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Digital Twins in the Context of Ensuring Sustainable Industrial Development

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Abstract

Background: Currently, there is a megatrend towards digitalisation and servitisation using digital technologies and digital twins to support the digital transformation of the economy. In the literature, new digital technologies are seen as creating added value, strengthening customer relationships and accelerating the process of servitisation from manufacturing. The implementation of such a complex of technologies and business solutions can lead to the adaptation of the product and service life cycle, as well as the entire business model, to full servitisation.

Objective: This study reveals the role of digital twins in the context of entrepreneurship in compliance with the Sustainable Development Goals (SDGs). By constructing a thematic map of scientific clusters and SDGs, the relationship between science and practical aspects is established.

Methods: Research into digital twins has led to the use of research methods such as scientific abstraction and synthesis, historical, grouping, analogy, structural-logical modelling, tabular and logical generalisation methods, as well as the bibliometric analysis method based on VOSviewer software.

Results: The study analyses the evolution of the latest technology, which demonstrates the relevance of digital twins as one of the key technologies for digitalisation in many business processes. Special attention is paid to the role of digital twins in the implementation of the SDGs. The results of the bibliometric review indicate scientific interest in researching digital twins in the fields of modelling, information technology, operational management, automation and robotics. The thematic map combining scientific clusters and SDGs highlights the importance of digital twins in entrepreneurship and ensuring sustainable industrial development.

Conclusion: This study provides valuable information for managers as it proves the need to implement digital twins, which enable intelligent manufacturing, serve as the main technology supporting Industry 4.0, can reflect physical information in cyberspace and manipulate physical objects by studying and researching information models in manufacturing. Therefore, future research should focus on developing reliable mechanisms for applying digital twins in the context of the SDGs in areas such as the economy, social aspects and the biosphere. This will ensure the competitiveness of the industrial sector and the country.

Index Terms

Digitalisation; Industry 4.0; Digital twin; Sustainable development goals; SDG; Bibliometric review; Modelling.

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1 INTRODUCTION

1.1 Contemporary review articles

The scientific concept of digital twins is developing alongside information technology, machine learning and sensor technology. Research into digital twins is an area of interest for many scientists based on their geographical location, affiliation, research methods and various economic sectors.

Digital twins are among the top 10 technological trends for the industrial sector in recent years. Rathore et al. (2021) highlighted the role of big data and AI/ML in creating digital twins or systems based on digital twins for various industrial needs. In addition, the authors identified tools that can work more efficiently through the use of artificial intelligence, described the research potential of AI/ML for digital twins and highlighted the challenges and current opportunities for their implementation. A limitation of the study was that it did not determine the impact of the proposals on the economic components of the Sustainable Development Goals (SDGs), such as ensuring decent work and economic growth, overcoming poverty, developing infrastructure and innovation and ensuring responsible consumption and production. It should be noted that the tools proposed by the authors were geared towards countries with stable and secure economies.

Lo et al. (2021) focused on the introduction of digital twins in industry, especially in manufacturing, in order to monitor labour productivity, modelling results, optimising business processes and predicting potential errors. The authors proved that digital twins play an important role at any stage of the product life cycle from design, production and logistics to the end of the shelf life. The paper also identified the prospects for advancing digital twin technologies for the industry. That, in turn, created certain limitations, as the effectiveness of such proposals in the long term was not proven and the key research areas were highly specialised.

Jamwal et al. (2021) analysed and proposed a new scope of research in the field of Industry 4.0 and digital twins. Pylianidis et al. (2021) focused on the study of digital twins in agriculture. They are used by an increasing number of industries, transforming them and opening up new opportunities. The authors' review of the literature of 2017-2020 allowed them to identify options for using digital twins in agriculture compared to other economic sectors. The relevance of such a study was confirmed by Mamchur et al. (2025), who presented a strategy for agribusiness development using the Hoshin Kanri model. The application of such a model requires elements of digital twins, which will significantly accelerate and adapt the processes of agribusiness management.

Scientific papers show how digital twins work in different manufacturing and knowledge-intensive sectors. Mandolla et al. (2019) focused on using digital twins to make metal parts for the aviation industry. Digital twins were proposed for additive manufacturing in the aviation industry through the use of Blockchain solutions. The models described in the paper have somewhat lost their relevance due to the rapid development of information technology. In addition, the focus was exclusively on the aviation industry, which cannot be adapted to other types of manufacturing.

In turn, Bhati et al. (2025) argued that digital twin technology plays a crucial role in the modernisation and optimisation of many industries. The economy encompasses established sectors such as marine energy systems, shipbuilding and operations, aquaculture and fishing, along with emerging areas including coastal protection and deep-sea mining. Many of these sectors are crucial to fulfilling the SDGs, especially climate action and marine biodiversity. Incorporating digital twin (DT) technologies into the blue economy can offer added value by increasing operational efficiency, improving risk management and promoting sustainable practices. A lot of these sectors are extremely important for meeting the SDGs, especially when it comes to climate action and marine biodiversity. One thing to keep in mind is that the study covered all the SDGs, but the authors only picked the environmental ones.

Björnsson et al. (2020) focused on the fact that medicine requires handling and analysis of extensive datasets, and employing digital twin models can speed up some processes. For example, according to certain indicators, it is more appropriate to select medicines using digital twins than by trial and error. Shihabi et al. (2025) took a slightly different approach to digital twins in the medical field, focusing on 3D modelling. The authors also described the application of Visual Basic software and 3D overlay methods using Viewbox software to analyse changes in the patient's jaw.

Schrotter & Hürzeler (2020) focused on the urban development of Zurich with the help of digital twins for the city administration. Three-dimensional spatial data and their models turn a city into a smart city, which means creating various digital platforms and accelerating many management processes. Only in this case can decision-making processes be supported in an understandable way.

Fan et al. (2021) proposed the main paradigms of digital twins of a city to avoid disasters and crises: analysis of certain data to collect analytical information, data integration and analytics, game-theory decision-making by many participants and dynamic network analysis. For each component, the current state of the art related to artificial intelligence methods and approaches was examined and gaps were identified. Moufid et al. (2024) identified six key aspects of urban regeneration, including decision support, prioritisation of problem areas, stakeholder participation, determination of the regeneration scenario, development and implementation of regeneration actions and post-regeneration analysis. The authors assessed the impact of digital technologies in these dimensions by examining their interaction with critical areas of urban regeneration through a spatio-temporal analysis of published literature. The findings outlined the emerging applications and benefits of new digital technologies at different stages of urban regeneration, from site selection to project evaluation. The study comprehensively assessed how urban regeneration processes can be enriched by innovative application technologies and suggested ways forward for future digitally integrated approaches to urban regeneration.

Based on the results of our literature review, we can observe the peculiarities of implementing digital twin technology in various industries. At the same time, each of them uses individual models, specialised software and digital skills. Thanks to the support of artificial intelligence, digital transformation through the implementation of digital twin technology has begun to advance in many industries, such as smart manufacturing, oil and gas production, construction, bioengineering and automotive. However, according to Nguyen et al. (2021), despite the fact that many countries have started the initial phase of 5G deployment, it is still in its infancy, and researchers from academia and industry are facing challenges in developing its further potential. The application of digital twin technology is new to 5G/6G networks, despite its obvious potential in the design and deployment of complex 5G environments. That is why the authors explained how digital twins can become a powerful tool for realising the potential of the 5G network. It should be noted that 5G/6G is only available in certain countries around the world and the proposals described are a prospect for the future.

