecosystems. Among these, digital twins have emerged as key enablers of industrial transformation by integrating real-time data, simulation, and predictive analytics. This study presents a systematic literature review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to examine the role of digital twins in driving innovation, operational efficiency, and sustainability across industries. Using the Scopus database, an initial pool of 220 articles was identified, of which 15 studies were selected through a rigorous screening and eligibility process. The findings indicate that digital twins function as multidimensional strategic tools that enhance predictive maintenance, optimize resource utilization, and accelerate product development through virtual prototyping. In addition, digital twins contribute to sustainability by supporting energy efficiency, circular economy practices, and environmental, social, and governance (ESG) objectives. These capabilities highlight their role in enabling organizations to transition from reactive to proactive and data-driven decision-making systems in complex industrial environments globally and across diverse sectors. Importantly, the review highlights the organizational and human implications of digital twin adoption. The integration of digital twins creates hybrid decision-making environments where human judgment is augmented by algorithm-driven insights, influencing accountability, trust, and workforce roles. This transformation necessitates the development of new competencies, including data literacy, digital collaboration, and adaptive decision-making, while emphasizing the role of human resource management in facilitating reskilling, change management, and the development of data-driven organizational cultures. The study also identifies key challenges, including high implementation costs, interoperability issues, data security concerns, and resistance to change. By synthesizing technological, strategic, and human perspectives, this research positions digital twins as drivers of both operational and organizational transformation. The findings provide valuable insights for practitioners and policymakers seeking to leverage digital twin technologies for sustainable and competitive industrial development.

Keywords: Digital Twins; Industrial Transformation; Industry 4.0; Innovation; Sustainability; Human Resource Management; PRISMA

1. Introduction

The rapid advancement of digital technologies has fundamentally reshaped the industrial landscape, driving a shift toward data-driven, intelligent, and interconnected systems. The emergence of Industry 4.0 has accelerated the adoption of technologies such as Artificial Intelligence (AI), Blockchain, and the Internet of Things (IoT), enabling organizations to transform traditional operational models into adaptive and automated ecosystems (Gupta and Singh, 2024; Tabet et al., 2026). Supported by Big Data analytics, cloud computing, and cyber-physical systems, these technologies have enhanced capabilities in real-time decision-making, operational efficiency, and mass customization.

Within this paradigm, Digital Twin (DT) technology has emerged as a pivotal enabler of industrial transformation. Digital twins are dynamic virtual representations of physical products, processes, or systems that continuously evolve through real-time data integration (Yazdi, 2024). Unlike static, assumption-driven simulation models, digital twins function as living models, enabling predictive and prescriptive decision-making through continuous updates (Rakshit et al., 2024).

Digital twins operate across multiple levels, including products, processes, and systems providing integrated visibility and control across value chains (Kankam et al., 2022). Their integration with IoT, AI/ML, and cloud computing creates continuous feedback loops between physical and digital environments, enabling proactive monitoring, fault detection, and process optimization (Murthy et al., 2022; Mo et al., 2025). From a strategic perspective, digital twins enhance research and development through virtual prototyping, improve operational processes, and strengthen supply chain responsiveness (You et al., 2022). They also contribute to sustainability by optimizing energy use and supporting circular economy practices (Ali et al., 2025; Kumar and Tiwari, 2026).

Beyond technological advancements, digital twins are reshaping the human and organizational dimensions of work. Their integration into industrial systems creates hybrid human-machine decision environments, influencing accountability, decision ownership, and behavioral responses. This shift necessitates new

competencies such as data literacy, adaptive decision-making, and digital collaboration. At the same time, organizations face resistance as employees transition from intuition-based to data-driven decision-making, highlighting the role of HR in reskilling, change management, and fostering trust in intelligent systems. Concerns related to monitoring, privacy, and autonomy further emphasize the need for robust ethical and governance frameworks.

