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Bibliometric Analysis of Digital Twin Technology

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ABSTRACT

Digital twin technology has emerged as a transformative innovation that enables the creation of virtual representations of physical systems, facilitating real-time monitoring, simulation, optimization, and decision-making across various domains. Given the rapid growth of scholarly interest in this field, a comprehensive understanding of its intellectual structure and research evolution is needed. This study aims to map the global research landscape of digital twin technology through a bibliometric analysis of publications indexed in the Scopus database. Bibliometric techniques were employed to examine publication trends, influential authors, institutions, countries, highly cited documents, collaboration networks, and keyword co-occurrence patterns. The analysis was conducted using VOSviewer to visualize scientific relationships and emerging research themes. The results indicate a substantial increase in digital twin research, particularly after the widespread adoption of Industry 4.0 initiatives. Keyword analysis identifies digital twin as the central research theme, strongly associated with artificial intelligence, Internet of Things, machine learning, smart manufacturing, sustainability, and decision-making. Overlay visualization reveals that recent studies increasingly focus on predictive analytics, energy efficiency, and sustainable development, while density analysis highlights artificial intelligence and IoT as dominant supporting technologies. Country collaboration analysis shows that China, the United States, and several European nations are the leading contributors to the field, whereas citation analysis demonstrates the significant influence of foundational conceptual and review studies. The findings suggest that digital twin technology is evolving toward more intelligent, interconnected, and sustainability-oriented applications. This study contributes to the literature by providing a comprehensive overview of the development, knowledge structure, and future research directions of digital twin technology.

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1. INTRODUCTION

The exponential progress in the area of digitalization has revolutionized the way industries design, measure, and optimize physical entities [1]. One of the most significant inventions that came into existence in the period defined by Industry 4.0 is the Digital Twin technology. The Digital Twin can be described as a virtual image of any physical object, process, or system that communicates

with the latter through the use of sensors and simulation tools as well as modern means of communication. As a result, technologies like IoT, artificial intelligence (AI), cloud computing, and big data contribute to simulating certain circumstances, predicting the outcomes, and improving the quality of decision-making processes within a company in real-time mode [2]. Initially used in aerospace and manufacturing industries, this technology has already found applications in healthcare, smart cities, transportation, energy, and educational sectors because of its ability to increase productivity and cut down costs [3].

Digital Twin technology is being widely utilized in connection with the rising need for innovations driven by data and intelligent automation. Companies working in industrial settings aim to implement technological solutions that increase efficiency, while minimizing risk and avoiding disruptions to operations [4]. With the ability to continuously monitor and simulate how the performance of machinery could be improved, Digital Twins represent the key technology capable of meeting this objective. In the field of healthcare, researchers are investigating the possibility of implementing Digital Twins to model organs and disease conditions of patients in order to develop personalized approaches to treatment. Urban planners use Digital Twins to enable the development of smart cities, as they help to monitor such aspects of urban life as traffic, energy usage, and environmental factors [4].

As Digital Twin technology becomes more widely adopted, there has been an increasing amount of academic research in this area. Scholars from multiple fields have been conducting research on concepts, frameworks, implementation models, enabling technologies, limitations, and future directions of Digital Twin [2]. The rising publication numbers suggest that Digital Twin has become a significant area of study in engineering, information systems, computer science, and management research. In addition to technological innovations, academic papers examine problems associated with cybersecurity, interoperability, data integration, ethics, and sustainability. The fast expansion of literature opens up new possibilities and imposes difficulties for scholars working on this subject matter. On the one hand, the growing body of research literature helps better understand the advances in technological innovation and industrial application. On the other hand, the increasing number of publications poses challenges in terms of identifying key topics, influential authors, collaboration networks, and research directions [4].