Digital twins have evolved into a mature concept that unlocks significant potential in various business areas. The use of digital twins is currently experiencing a period of rapid growth and capitalisation, with a particular emphasis on their implementation within the industrial domain. Drawing on the findings of the bibliometric analysis by Ren et al. (2025), the article presents a comprehensive review of technologies/tools that support the industrial application of digital twins. The results show that simulation, sensors and cloud computing dominate the basic and advanced technologies. In addition, this paper explores various industrial processes using digital twins. Through the combination of bibliometric analysis, the latter pay more attention to additive manufacturing and data processing. Finally, according to Schneider's theory, the evolution of digital twins in an industrial context is analysed.

The review conducted by Mayer et al. (2025) was grounded in a systematic literature review and bibliometric analysis to investigate how digital twins (DTs), augmented reality (AR) and artificial intelligence (AI) support the reconfiguration of cyber-physical systems (CPS) in modern manufacturing. The findings highlighted the individual and combined impact of DTs, XR and AI on reconfiguration processes. DT significantly reduces reconfiguration time and improves system availability, AI facilitates decision-making and XR improves the interaction between the worker and the production equipment. Despite these advances, there is a gap in research into the combined use of these technologies, indicating potential areas for future investigation.

Hassani et al. (2022) reviewed the current trajectory of digital twin applications to support overall sustainability in the context of the 17 UN Sustainable Development Goals. Furthermore, it brings together researchers and readers from different fields of study to gain a deeper insight into emerging digital twin technologies and the current value that this technology has brought to support the UN SDGs, and to identify areas with potential for further research to better contribute to the remaining targets of the 2030 Agenda.

Garske et al. (2024) were convinced that digital twins can accelerate sustainable economic development by using big data and artificial intelligence to model the state, response and potential evolution of physical systems. Their results showed important starting points for the open and fair use of data in the field of EU digital law, while respecting the goals of its sustainable development.

In the vast majority of scientific works presented, the digital twin is described as a specific technology for a clearly defined industry. There are no general scientific models for the formation of digital twins that can be used to assess the advantages, tools and risks. In addition, our literature review revealed a significant shortcoming in that the authors do not mention changes or opportunities for implementing the SDGs in the context of introducing digital twins. Almost all of the works included in the review show a tendency to implement SDGs in economic, social and environmental areas. It is precisely innovative technologies in all sectors without exception that will ensure the implementation of the 17 SDGs set for 2030.

1.2 Rationale

Digital technologies have rapidly penetrated the life of society, adapted and changed industries, continue to transform business models of enterprises and shape their future development strategy. The paper shows that the future is linked to both. The rapid growth of the internet of things, big data, cloud technologies and artificial intelligence has led to the formation of certain opportunities in many industries (Anitha et al., 2024; Jiang et al., 2025). The number of devices connected to the internet and the formation of IT ecosystems is growing every year, which helps generate and process large amounts of data. Combining offline activities of enterprises with an online component is becoming increasingly important. That is why digital twins can help ensure a full-fledged connection between the offline and online sectors of the economy in real time. It has already been proven that digital twins are virtual prototypes of a physical object or a group of objects designed to model their behaviour. Virtual models can determine the state of physical objects, as well as anticipate and evaluate changes (Tao et al., 2017). Digital technologies play an essential role in enhancing national economic competitiveness and stimulating economic growth of the entire global market (Dembski et al., 2020). The implementation of cutting-edge digital solutions helps increase the competitiveness of enterprises and staff productivity (Velusamy et al., 2024), reduces business costs, allows storing and protecting conference information, reduces barriers to enterprises entering new markets and has a multiplier effect on the overall development of the national economy (Lim et al., 2020; Zhang et al., 2022).

In the current phase of global international relations, international organisations are active participants in shaping the external landscape. The adoption of global SDGs at the UN summit can be considered an important area of international organisations' efforts towards economic digital transformation. The UN programme sets standards that serve as a universal guide for the effective use of digital technologies (Mihai et al., 2022). The UN activities to implement sustainable development policies aim to achieve control over the stages of the technological revolution in the field of information and communication technologies to build a perfect reality, as well as the development of the international system by 2030 (Hassani et al., 2022; Garske et al., 2024). Thus, the constructive international use of technology is a planned process that can help eliminate the negative effects of civilisational progress.

1.3 Objectives

Given the relevance of the use of digital twins in various areas of economic activity, the purpose of this paper is to develop a thematic map of the use of digital twins in the implementation of the SDGs. To achieve the set objective, the following tasks were formulated:

- consider the evolution of the latest technology, namely digital twins;
- justify the peculiarities of digital twins, taking into account their advantages, tools and risks;
- explore the concept of digital twins in the UN SDGs;
- perform a bibliometric analysis of scientific works in the Scopus database;
- substantiate the peculiarities of digital twins from a practical and scientific perspective.

This determines the relevance of the presented study. The remaining sections of this article detail the goal of developing and implementing a digital twin in the activities of enterprises in the context of the SDGs. Section 2 substantiates the research methodology, which includes modern methods. Section 3 is devoted to the results of the study, solving tasks such as bibliometric review, practical aspects of digital twins and the relevance of digital twinning to the SDGs. Section 4 contains a discussion that identifies the benefits of the work as well as potential areas for further research. Section 5 summarises the conclusions of the paper.

2 RESEARCH METHODS

The research questions of this review article involve the application of the PRISMA methodology to critically evaluate published systematic reviews on the topic of digital twins. The chosen methodology allows an accurate and systematic description of the tasks defined in accordance with the objectives of the scientific paper (Andarwati Kunharyanto, 2025). In accordance with the PRISMA recommendations (Page et al., 2021), the following key areas were identified: identification, screening and inclusion (Table 1).

Table 1. *Components for ensuring PRISMA methodology.*

PRISMA context	Area	Research criteria
Identification	Search focus	Digital twin in the context of ensuring sustainable industrial development
	Search keywords	"digital AND twin AND industry"
	Search period	1982-2025 (July)
	Search database	Scopus
	Search field	Article title, Abstract, Keywords
	Publication stage	Indexed in Scopus
	Search result	n = 8923
Screening	Language	Limited to "English"
	Document type	Limited to "Article"
	Subject areas	Not limited
	Country	Not limited
	Publication stage	Not limited
	Keyword	Not limited
	Affiliation	Not limited
	Source type	Not limited
	Consolidated results	n = 2883 documents
Inclusion	Analysis method	Bibliometric analysis
	Agenda proposal method	Scientific research vs practical aspects

Stage 1: Identification. This involves identifying scientific sources (articles, journals, reviews) on a specific topic. Resources may be found in scientific databases, libraries, online publications and on company websites. In this work, restrictions were set and the Scopus scientometric database was selected. The search term for the closest match to the publications contained the keyword "digital AND twin"; the analysis was conducted in July 2025 in the Scopus scientometric database. The search results revealed n = 38,527 works. Such a significant number of works testifies to the scientific interest in the topic of digital twins, but for an accurate result, it is worth applying restrictions based on criteria. This will avoid the risk of inconsistency and duplication and facilitate bibliometric analysis. Therefore, the works found were refined by adding "digital AND twin AND industry" to the search instead of "digital AND twin", resulting in n = 8923 papers. Additional criteria such as language restrictions and document type yielded n = 2883 documents for analysis of scientific works on the topic of digital twins in the context of industry.

Stage 2: Screening. A review of publications in the Scopus database revealed that research into digital twins began in 1969; under the keyword "digital AND twin AND industry" in 1982.

The data obtained based on a search for the keyword "digital AND twin AND industry" for the period 1982-2025 were saved in a CSV file. The next step was to process them as graphical data using VOSviewer software, which allowed us to form a network visualisation of the most frequently used terms and their clustering in publications. The use of the VOSviewer software application (version 1.6.19) made it possible to identify the main links between existing data visualisation concepts and to form graphical maps of bibliometric analysis visualisation. Figure 1 shows the algorithm for researching and tracking the bibliometric review of scientific works on the topic "digital AND twin AND industry".