Despite their growing significance, existing literature remains fragmented, often focusing on specific industries or technical aspects without adequately addressing digital twins as strategic enablers of holistic industrial transformation. Limited attention has also been given to their human and organizational implications. To address these gaps, this study undertakes a systematic literature review using the PRISMA framework to examine the role of digital twins in driving innovation, operational efficiency, sustainability, and organizational transformation.

Accordingly, the study is guided by the following research question:

How does digital twin technology act as a strategic enabler in industrial transformation, and what are its implications for organizational and human systems?

By integrating technological, strategic, and human perspectives, this study contributes to the literature by positioning digital twins as drivers of intelligent, adaptive, and sustainable industrial ecosystems. This study makes a distinct contribution by integrating a human resource perspective into digital twin research, an area that remains underexplored.

2. Literature Review

2.1 Conceptual Foundations of Digital Twins in Industry 4.0

Digital twins have emerged as a foundational pillar within Industry 4.0, representing a shift from static, simulation-based models to dynamic, data-driven representations of physical systems (Stavropoulos et al., 2022). A digital twin is a real-time virtual representation that evolves through continuous data integration, enabling monitoring, prediction, and optimization (Kamburjan et al., 2022).

Unlike traditional models based on predefined assumptions, digital twins enable bi-directional communication between physical and virtual systems, supporting predictive and prescriptive decision-making and enhancing operational responsiveness (Rakshit et al., 2024). This marks a fundamental shift in managing complex systems. Moreover, digital twins extend beyond individual assets to encompass processes, systems, and organizational ecosystems, enabling integrated visibility and systemic understanding (Kankam et al., 2022).

2.2 Technological Architecture and Enabling Ecosystem

The effectiveness of digital twins is supported by a multi-layered architecture integrating physical systems, data acquisition, communication networks, and advanced analytics. Sensors capture real-time data, which is transmitted through IoT systems and processed on cloud platforms (Hemdan et al., 2023). The digital model layer converts this data into actionable insights using AI and machine learning (Li et al., 2023), while application interfaces enable monitoring and decision-making (Cao and Jiang, 2024).

This creates a closed-loop system where digital insights continuously inform physical operations, enabling adaptive control and optimization (Mo et al., 2025). Integration with big data, blockchain, and cloud technologies enhances scalability and transparency (Gupta et al., 2025). Strategically, digital twins function as a central nervous system within industrial ecosystems, enabling intelligent automation and real-time decision-making (Murthy et al., 2022).

2.3 Digital Twins as Drivers of Innovation and Operational Excellence

Digital twins accelerate innovation and operational performance by enabling virtual prototyping, reducing physical testing, and shortening development cycles (Lim et al., 2020). They also support predictive maintenance through real-time analytics, reducing downtime and improving asset utilization (You et al., 2022).

Across industries, digital twins enhance process optimization and system performance, particularly in manufacturing, supply chains, and transportation (Gao et al., 2022). Their integration with AI expands capabilities in areas such as cybersecurity and intelligent automation (Sarker et al., 2024). Emerging developments, including cyber twins and electronic digital twins, extend these capabilities to more advanced predictive systems

(Bamunuarachchi et al., 2021; Massaro, 2025). This capability also supports a shift toward data-driven innovation ecosystems, where organizations can continuously refine products and processes based on real-time feedback. By enabling rapid experimentation and iterative learning, digital twins reduce uncertainty and enhance strategic agility, allowing firms to respond more effectively to dynamic market conditions.

2.4 Sectoral Applications and Industrial Transformation

Digital twins have demonstrated applications across sectors such as manufacturing, healthcare, and infrastructure, improving efficiency, predictive capabilities, and system optimization (Abadi et al., 2025; Dwivedi et al., 2024; Meng et al., 2024). These applications highlight their versatility as enablers of industrial transformation.

2.5 Digital Twins and Sustainability: ESG and Circular Economy Perspectives

Sustainability has emerged as a critical dimension of digital twin adoption. Digital twins enable organizations to optimize resource utilization, reduce waste, and improve energy efficiency (Ali et al., 2025). They also support circular economy practices by facilitating material monitoring, reuse, and recycling (Kumar and Tiwari, 2026).