In this case, bibliometrics has become one of the critical ways of assessing the development of scientific literature in a systematic and quantitative way. Bibliometrics entails the utilization of statistical and mathematical techniques to analyze patterns in academic literature concerning citation patterns, authors, keywords, publication output, and collaborative networks. By employing bibliometric analysis, scholars can ascertain notable publications, key individuals, top organizations, and emerging themes in a certain discipline. Unlike conventional literature reviews, bibliometric analysis presents a more accurate and all-encompassing picture of scientific development since it allows the visualization of connections between publications and communities conducting research on them. Recently, the adoption of bibliometric software like VOSviewer, Scopus analytics, and CiteSpace has become prevalent since these applications allow the identification of research maps and knowledge [5].

Although Digital Twin technology is gaining more recognition today, the existing literature lacks an extensive examination of its historical development and intellectual structure. The available literature tends to concentrate either on particular application areas or technical elements of the technology but not on publication dynamics and scholarly achievements in general. In addition, given that Digital Twin research is multidisciplinary, recognizing associations between different nations, organizations,

authors, and research themes is crucial for defining future research agendas and potential cooperation areas. Bibliometric study will help understand the development trajectory of Digital Twin research over time, identify nations and institutions that have made significant contributions to the field, detect dominant themes within Digital Twin research, and uncover emergent research themes in need of additional exploration. Therefore, conducting a bibliometric study on Digital Twin technology will be helpful in guiding researchers, professionals, and policy makers in comprehending the current stage of research in the area and developing future research agendas.

Due to the explosive increase in the number of publications associated with the Digital Twin technology, several problems arise when assessing the overall state of development, trends, and structural characteristics of knowledge. While many investigations have been dedicated to the applications and technical issues of Digital Twins, there is still a lack of any systematic study on publication dynamics, key researchers, major countries, collaboration maps, and new research areas within this domain. The multidisciplinary character of Digital Twin investigation also makes the detection of possible knowledge gaps and promising future research directions challenging for researchers. As a result, scholars could not obtain an overview of the history and tendencies in Digital Twin studies and understand the main directions of current investigations. In this regard, the necessity to conduct bibliometric analysis arises. The goal of this research is to explore the growth pattern, citation structure, collaboration network, research topic and so forth of Digital Twin technology using bibliometrics approach.

2. METHODS

In this research, a quantitative bibliometric research method will be applied in order to investigate the evolution and trends of research on Digital Twin technology. The use of bibliometric analysis is justified since it helps objectively assess scientific literature using statistical and graphical methods. The research objectives include the identification of publication dynamics, key authors, institutions, citation characteristics, collaboration networks, and prominent themes in Digital Twin technology. It would be appropriate to use bibliometric analysis in this research since it gives an unbiased assessment of the intellectual structure and development of scientific research in a specific field of science. The data needed for analysis will be sourced from reliable academic publications that contain scientific literature on Digital Twin technology.

This process involves conducting a literature search on various articles through the use of key words like “Digital Twin,” “Digital Twin Technology,” “Digital Twin Systems,” among others. The articles can be obtained from the indexed scientific literature database, such as Scopus or Web of Science, within the pre-specified time frame to ensure relevancy and consistency. The inclusion criteria for the selection of the literature include the use of English language articles that have been published in scholarly journals or conference papers and those dealing directly with the subject matter of the Digital Twin technology. Once the data are collected, the duplicates and unrelated articles are filtered out. Further, the bibliographic details, including titles, authors, affiliations, abstracts, key words, citations, and references are exported for subsequent analysis.

The bibliometric analysis is carried out utilizing some bibliometric software packages, for instance, VOSviewer and Microsoft Excel. There are several bibliometric measures that will be considered, including the number of publications per year, citation analysis, co-authorship analysis, keyword co-occurrence analysis, and country or institutional cooperation analysis. Citation analysis can be used to identify highly cited publications and authors, while keyword co-occurrence analysis can assist in identifying dominant topics and hot issues. Network visualization methods are used to demonstrate the connections between researchers, institutions, and topic areas.

Finally, the results derived from the bibliometric analysis will be analyzed descriptively.