The restrictions imposed may lead to certain advantages or risks. For example, the restriction on the language of publication allows the correct creation of a keyword visualisation map, taking universality into account. The restriction on the type of document made it possible to analyse articles, since it is in such documents that theoretical aspects, practical results and scientific perspectives are present. Reviews or conference abstracts, due to their limited amount of information, create the risk of keyword branching. In turn, books are highly specialised, which creates the risk of identifying unnecessary words.

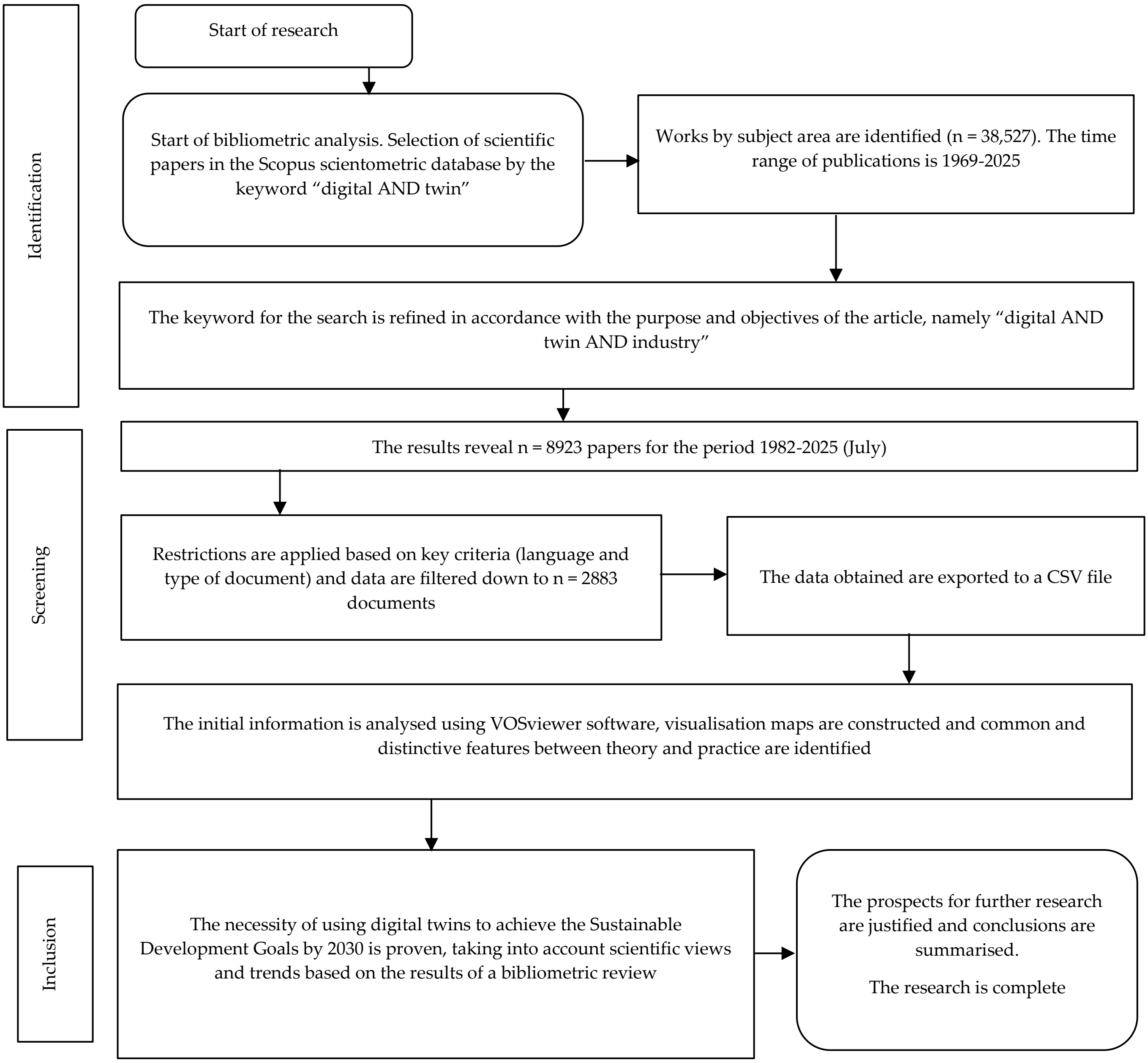


Figure 1. *Block diagram of research into digital twins in the context of bibliometric review vs practical aspects.*

Stage 3: Inclusion. The final step of the study made it possible to obtain the results of the bibliometric analysis in the form of visualisation maps and tables with data. It also made it possible to form a thematic map of the combination of scientific views and practical aspects of the implementation of digital twins in the context of the SDGs.

In addition, research into digital twins led to the use of the following methods: scientific abstraction, analysis and synthesis in studying the essence of digital twins; historical – to consider the evolution of views on the development of digital twins in various sectors of the economy; grouping – to classify the key determinants of digital twins in the context of sustainable economic development goals; analogy – to compare approaches to the use of digital twins; structural-logical modelling – to form a thematic map of the combination of digital twins and SDGs; tabular and logical generalisation methods – for conducting a bibliometric review of scientific publications.

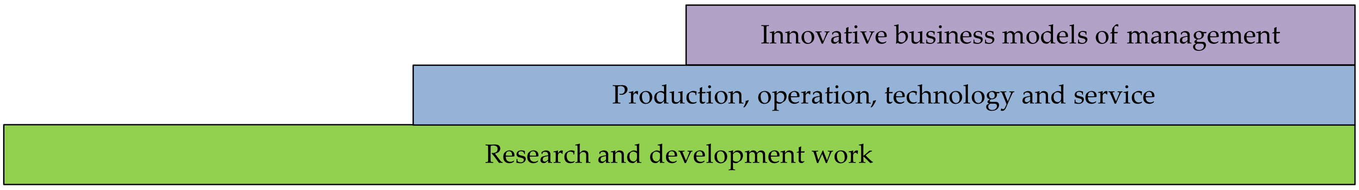
The data obtained by searching for the keyword search results for “digital AND twin” were exported as a CSV file document. The next step was to process them in the form of graphical data using the VOSviewer software, enabling network visualisation of frequently used terms and their clustering. The software also facilitated identifying core relationships and links between the existing data visualisation themes and producing visual maps for bibliometric insights. We performed this systematic review in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Page et al., 2021) guidelines and a bibliometric review based on a document exported from the Scopus scientometric database (see data availability statement in the Additional Information and Declarations section).

3 SOLUTIONS AND RESULTS

3.1 Digital twins: evolution of latest technology

Experimentation is a common method of testing the viability of a theory or a created product, i.e., it is a universal tool for researching both theoretical views and practical aspects of activity. However, as digital transformation progresses, testing methods for ideas and products are being reshaped through adaptation of computer modelling. Whereas testing was limited to relatively simple simulations a few decades ago and required manual setup, today it is practically unlimited. The concept of “digital twins” has emerged, i.e., virtual constructs that can simulate complex physical objects (Krasnobayev et al., 2023).

The development trajectory of digital twins and the technologies on which they are based has been the subject of many scientific papers that explore how these solutions are applied within the operational processes of actual enterprises. Figure 2 below identifies four stages in the advancement of digital twin technology. Technology design approaches began to be applied in the 1980s, when the first commercial software solutions for its computer implementation appeared.