In urban contexts, digital twins contribute to smart city initiatives by improving infrastructure efficiency and resilience (Omran et al., 2025). Additionally, they enhance workplace safety, transparency, and regulatory compliance, supporting broader ESG objectives (Aagaard and Vanhaverbeke, 2024). Beyond operational benefits, digital twins contribute to aligning business strategies with sustainability objectives by enabling real-time tracking of environmental impact metrics. This integration supports informed decision-making and enhances organizational accountability toward ESG goals, reinforcing their role in sustainable industrial transformation.

2.6 Human and Organizational Implications: an HR Perspective

While the technological benefits of digital twins are well-documented, their human and organizational implications remain underexplored (Holopainen et al., 2024). Their integration creates hybrid decision environments where human judgment is augmented by algorithm-driven insights (Mo et al., 2025), requiring new competencies such as data literacy, digital collaboration, and adaptive decision-making.

This shift may alter accountability structures, potentially reducing perceived ownership of outcomes. From an HR perspective, successful adoption requires reskilling, change management, and fostering trust in data-driven systems (Sarker et al., 2024).

2.7 Challenges and Research Gaps

Despite their potential, digital twin adoption faces challenges including high implementation costs, lack of standardization, interoperability issues, and data security concerns (Dwivedi et al., 2024; Hemdan et al., 2023). Organizational resistance and limited understanding of data-driven decision-making further hinder adoption. Existing research remains fragmented, focusing primarily on technological aspects with limited attention to strategic and human dimensions. In particular, the intersection of digital twins with HR practices and organizational behavior remains underexplored.

2.8 Synthesis and Direction for the Present Study

The literature indicates that digital twins serve as enablers of innovation, efficiency, and sustainability. However, the fragmented nature of existing research highlights the need for a comprehensive synthesis integrating technological, strategic, and human perspectives. Accordingly, this study adopts a PRISMA-based systematic review to examine digital twins as strategic enablers of industrial transformation and their implications for organizational and human systems.

3. Methodology

This study adopts a systematic literature review (SLR) approach to examine the role of digital twin technology as a strategic enabler of industrial transformation. The review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure a structured process for identifying, screening, and selecting relevant studies. A hybrid analytical approach is employed, combining bibliometric insights with qualitative thematic analysis.

The literature search was conducted using the Scopus database. A structured search query (“digital twin”) AND (“industrial transformation”) AND (“innovation”), limited to English-language publications, yielded an initial pool of 220 articles. Following the PRISMA process (Page et al., 2021), 45 articles were shortlisted after screening titles and abstracts, and 15 studies were selected after full-text evaluation based on relevance (Table 1).

The inclusion criteria focused on studies addressing digital twin applications in industrial transformation, innovation, or sustainability, including peer-reviewed journal articles, conference papers, and scholarly book chapters. Non-relevant and non-English studies were excluded. Data were analyzed through bibliometric examination and thematic coding to identify key areas such as technological architecture, innovation outcomes, sustainability contributions, organizational implications, and implementation challenges. While the use of Scopus ensures high-quality coverage, it may limit inclusion of studies from other databases, which is acknowledged as a limitation.

Table 1: Key studies on digital twins as strategic enablers of industrial transformation