3. RESULTS AND DISCUSSION

3.1 Keyword Co-Occurrence Network

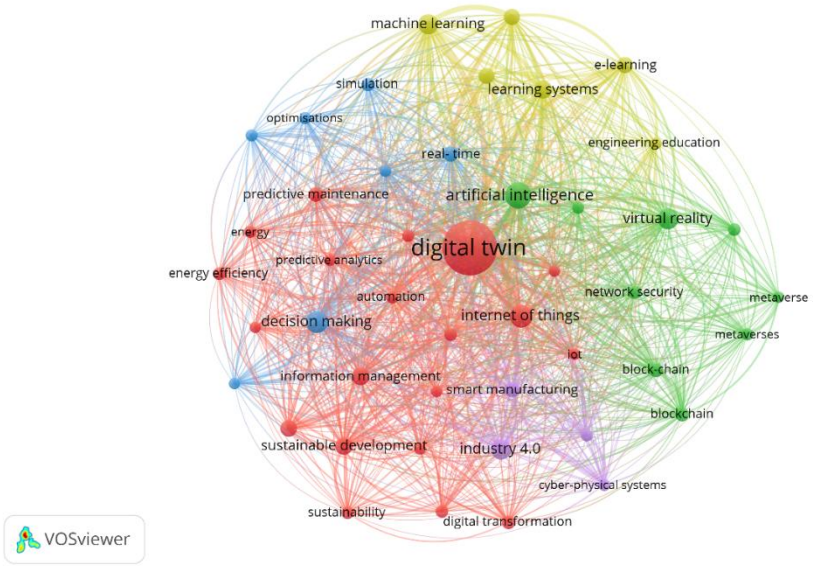

Figure 1. Network Visualization
Source: Data Analysis Result, 2026

From the keyword co-occurrence network, it is clear that "digital twin" is the core word in the entire research network. This is because the size of the node is big, which means that it is highly frequently used, but the placement of this node is in the center, which signifies its interconnection with various other themes such as artificial intelligence, internet of things, industry 4.0, smart manufacturing, simulation, and predictive maintenance.

The red cluster depicts the main technological and industrial base for studies related to digital twins. Internet of things, smart manufacturing, industry 4.0, automation, decision making, information management, energy efficiency, sustainability, and sustainable development are the keywords from the red cluster indicating that there is a focus on digital twins being used for industrial change and improved data management. The yellow group points out the link between digital twin technologies and intelligent learning systems. The terms such as machine learning, learning systems, e-learning, engineering education, simulation, and real time demonstrate that digital twin studies have become popularized in relation to computation learning, education, and simulated learning. Therefore, besides the use of digital twins in industry surveillance purposes, there is a clear shift in utilizing digital twins in learning activities.

The green cluster is an indication of new developments in the use of digital and immersive technologies. Terms such as artificial intelligence, virtual reality, blockchain, block-chain, network security, metaverse, and metaverses point to a possible development in the application of digital twins from physical to virtual environments, as well as digitally secure ecosystems.