1st stage (1985–2000)	2nd stage (2001–2012)	3rd stage (2013–2016)	4th stage (2017–2025)
Digital twins as a concept 3D modelling Automation Computer-based digital control Robotics Data storage on servers	Digital simulation 3D modelling Browsers and web access	Internet of things (IoT) Big data analytics Cloud-based data storage Rapid feedback from the object at different stages of its life cycle	Virtual reality / Augmented reality (VR/AR) Intelligent services Autonomous operation Data recovery Artificial intelligence 3D bioprinting Biodegradable sensors Hyper-personalisation

Figure 2. *Evolution of digital twin development.*

The first stage is defined as 1985-2000, when technologies such as 3D modelling and computer numerical control emerged. In the second stage (2001-2012), technologies such as virtual assembly, modelling before physical prototype production are distinguished. In the third stage (2013-2016), technologies such as fast feedback from the object during design, manufacturing and operation stages, along with products with augmented digital services are highlighted. The final, fourth stage, which began in 2017, recognised innovations such as human-machine interaction and autonomous operation of digital twins, including self-repair capabilities. It also highlighted augmented and virtual reality, new formats of human-machine interaction that bring the technology in digital twin technology towards a qualitatively new level (Nishant et al., 2020; Abad-Segura et al., 2024). Obviously, each of these stages has a narrower timeframe due to the rapid development of technology and digital transformation.

Today, digital twin have become a core technology driving digital transformation across business operations. The development and implementation of digital twin solutions can cost tens of thousands of dollars. When estimating the costs, one should take into account the risks that can be predicted and eliminated with the help of these technologies. If the potential losses from the risks significantly exceed the costs of their development, it is not advisable to invest in them. In addition, the effective use of digital twins pays off quickly.

Advancing digital twins in manufacturing will demand the participation of not only programmers, testers and designers, but also specialists in areas such as data science and cybersecurity. A limited number of enterprises are currently ready to solve tasks of such development on their own, without involving experienced partners or outsourcers.

3.2 Features of digital twins

A digital twin is a specific combination of parameters that describe a physical object or process in a comprehensive way. Sometimes it looks very clear, because for convenience, the digital twin is visualised on screen. This leads to a full-fledged digital copy of a real object for use in special software. A single product, an entire technological process, an enterprise or even an industry sector can get its own "twin" (Yu et al., 2024).

Until recently, digital modelling was static. To accurately simulate processes, data had to be captured and adjusted manually. Today, everything has changed: IoT tools, open APIs, artificial intelligence and big data tools make the digital twin as responsive as possible because the model can be automatically updated based on constantly flowing data. This makes modelling easier and more accurate. To effectively build a digital twin, one should consider the benefits of their use, as well as tools and risks that may arise in the process of their implementation (Figure 3).

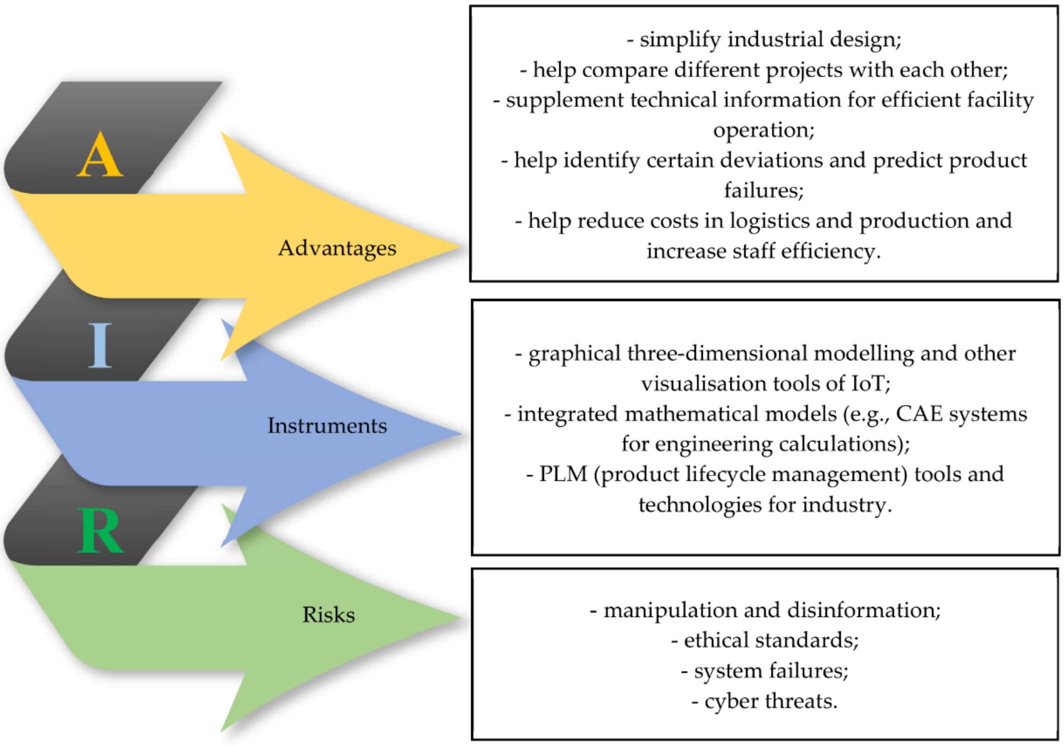


Figure 3. *Advantages, instruments and risks of creating digital twins.*

All of this allows the user to create an accurate virtual image of an object that can be used in almost any field – from industry to medicine. The technology has become very popular because the digital twin enables solving a range of highly complex tasks, such as helping create safe medical equipment and reliable machines. The digital twin of an enterprise can simulate complex production management and plan it in the smallest detail (Osama, 2024; Jiang et al., 2025).

It should also be noted that as artificial intelligence continues to advance, there is a risk of creating digital twins – virtual copies of real people. This technology poses a number of threats, namely regarding privacy issue and ethical issues. As for privacy, a few minutes of audio or video content is enough to create digital doubles. This puts privacy at risk, as a digital copy can mimic the appearance, voice and behaviour of a real person (Yi, 2023; Zhang et al., 2025).

Secondly, the creation and use of digital doubles raises ethical issues. Who is responsible for the actions taken by digital doubles? What are the rights and obligations of the creators and "owners" regarding these digital replicas? There are also security threats, i.e., digital twins can be used for cyber-attacks. Attackers can gain unauthorised access and use it to deceive identification systems and access confidential information.

To counter the threats posed by digital twins, the following measures should be taken: developing a legal framework governing the creation and use of digital twins, strengthening privacy protection mechanisms, and creating systems to detect and block digital twins used for disinformation or cyber-attacks (Biliavska et al., 2025) and raising awareness of risks associated with digital twins among users and professionals. In sum, digital twins are a powerful tool that can change the way we interact with technology and communications. However, a balanced approach to advancing and governing this technology will allow us to use its potential while minimising the risks (De Benedictis et al., 2023; Tan et al., 2023).

Sophisticated digital models help in technically complex production – for manufacturing control and predictive maintenance of products. Therefore, digital twin technology is most widely used in industry today.

As the concept of digital twins in production originated in the aerospace industry, the industry giants initially found the widest application. Boeing, Airbus and SpaceX all use digital twins to optimise production and make effective management decisions. However, such technologies are also in high demand in other industries and are actively used in the automotive, electronics and pharmaceutical sectors.

3.3 Digital twins in the context of the UN SDGs

The concept of sustainable development has emerged against the backdrop of global recognition of environmental issues, progress in civil society, scientific research and scarcity of natural resources. Today, sustainable development is usually understood as a balance between socio-economic and environmental development, or as economic growth without harming the environment, thereby helping solve a number of social problems. Achieving the UN global goals by 2030 will require radically more sustainable approaches to managing goods and services across their full life span (facility or service, from design to use to decommissioning).

Digital twins are virtual products, for example, even of such a complex ecosystem as a city in real time. They are used for modelling and, in particular, provide a safe environment for testing various innovations. By simulating the entire value chain related to products and services, they enhance sustainability across the entire life cycle—starting with reuse-oriented design and reduced material consumption during production and assessing carbon emissions, to modelling logistics for circular economy systems. Given the summary in Figure 4, one can infer that digital twins are already being widely used in various activities and thus contribute to the implementation of certain SDGs.