Author(s)	Article Title	Journal, Year (Citation)	Key Findings
Lim et al.	A digital twin-enhanced system for engineering product family design and optimization	Journal of Manufacturing Systems, 2020 (148)	Digital twin can provide decision support to enhance product lifecycle management and engineering product family design.
Sarker et al.	Explainable AI for cybersecurity automation, intelligence and trustworthiness in digital twin: Methods, taxonomy, challenges and prospects	ICT Express, 2024 (114)	Digital twins (DTs) are an emerging digitalization technology with a huge impact on today's innovations in both industry and research.
Bamunuarachchi et al.	Digital twins supporting efficient digital industrial transformation	Sensors, 2021 (44)	Cyber Twins (CTs), an extension of Digital Twins, support cost-efficient Industry 4.0 application with approximately 60% of the cost of IoT platform-based application development.
Gao et al.	Application of Digital Twins and Building Information Modeling in the Digitization of Transportation: A Bibliometric Review	Applied Sciences (Switzerland), 2022 (24)	Digital twin technologies assist in the digitalization of transportation improving the efficiency of intelligent transportation system element management.
Zhao et al.	A machine learning and CFD modeling hybrid approach for predicting real-time heat transfer during cokemaking processes	Fuel, 2024 (21)	Digital Twin is paving the way to simulate the heat transfer during the cokemaking process with high accuracy and efficiency, thereby demonstrating its capacity to significantly reduce energy consumption within the cokemaking industry and development of smart cokemaking process.
Massaro	Electronic Artificial Intelligence and Digital Twins in Industry 5.0: A Systematic Review and Perspectives	Machines, 2025 (3)	The Electronic Digital Twin (EDT) tools are useful to comprehend the modeling concepts functional to the AI application using the output of the circuit simulations. The output of the circuit is used to train the AI model, thus strengthening the capability to classify and predict the real behavior of production machines with a good accuracy.
Sharotry et al.	A digital twin framework of a material handling operator in industry 4.0 environments	Interconnected Supply Chains in an Era of Innovation - Proceedings of the 8th International Conference on Information Systems, Logistics and Supply Chain, ILS 2020 (3)	The paper presents framework of a manual material handling operator to enhance worker performance using digital twin approach.

Source: Accessed on 6 April 2026 (Scopus database), compiled by the authors.

4. Results and Analysis

The systematic review, conducted using the PRISMA framework, resulted in the selection of 15 high-quality studies that collectively examine the role of digital twins across multiple industrial domains. The analysis of these studies reveals that digital twin technology functions as a multidimensional strategic enabler, driving transformation through interconnected pathways of operational efficiency, innovation, sustainability, and organizational evolution.

A dominant theme emerging from the literature is the role of digital twins in enhancing operational intelligence and efficiency. By leveraging real-time data and predictive analytics, digital twins enable organizations to transition from reactive to proactive decision-making. This is particularly evident in manufacturing and industrial systems, where digital twins facilitate predictive maintenance, reduce downtime, and optimize resource utilization (You et al., 2022; Abadi et al., 2025). The integration of AI-driven models further strengthens this capability by enabling continuous learning and self-optimization within production environments (Mo et al., 2025). As a result, organizations achieve not only cost efficiencies but also improved system reliability and performance.

Closely linked to operational efficiency is the role of digital twins in accelerating innovation and product development. The ability to simulate, test, and refine products in a virtual environment significantly reduces the need for physical prototyping, thereby shortening development cycles and lowering associated costs (Lim et al., 2020). This virtual experimentation capability enables organizations to explore multiple design scenarios and optimize outcomes before implementation. Moreover, digital twins support advanced applications such as real-time process modeling and hybrid simulation, as demonstrated in industrial processes like heat transfer optimization (Zhao et al., 2024). These capabilities position digital twins as critical tools for fostering continuous innovation.

Another key finding is the contribution of digital twins to sustainability and circular economy practices. The literature indicates that digital twins enable precise monitoring of energy consumption, material flows, and system performance, thereby facilitating resource optimization and waste reduction (Ali et al., 2025; Kumar and Tiwari, 2026). In addition, digital twins support environmental and social governance (ESG) objectives by enhancing transparency, improving safety, and enabling data-driven compliance mechanisms (Aagaard and Vanhaverbeke, 2024). Their application in smart cities and infrastructure systems further demonstrates their potential to promote urban sustainability and resilience (Omrany et al., 2025).