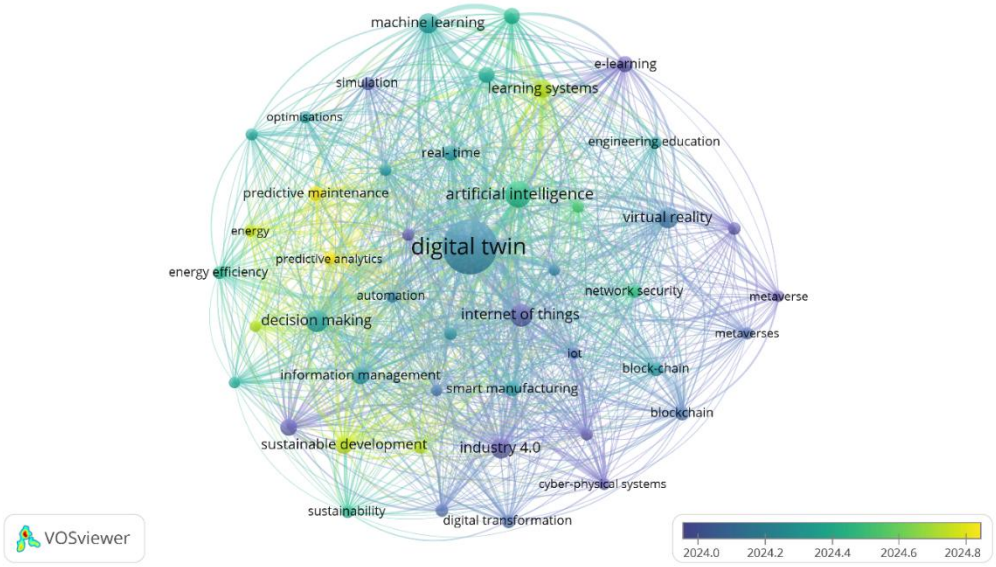

Figure 2. Overlay Visualization
Source: Data Analysis Result, 2026

Through the overlay visualization, one can see the evolution of research on digital twins in time because topics are represented based on their average publishing year. Being positioned at the center of the graph, digital twin is clearly seen as the primary theme linking different fields of study. The nodes that appear in green and yellow colors refer to recent research areas, whereas those in blue and purple reflect older ones. Thus, the above-mentioned information shows that initially being related to industry and manufacturing, the research field under consideration has expanded to intelligent and digital solutions.

Some notable trends have emerged during the latest era, as seen from the highlighted nodes in yellow color. Terms like decision making, sustainable development, predictive analytics, predictive maintenance, energy, and energy efficiency imply the importance placed nowadays on the application of digital twins for purposes of optimization and decision-making. This trend implies an evolution from simply representing physical objects with virtual models to utilizing digital twins for optimization and decision-making purposes.

On the other hand, concepts like metaverse, virtual reality, blockchain technology, cyber physical systems, digital transformation, and Industry 4.0 are represented in deeper shades of blue and purple colors, which means that they were introduced earlier and have already laid a considerable foundation in academic literature. Even though these concepts continue to be relevant, the results of the map overlap indicate that the new academic frontier lies in linking digital twins with artificial intelligence and machine learning along with sustainable and decision-oriented models. Hence, further academic endeavors will revolve around intelligent sustainable digital twin systems capable of real-time analysis and autonomous decision-making.