Digital twins are successfully used in supply chain management. This is facilitated by the widespread use of IoT tools in logistics. Almost every item in the warehouse can be digitised and digital twins serve to effectively organise the warehouse, shipping and unloading processes. Visualisation allows logistical system operators to visually monitor the placement of pallets in the warehouse or track movement of vehicles. It should be emphasized that digital twin technologies support optimal packaging choices and the formulation of a strategy for using containers or containers.

In the retail sector, digital twin technologies not only improve logistics but also have a direct impact on the performance of staff. Selecting a location for a store, designing its interior, optimising the layout and organisation of sales aisles, conducting category management, displaying of goods, merchandising – all of this cannot work without digital twins. Eventually, each product may have digital twins. This will allow us to track the movement of each product, help predict demand and reduce the likelihood of theft.

ECONOMY

Goal 8. Integrating digital twins speeds up workflows and therefore facilitates the completion of tasks, leading to a change in skills and professions. Well-organised workflows increase production and thus economic growth.

Goal 9. Digital twins are an innovative trend in infrastructure development. Smart technologies, modelling, information technologies and opportunities are the key drivers of economic growth of the country's economy.

Goal 10. Automated processes with digital twins eliminate bottlenecks.

Goal 12. Digital twins allow us to save resources (raw materials, labour, energy and water) and thus implement regional and national environmental policy programmes.

Goal 17. Using the capabilities of digital twins, it is possible to organise international cooperation and development of joint projects (alliance, co-branding and start-up projects)

SOCIETY

Goals 1–2. These goals are designed to protect the population; digital twins can contribute to this by making calculations in product design. Global warming, wars and other environmental changes require a broad range of factors that must be considered for efficient farming, livestock or vegetable production. Digital twin technologies help make accurate, quick and efficient calculations in these areas.

Goal 3. Digital twins are a trend in the future of medicine.

Goal 4. Digital twins influence the learning processes of people of all ages, from schoolchildren to advanced training for experienced staff. Interactive games, digital learning applications and digital modelling help improve education quality.

Goal 5. Digital twins equalise work by gender, age and salary. This eliminates the "glass cliff" or "sticky floor" effect. Under certain conditions (war, lack of experience or education), professions no longer depend on gender.

Goal 7. Employing digital twins in the energy sector supports innovation and deployment of alternative energy sources, ensuring a consistent supply of vital resources.

Goal 11. Smart cities are already proving their effectiveness by speeding up and facilitating the processes of servicing different segments of the population.

Goal 16. Modelling, bionics and information technologies contribute to building a peaceful, inclusive society that supports sustainable development and fosters effective, transparent and inclusive institutions at every level.

BIOSPHERE

Goal 6. Digital twins in any industry will allow water to be provided or purified in line with appropriate sanitary requirements and tested for quality requirements based on established standards to the maximum extent possible.

Goal 13. Automated machine mapping, fault or flood prediction and geological research are facilitated by digital twins using a range of IT models and technologies.

Goal 14. Digital twins have made it possible to monitor marine flora and fauna, aquaculture, currents, coral reef ecosystems; monitor pollution levels; use equipment and technologies to assess fish health, which is a relatively innovative approach but allows timely development of a programme to protect marine ecosystems.

Goal 15. In the context of rapid global warming, digital twin technology will help develop means to protect terrestrial ecosystems, preserve forests and protect plantations from pests using artificial intelligence or drones.

Figure 4. *How digital twins contribute to SDGs*

Today, medicine already uses advanced virtual models of human organs in diagnostics and therapy. It is likely that in the future, expansion of medical data will enable physicians to develop "medical twins" of a patient, based on comprehensive data about their body. This opens up fantastic opportunities in therapy, or even allows us to predict illnesses before any symptoms manifest (Shihabi et al., 2025).

Product development and prototyping are indispensable for the aviation industry. 3D visualisation improves the collaboration of designers, engineers and other specialists and enables them to evaluate and create analogues of complex systems more effectively. Thanks to engaging training in interactive 3D, AR or VR environments, employees can better absorb information without endangering themselves in the workplace. Creating work instructions in mixed reality using models of the actual product simplifies and optimises inspection, maintenance and repair (Lo et al., 2021). With virtual showrooms and 3D configurators, customers can view all aircraft options and make a purchase decision.

Architects and designers can easily transfer models to immersive VR or AR environments, allowing interactive discussions in real time. This will allow more frequent and quicker design adjustments, which means that errors can be identified and eliminated more quickly. Reproducing full-size models in AR on the work site helps better explain the idea to project participants. In the automotive industry, 3D visualisation helps improve collaboration among all employees and avoid the delays that often occur when using traditional software.

Generating photorealistic renders and interactive 3D configurators based on available 3D data, creating interactive 2D and 3D applications for IVI systems and digital cockpits, recreating situations and visualising results in a safe virtual RT3D environment is the future trend in the automotive industry. Interactive and immersive applications help consolidate knowledge and improve productivity.

Digital twins in construction primarily allow modelling and checking projects for compliance. This method reduces downtime and improves communication among teams in the office and on the construction site; it recreates important learning situations in interactive and immersive environments.

In the energy sector, the implementation of digital twins is expected to enhance service quality, reliability and speed, while also minimizing maintenance errors using AR. Digital twins combine geospatial information, data from sensors and models, allowing real-time visualisation of spaces. Decision makers will have all the data they need to optimise operations and allocate resources.

Digital twin technology is not easy to master and its entry onto the mass market is only beginning. However, tools that are more accessible to businesses are also emerging – equally visualised, but without overly complex functionality and mathematical models.

This simplified model is often referred to as a "digital shadow" – it provides only a partial representation of the real-world object data, such as weight, geolocation, position, etc. Digital twins are often referred to as such tools – they are relatively simple, provide workflow visualisation, convenient monitoring and data analytics.

3.4 Bibliometric analysis of scientific papers in Scopus database

As a result of analysing the works presented in the Scopus scientometric database (n = 2883) papers were identified for the period 1982-2025. A review of scientific publications in the Scopus scientometric database allowed us to select the top 10 most cited papers (over 1000 times). This confirms the relevance of the development of digital twins, in both the scientific field and practical activities, see Table 2.

Research into digital twins in industry (Rank 1), which is related to the development of Industry 4.0, is reflected in the work of Tao et al. (2018b), where the authors focused on the key components of digital twins. Fuller et al. (2020) described digital twins as a new concept in industry, especially in defence. The authors focused on digital technologies and presented an assessment of advanced technologies, challenges and opportunities for digital twins (Rank 4). Schleich et al. (2017) identified the benefits of digital twins for industrial processes and proposed a reference model, Skin Model Shapes, which serves as a digital twin of a physical product in the design and manufacturing process (Rank 10). Jones et al. (2020) focused on a literature review of digital twins in manufacturing (Rank 3). Somewhat similar was the work of Liu et al. (2021), which provided an in-depth literature review in terms of concepts and technologies for industrial applications of digital twins (Rank 7). Rasheed et al. (2020), ranked 9th in terms of citations, provided an overview of methodologies and methods related to the construction of digital twins, mainly from a modelling perspective. The advantages of the digital concept were established, key terminology was formed and other characteristics of digital twins for the industrial sector were defined.