The review also highlights the sectoral versatility of digital twin applications, reinforcing their role as enablers of industrial transformation across domains. In healthcare, digital twins enable patient-specific simulations and real-time monitoring, improving treatment outcomes and operational efficiency (Dwivedi et al., 2024). In the architecture, engineering, and construction (AEC) sector, they enhance safety management and lifecycle monitoring (Meng et al., 2024), while in transportation, they optimize system performance and infrastructure management (Gao et al., 2022). Similarly, in oil and gas operations, digital twins support predictive maintenance and risk management in complex environments (Abbas et al., 2021). These applications demonstrate the adaptability of digital twin technology to diverse industrial contexts.

Beyond technological and operational benefits, a critical insight emerging from the analysis is the transformation of organizational and human systems. Digital twins introduce hybrid decision-making environments, where human expertise is augmented by algorithm-driven insights. This shift necessitates new competencies, including data literacy, analytical thinking, and digital collaboration skills. At the same time, it alters traditional accountability structures, as decision-making authority becomes distributed between human actors and intelligent systems. Such changes may lead to challenges related to perceived responsibility, trust in automated systems, and behavioral adaptation within organizations.

The findings further indicate that the successful adoption of digital twins is contingent upon organizational readiness and cultural alignment. Resistance to change, lack of understanding of data-driven decision-making, and concerns related to privacy and control can hinder implementation. These challenges underscore the critical role of leadership and human resource management in facilitating digital transformation through training, change management, and the development of a culture that supports innovation and continuous learning.

Finally, the analysis identifies several implementation challenges that persist across studies. High initial investment costs, lack of standardized frameworks, interoperability issues, and data security concerns remain

significant barriers to adoption (Dwivedi et al., 2024; Hemdan et al., 2023). While technological advancements continue to address some of these issues, the need for integrated strategies that combine technological, organizational, and regulatory perspectives remains evident.

In synthesis, the findings demonstrate that digital twin technology acts as a strategic enabler of industrial transformation by simultaneously enhancing operational performance, driving innovation, supporting sustainability goals, and reshaping organizational dynamics. This multidimensional impact highlights the importance of adopting a holistic perspective that integrates technological capabilities with human and organizational considerations.

5. Discussion

The findings of this study position digital twin technology as a strategic enabler of industrial transformation, extending its role beyond operational efficiency to innovation, sustainability, and organizational adaptation. The synthesis of literature indicates that digital twins facilitate a shift from reactive to predictive and prescriptive decision-making systems, supported by real-time data integration and advanced analytics (Mo et al., 2025; Rakshit et al., 2024). This aligns with the evolving perspective of Industry 4.0, where decision-making is increasingly embedded within dynamic, feedback-driven systems rather than linear processes.

A key theoretical implication lies in the integration of innovation and digital transformation frameworks. Digital twins enable continuous experimentation through virtual prototyping and simulation, thereby accelerating product and process innovation while reducing uncertainty (Lim et al., 2020). At the same time, their capability to optimize resource utilization and monitor system performance links them closely with sustainability and ESG-oriented models (Ali et al., 2025; Kumar and Tiwari, 2026). This dual role suggests that digital twins act as a bridge between efficiency-driven and sustainability-driven transformation.

The findings also highlight an important yet underexplored dimension, the organizational and human implications of digital twin adoption. The emergence of hybrid decision environments, where human judgment is augmented by algorithm-driven insights, alters traditional structures of decision authority and accountability. This shift has implications for organizational behavior, particularly in terms of trust in systems, responsibility attribution, and decision ownership. Employees are increasingly required to interpret and act upon data-driven recommendations, indicating a transition toward more analytical and adaptive roles.

From a practical standpoint, the results suggest that the successful implementation of digital twins depends on more than technological capability. Organizations must align digital twin adoption with strategic objectives, ensuring that investments contribute to innovation, operational excellence, and sustainability outcomes. Equally important is organizational readiness, including the development of data-driven cultures and cross-functional integration.