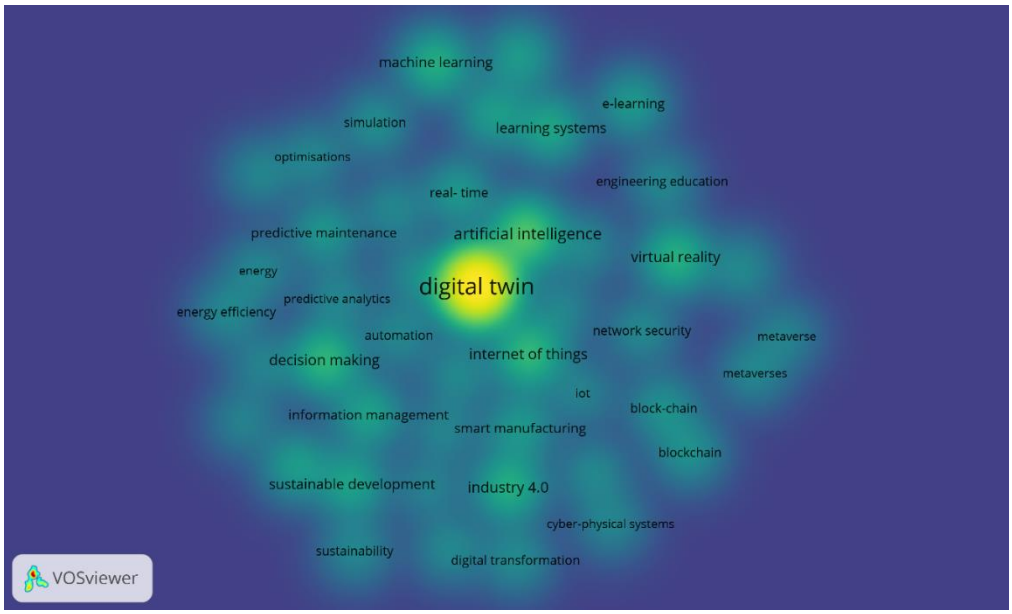

Figure 3. Density Visualization

Source: Data Analysis Result, 2026

The visualization of density is effective in pointing out the density and sophistication of the themes in digital twin studies. From the dense cluster that surrounds digital twin, it is clear that the theme of digital twin is the most common one used and has the highest connection to other concepts, therefore proving the fact that digital twin is the intellectual nucleus of the literature. The topics that are very close to digital twin and are colored green are artificial intelligence, internet of things, decision making, information management, machine learning, and smart manufacturing, among others. These themes seem to be the main research directions that can facilitate the evolution of digital twin technology.

Conversely, keywords found in darker shades of green and blue regions including metaverse, blockchain, cyber-physical systems, virtual reality, digital transformation, sustainability, and engineering education have a low research density, meaning that they are relatively less researched topics in the area of digital twins. The aforementioned regions denote possible research opportunities for the future, especially since there is a growing trend among researchers in the integration of digital twins with technologies such as immersive virtual worlds, decentralized systems, and sustainability efforts. As such, the density map highlights that while digital twins can be said to be highly grounded in areas like AI, IoT, and manufacturing, there are new research avenues to explore.

3.2 Co-Author Visualization

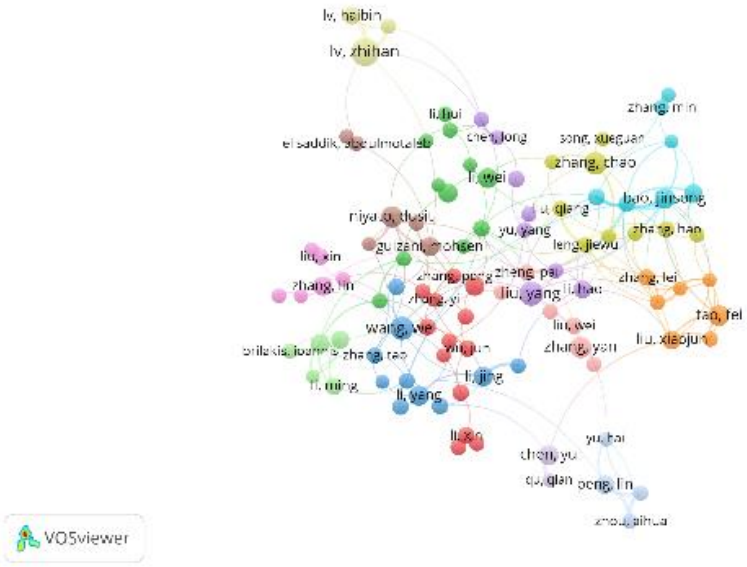

Figure 4. Author Visualization
Source: Data Analysis

Figure 4 shows the network of collaboration in research into digital twin technology. Multiple clusters can be seen, signifying the existence of researcher communities which collaborate with one another, working actively in particular subfields of literature. Zhang Hao, Zhang Min, Wang Wei, Liu Xiaojun, Chen Yu, and Song Weiguan are positioned rather centrally in their clusters, proving their crucial importance as contributors to knowledge communication and research advancements. High density of connections between many scholars confirms the highly collaborative nature of digital twins research, as it is quite interdisciplinary, involving engineering, artificial intelligence, manufacturing, IoT, and data analysis. On the other hand, a variety of separate clusters shows that research processes occur in several special groups, studying various aspects of digital twin technology. It means that the field not only has a well-established system of collaboration, but also allows space for expanding it and increasing interaction between researchers working in different fields of study.