Table 2. *Most cited papers for keywords "digital AND twin AND industry.*

Rank by number of citations in Scopus database	Authors, year of publication	Title of work	Edition
Rank 1 (n = 2874)	Tao et al. (2018b)	Digital Twin in Industry: State-of-the-Art	IEEE Transactions on industrial informatics
Rank 2 (n = 2331)	Tao et al. (2018a)	Digital twin-driven product design, manufacturing and service with big data	The International Journal of Advanced Manufacturing Technology
Rank 3 (n = 1666)	Jones et al. (2020)	Characterizing the Digital Twin: A systematic literature review	CIRP journal of manufacturing science and technology
Rank 4 (n = 1634)	Fuller et al. (2020)	Digital twin: enabling technologies, challenges and open research.	IEEE access
Rank 5 (n = 1692)	Ivanov (2020)	Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case	Transportation Research Part E: Logistics and Transportation Review
Rank 6 (n = 1398)	Negri et al. (2017)	A review of the roles of digital twin in CPS-based production systems.	Procedia manufacturing,
Rank 7 (n = 1354)	Liu et al. (2021)	Review of digital twins for concepts, technologies and industrial applications	Journal of manufacturing systems
Rank 8 (n = 1307)	Qi & Tao (2018)	Digital Twin and Big Data Towards Smart Manufacturing and Industry 4.0: 360 Degree Comparison	IEEE Access
Rank 9 (n = 1235)	Rasheed et al. (2020)	Digital twin: Values, challenges and enablers from a modelling perspective	IEEE Access
Rank 10 (n = 1176)	Schleich et al. (2017)	Shaping the digital twin for design and production engineering	CIRP Annals Manufacturing Technology

Negri et al. (2017) analysed the evolution of digital twins from the initial concept in the aerospace industry to innovative interpretations in the field of intelligent manufacturing (Rank 6). The most cited works on the topic of "digital twins" presented in the Scopus scientometric database prove that this is a multidisciplinary field, not just an industrial complex. Differently from the previous studies, Qi & Tao (2018) considered the digital twin as a big data processing technology on the way to smart manufacturing and Industry 4.0 (Rank 8). Rapid changes and globalisation processes have contributed to the development of digital twins in related industries. For example, Ivanov (2020) focused not only on medical aspects, but also on logistics issues using digital twin technologies in the context of the COVID-19 pandemic (Rank 5).

Technological developments have led to an increase in the volume of information that needs to be processed, in both the manufacturing and service sectors. That is why Tao et al. (2018a) examined methods of applying digital twins in the design and processing of large datasets (Rank 2). Thus, the use of digital twins will eliminate problems arising from human error and automate processes.

Given the significant scientific interest in the topic of digital twin in various fields, it was decided to limit the data for bibliometric analysis to the subject matter of this paper. According to the description in the methodology, as a result of information and search research, 2883 papers were found for the keywords "digital AND twin AND industry" as of July 2025, which indicates the relevance, scientific and practical interest. The issue of digital twins in industry is a subject area of various fields, namely: engineering (30.2%), computer science (22.9%), materials science (6.3%), physics and astronomy (5.2%), chemical engineering (4.4%), business, management and accounting (4.3%), mathematics (4.2%), energy (3.9%), social sciences (3.6%), environmental science (3.2%) and other (11.8%). Keyword analysis using software allowed us to create a visualisation map (Figure 5) and identify scientific clusters based on similarity.

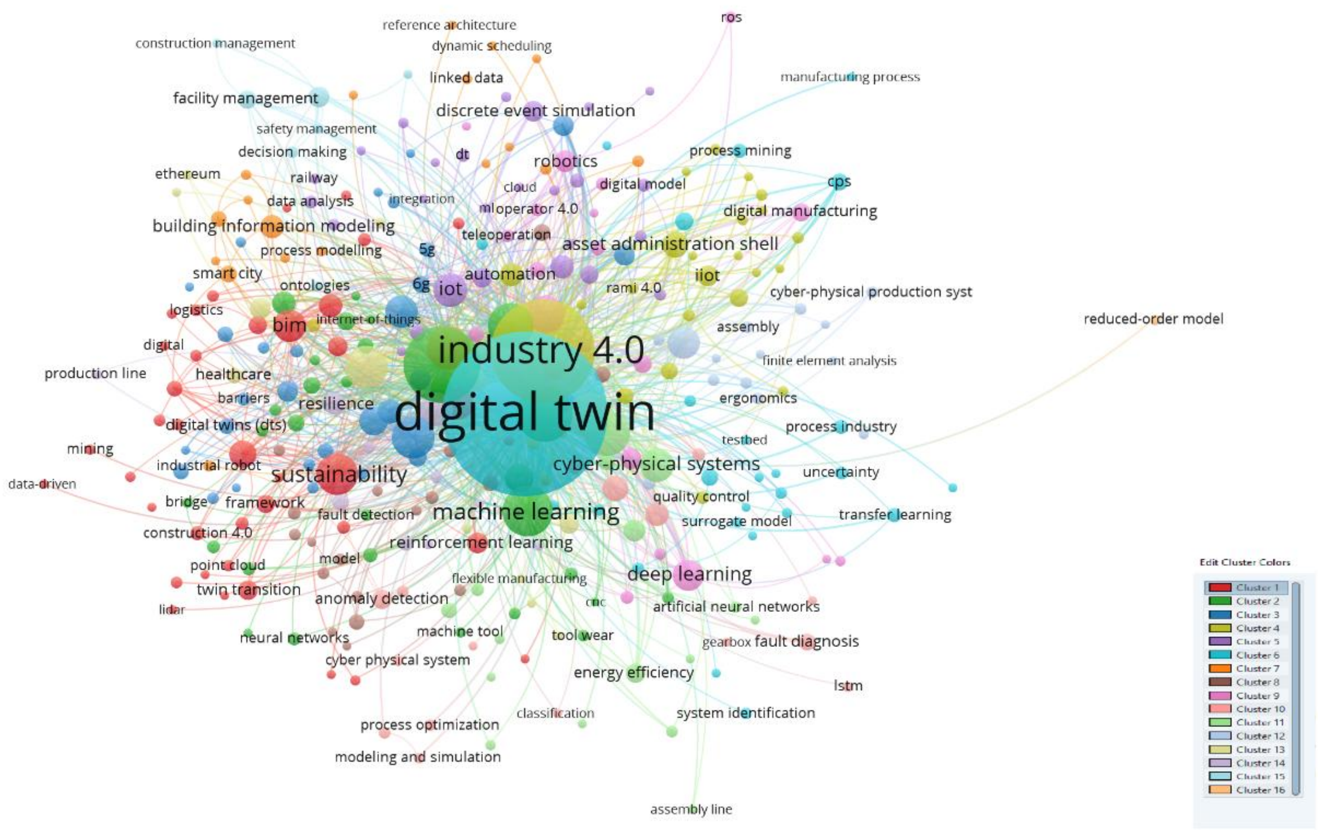


Figure 5. *Visualisation map of search keywords "digital AND twin AND industry" in Scopus database.*

The resulting pattern indicates the relevance and prevalence of the key phrase “digital twins”, which proves the significance of the corresponding circle. A total of 16 scientific clusters were formed as a result of data processing.

Cluster 1 – “Modelling” because the keywords presented are focused on modelling: 3D modelling, building information modelling (BIM), construction 4.0, digital transformation, modelling, numerical simulation. This cluster is relevant because it provides management approaches to digital twins, decision-making skills and process modelling.

Cluster 2 – “Monitoring”, which is important for analysing information and finding alternative solutions. Keywords of this cluster: monitoring, optimisation, smart manufacturing systems, visualisation, machine learning, case study, intelligent systems.

Cluster 3 – “Development of digital twins” is focused on research describing the development of digital twins, as confirmed by the following keywords: game theory, 5g and 6g, federated learning, resource allocation, industrial internet of things (IIoT), sustainable development, virtual reality (VR), digital twin technology, manufacturing industry and bibliometric analysis.