The role of human resource management emerges as critical in this context. Organizations need to invest in reskilling and upskilling initiatives to build competencies such as data literacy and analytical decision-making. Additionally, HR must address resistance to change and foster a culture that supports digital adoption. Concerns related to privacy, monitoring, and employee autonomy further necessitate the development of ethical and governance frameworks to ensure responsible implementation.

Finally, persistent challenges such as high implementation costs, interoperability issues, and data security concerns continue to influence adoption decisions (Dwivedi et al., 2024; Hemdan et al., 2023). Addressing these barriers requires integrated strategies combining technological, organizational, and regulatory approaches.

5.1 Theoretical Implications

This study contributes to the literature by positioning digital twins as dynamic, data-driven systems that extend beyond traditional simulation models to function as continuous decision-support mechanisms. By enabling real-time feedback loops between physical and digital environments, digital twins align with cyber-physical system and systems thinking perspectives, shifting decision-making from linear to adaptive and predictive processes (Mo et al., 2025; Rakshit et al., 2024).

The findings also integrate digital twin adoption with innovation and sustainability frameworks, demonstrating that digital twins facilitate continuous experimentation, accelerate product development, and support resource optimization (Lim et al., 2020; Ali et al., 2025; Kumar and Tiwari, 2026). This highlights their dual role in driving both efficiency and ESG-oriented transformation.

Importantly, the study extends existing research by incorporating the human and organizational dimension, showing that digital twins create hybrid decision environments that influence accountability, trust, and decision-making behavior. This opens new avenues for research at the intersection of technology, organizational behavior, and HR systems.

5.2 Practical Implications

From a managerial perspective, the findings suggest that digital twin adoption should be approached as a strategic initiative rather than a purely technological investment. Organizations must align digital twin implementation with broader goals related to innovation, efficiency, and sustainability.

Successful adoption requires organizational readiness, including the development of data-driven cultures and cross-functional integration. Human resource management plays a critical role in this process by enabling reskilling and upskilling, fostering adaptability, and managing resistance to change.

Additionally, organizations must address concerns related to data privacy, employee autonomy, and system trust by establishing clear governance and ethical frameworks. Overcoming challenges such as high implementation costs and interoperability issues requires phased strategies and collaborative ecosystems (Dwivedi et al., 2024; Hemdan et al., 2023).

6. Conclusion

This study establishes that digital twin technology acts as a strategic enabler of industrial transformation, enhancing operational efficiency, supporting innovation, and contributing to sustainability. By enabling real-time, data-driven decision-making, digital twins facilitate a shift toward more proactive and adaptive organizational systems.

Beyond technological benefits, the study highlights the importance of integrating human and organizational factors, emphasizing the role of HR and culture in ensuring successful adoption. Digital twins, therefore, represent not only a technological advancement but also a catalyst for broader organizational transformation.

7. Limitations and Future Research Directions

This study is subject to certain limitations. First, the review is based solely on the Scopus database, which, although comprehensive, may exclude relevant studies indexed in other databases. Second, the analysis is limited to English-language publications, potentially overlooking valuable contributions from non-English sources. Third, the study relies on a relatively small sample of selected articles, which may restrict the generalizability of the findings. Additionally, as a systematic literature review, the study is conceptual in nature and does not include empirical validation.

Future research can address these limitations by incorporating multiple databases and expanding the scope of literature to include diverse geographical and linguistic contexts. There is a need for empirical studies examining the impact of digital twin adoption on organizational performance and decision-making outcomes. Further research should also explore human–technology interactions, particularly issues related to trust, accountability, and behavioral adaptation in data-driven environments. Moreover, the role of human resource practices in facilitating digital transformation warrants deeper investigation. Finally, developing standardized frameworks to address challenges related to interoperability, governance, and scalability would contribute to advancing both theory and practice in this domain.

Ethics Declaration

This study is based on a review of existing literature and does not involve human participants; therefore, ethical approval was not required.

AI Declaration

An AI tool (ChatGPT) was used for language refinement and structuring. All content and interpretations are the authors' own.

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