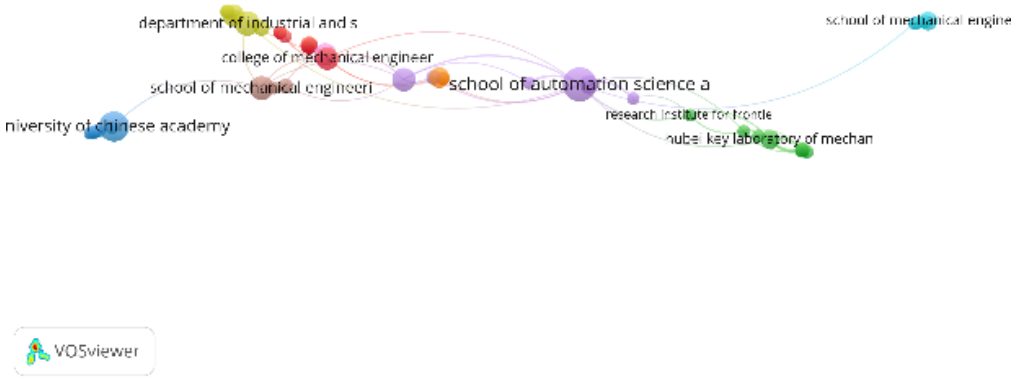

Figure 5. Institution Visualization
Source: Data Analysis

This network of institutional collaboration through co-authorship in relation to digital twin technology research can be depicted in an organization co-authorship network map. Such a network consists of several clusters, including some of the most important institutions like the School of Automation, College of Mechanical Engineering, Department of Industrial and Systems Engineering, and the Research Institute for Frontier Science. Based on its position in the center of the network, it can be concluded that the School of Automation functions as one of the centers of institutional collaboration in the network. Due to strong connections between institutions associated with engineering disciplines, digital twin technology research is still associated with manufacturing, automation, mechanics, and industrial engineering.

Meanwhile, the visual representation indicates that the collaboration process is quite concentrated, as only a few institutions hold prominent connections. The University of Chinese Academy, School of Mechanical Engineering, and School of Mechanical Engineering and Automation are some institutions that reside at the periphery yet still maintain connections to the whole research network through intermediary organizations. The conclusion that can be drawn is that institutional collaboration does take place and plays a role in advancing the development of digital twin technology, however, certain dominant institutions have managed to establish themselves. Collaboration among universities, research institutions, and even international entities would help in facilitating interdisciplinary collaboration and foster innovation within emerging fields such as artificial intelligence and smart manufacturing.