Cluster 4 – “Information technologies” combines words that prove the necessity of information technologies in the application of digital twins: automation, big data analytics, IIoT, information modelling, virtualisation, data management, cloud manufacturing, cyber-physical production system.

Cluster 5 – “Industry 4.0/5.0” because digital twin technology represents the latest opportunities in industrial activity. The keywords industry, optimisation, smart factory, virtual commissioning, 3D printing and optimisation confirm this fact.

Cluster 6 – “Operational management” because digital twins require certain consistent and integrated processes, as confirmed by the following keywords: process industry, process mining, knowledge graph, decision support, smart maintenance, time series, production planning, manufacturing process.

Cluster 7 – “Innovation”: dynamic scheduling, process modelling, smart city, standardisation, building information modelling (BIM), industrial robots.

Cluster 8 – "Technologies" as a separate cluster focused on keywords that influence technological decisions or processes: digitalisation, methodology, life cycle, product development, technology, review challenges, digital twin models.

Cluster 9 – "Automation": human digital twins, operator 4.0, object detection, computer vision, robotics, virtual reality, process simulation.

Cluster 10 – "Optimisation", which involves accelerating processes and efficient use of resources: process optimisation, modelling and simulation, finite element method, additive manufacturing.

Cluster 11 – "Effectiveness": real-time monitoring, operational efficiency, sustainable manufacturing, cyber-physical systems.

Cluster 12 – "Robotisation": robotic arms, human–robot interaction, augmented reality, collaborative robots, human–robot collaboration. This cluster demonstrates the speed of the digital twin and the acceleration of the technological process.

Cluster 13 – "Cyberspace": cybersecurity, blockchain, industry 5.0, smart contracts, industrial IoT, human-centric manufacturing.

Cluster 14 – "Control": process control, quality management, supply chain management, production line, manufacturing systems, fourth industrial revolution. Compliance with the control system ensures high-quality execution of processes when using a digital twin.

Cluster 15 – "Facility management" contains keywords focused on managing digital twins: safety management, facilities management, construction management, decision making.

Cluster 16 – "Reduced-order model" contains only one keyword. It is appropriate to combine this cluster with the first one, dealing with process modelling.

As a result of analysing the identified keywords, we can observe combinations or additions between clusters. Thus, modelling is a key element that is not unique to the first cluster. Innovation, technology, automation and cyberspace are clusters that combine alternatives for implementing digital twins. Operational management, performance and control are necessary for evaluating the effectiveness of digital twins in industry.

Table 3. *Top 15 keywords in scientific papers for keywords "digital AND twin AND industry" in Scopus database.*

Rank	**Keyword**	**Occurrences**	**Total link strength**	**Clusters (1-16) in which the keyword occurs**
1	digital twin	1370	2659	6
2	industry 4.0	549	1485	4
3	digital twins	294	666	2
4	artificial intelligence	157	486	2
5	machine learning	132	373	2
6	internet of things	108	346	2
7	industry 5.0	108	301	13
8	simulation	106	279	7
9	blockchain	96	280	13
10	digital twin (dt)	95	279	3
11	sustainability	91	147	1
12	virtual reality	72	229	9
13	cyber-physical system	60	231	5; 11
14	IoT	59	172	5
15	digitalisation	59	198	14
Other keywords		4105	729	1-16
Total		**7461**	**8860**	**-**

A bibliometric review using software allows us to identify the top 15 keywords and the number of citations in Scopus scientific papers that were filtered and taken for analysis, see Table 3.

The grouped keywords that occur most frequently in scientific works have found their place in various scientific clusters represented on the visualisation map. Thus, the most frequently cited keywords belong to clusters 2 – "Monitoring" and 5 – "Industry 4.0/5.0". It is also worth noting that not all clusters have top keywords, as some contain only 1-5 keywords. Modern data processing methods allow us not only to calculate the number of citations, but also to demonstrate a map of cross-citations between authors by country (Figure 6).

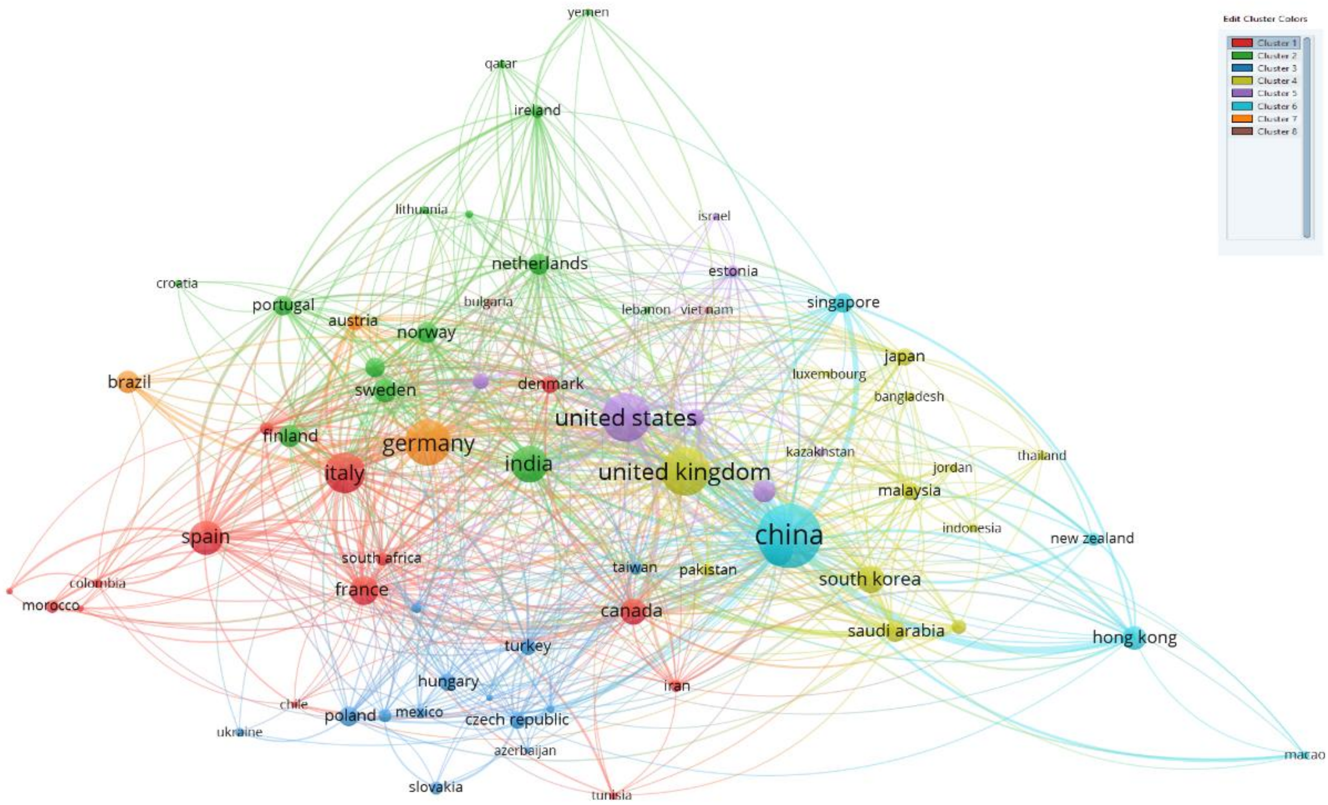


Figure 6. *International co-authorship links.*

The greatest scientific attention to the thematic focus of digital twins is concentrated in China (13.30%), which is confirmed by observation and a review of the literature published in the Scopus scientometric database. Other leading countries include the United States (7.83%), the United Kingdom (7.61%), Germany (7.12%), Italy (5.47%) and others. The VOSviewer software ranked countries according to the number of documents, mutual citations and strength of connections (Table 4) based on the established criteria.