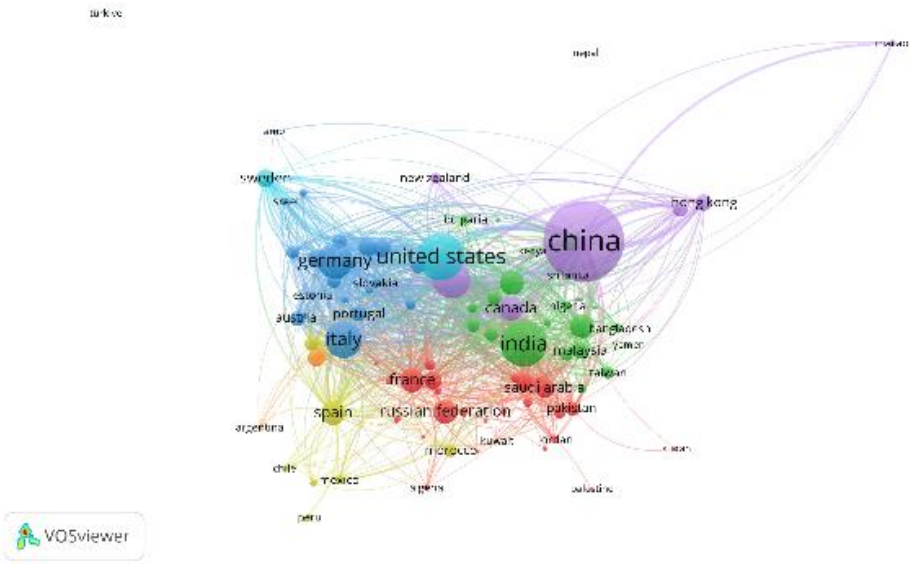

Figure 6. Country Visualization
Source: Data Analysis

From the network map of country collaborations, it is evident that China leads in the research on digital twin technology based on the largest node size and centrality in the network. China has established many connections with various countries such as the United States, India, Germany, Italy, France, Canada, and Australia. This implies that China leads the research efforts on digital twin technology in the world. The close relationship that exists between China and some of the other countries producing most research implies that digital twin technology is becoming increasingly international because of common interest in topics such as smart manufacturing, artificial intelligence, Industry 4.0, and cyber physical systems. The visualization also reveals the presence of several regional collaboration clusters. European countries such as Germany, Italy, France, Spain, and Sweden form a densely connected network, indicating active intra-regional cooperation. Meanwhile, emerging economies including India, Malaysia, Pakistan, Bangladesh, and Indonesia appear increasingly integrated into the global research ecosystem, often through collaborations with larger research hubs such as China and the United States. Peripheral countries such as Nepal, Morocco, Sudan, and Mexico maintain fewer connections, suggesting lower publication volumes or more limited international partnerships.

3.3 Citation Analysis

Table 1. Top Cited Research

Citations	Authors and year	Title
3661	[6]	Digital Twin in Industry: State-of-the-Art
2641	[7]	Digital twin-driven product design, manufacturing and service with big data
2214	[8]	Digital Twin: Enabling Technologies, Challenges and Open Research
1739	[9]	Industry 5.0: A survey on enabling technologies and potential applications
1669	[10]	Review of digital twin about concepts, technologies, and industrial applications
1568	[11]	The road towards 6G: A comprehensive survey

Citations	Authors and year	Title
1541	[12]	Digital twin: Values, challenges and enablers from a modeling perspective
1518	[13]	Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison
1396	[14]	Digital Twin-driven smart manufacturing: Connotation, reference model, applications and research issues
1330	[15]	Enabling technologies and tools for digital twin

Source: Scopus, 2026

Table 1 shows that the most cited studies in digital twin technology are dominated by review and conceptual papers, indicating that the field is still strongly shaped by foundational works that define concepts, frameworks, enabling technologies, and research challenges. The highest-cited article by [16], with 3,661 citations, confirms its central influence in explaining the state of the art of digital twins in industrial contexts. Other highly cited works, such as [6], [8], and [12], further show that scholars frequently refer to studies that clarify the relationship between digital twins, big data, smart manufacturing, Industry 4.0, and modeling approaches. The table also indicates that digital twin research is closely connected with broader technological transformations, including Industry 5.0, 6G communication, big data, and enabling technologies. The presence of works such as [9], [11] suggests that digital twin development is increasingly discussed within future-oriented digital infrastructure and intelligent industrial systems.

4. CONCLUSION

From the bibliometric analysis of the literature concerning digital twin technology, it can be seen that the field of study is rapidly growing and becoming increasingly multidisciplinary. The results show that the digital twin is considered to be the main research topic, being highly associated with the fields of artificial intelligence, IoT, machine learning, smart manufacturing, industry 4.0, and sustainability. The keyword co-occurrence, overlay, and density analysis shows that the recent research trends have become concentrated on decision-making, predictive analytics, energy efficiency, and sustainable development, which means that the focus has shifted from merely using digital twin technology towards more sophisticated applications of its capabilities. The analysis of co-authorship and institutional collaboration networks showed that collaborative work is crucial for the field of digital twins. Finally, from the country collaboration analysis, it becomes clear that China, the US, and several countries in Europe have contributed significantly to knowledge creation in the field. Lastly, based on the citation analysis, the intellectual underpinning of digital twin research includes the works devoted to its concepts and reviews.

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