Table 4. *Density of correlation between citations by country.*

Rank	Country	Documents n	%	Citations	Total link strength
1	China	542	13.30	26163	331
2	United States	319	7.83	11409	272
3	United Kingdom	310	7.61	14227	355
4	Germany	290	7.12	7428	195
5	Italy	223	5.47	8745	163
6	India	178	4.37	4138	157
7	Spain	161	3.95	3526	145
8	Australia	115	2.82	8617	149
9	France	111	2.72	5703	146
10	South Korea	103	2.53	2271	70

Rank	Country	Documents n	%	Citations	Total link strength
11	Canada	93	2.28	3257	130
12	Sweden	79	1.94	5297	80
13	Hong Kong	74	1.82	3242	78
14	Brazil	69	1.69	972	29
15	Finland	66	1.62	2342	60
Other		1342	32.93	150638	1790
Total	**71**	**4075**	**100**	**257975**	**4150**

Research into mutual citations among scientists indicates that they belong to different countries. According to the table, there is a close connection and citations between representatives of China, the United States and the United Kingdom. This is due to the rapid development of digital technologies in these countries, their powerful economies and stability.

As a result of the bibliometric review, a significant number of authors' works were processed and it was established that there may be a certain risk of bias in the research. This is due to the radically different geographical locations and, accordingly, conclusions based on economic or social stability. The authors also consider digital twins in completely different areas of application, which creates certain differences at the project implementation stage.

3.5 Digital twins: Practical aspects versus scientific field

Accenture and Dassault Systèmes have recently released a report that reveals how digital twins can drive innovation and also decrease costs and resource use, ultimately contributing to a more resilient and circular economy. According to this joint study ("Designing Disruption: The Critical Role of Virtual Twins in Accelerating Sustainability", Accenture and Dassault Systèmes, 2021), digital twins can help companies generate a combined economic benefit of USD 1.3 trillion by 2030 and achieve a 7.5 Gt CO_2 emission reduction in the next ten years.

These results were obtained for five use cases and represent only a small part of the benefits of systematic implementation of digital twins in all relevant industry sectors and in the public sector as a whole. The study examines use cases in five industries: construction, consumer goods, transport, life sciences and electricity and electronics.

Figure 7 below shows that the scientific clusters were formed based on the bibliometric review. The SDGs are linked via certain areas of activity in various industries, both manufacturing and knowledge-intensive. The identified areas were chosen because they are the most relevant for business, affect carbon emissions and have significant economic and social impacts. Digital twin technologies can provide significant innovations in the area of sustainable development, which makes it possible to achieve the UN goals and restructure the global economy towards a more circular and low-carbon one. Digital twins are an important step forward in ensuring sustainability and improving the economic performance of both businesses and countries. That is why the introduction of digital twins is an effective solution for all three aspects of sustainability: environment, economy and civil society.

Scientific validation and testing is an integral part of the actual implementation of the proposals in the SDGs. Achieving the UN SDGs requires the introduction of breakthrough innovations, as evidenced by the research in Cluster 7 (Brauner et al., 2022; Giuffrè & Shung, 2023). The use of digital twins will reduce the costs of production (Marinagi et al., 2023), reduce regulatory risks, enable new service models, reduce the need for space in operations and production (Kagermann & Wahlster, 2022; Rehman et al., 2023), provide opportunities for cross-functional cooperation (Casciani et al., 2022) and reduce the time to market for goods and services (Yun & Lee, 2019; Biliavska et al., 2024). These aspects are reflected in clusters 1–16.

The COVID-19 pandemic is believed to have slowed collective progress towards many of the SDGs. Now, as businesses and organisations around the world seek to accelerate the implementation of sustainability requirements, digital twinning technologies can play a key role in their implementation. The current level of digital twinning adoption globally is almost 10%, meaning that there is a large untapped potential for greater use of this technology to address global sustainability challenges and accelerate the achievement of the UN SDGs.

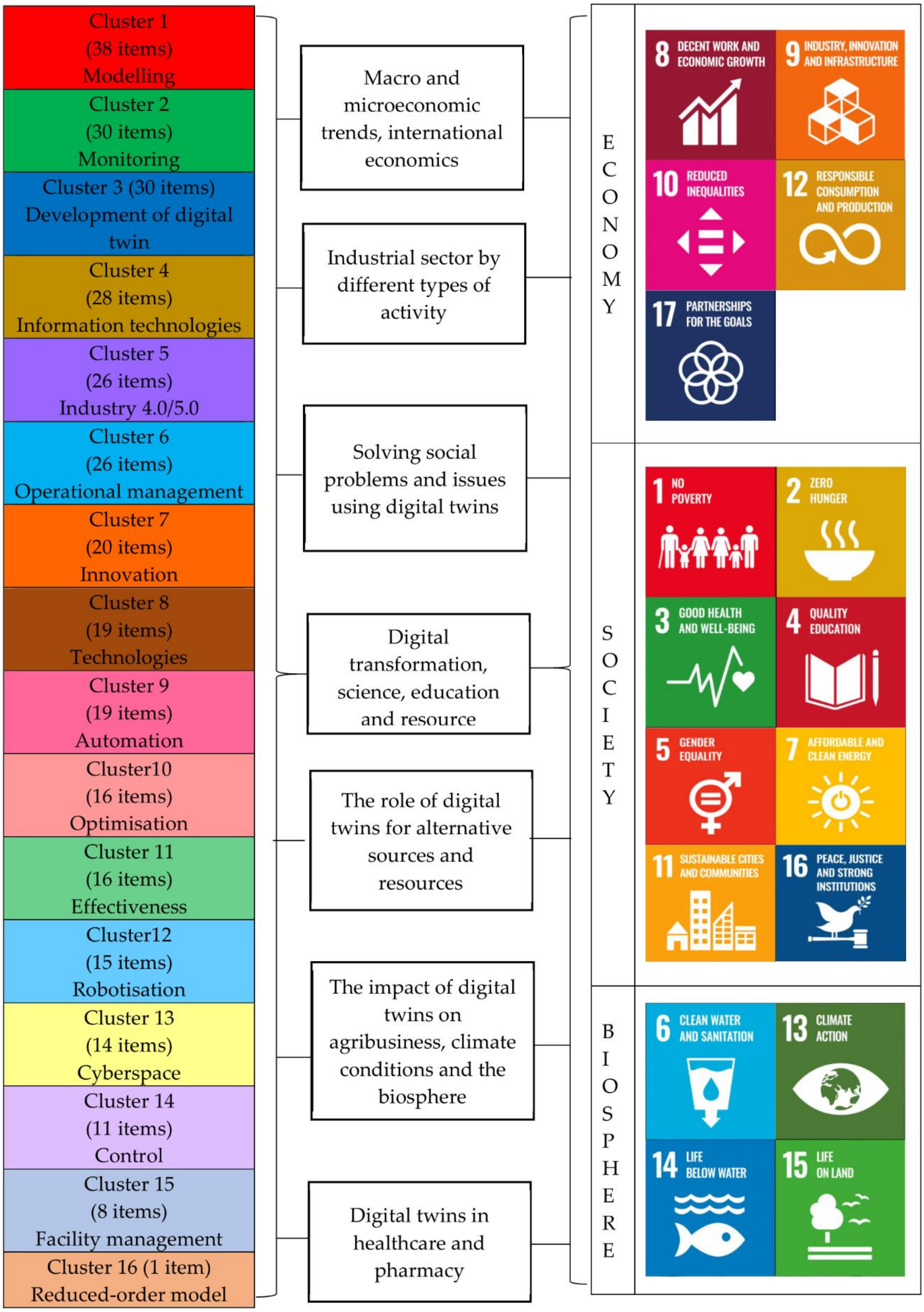


Figure 7. *Thematic map of digital twins in the context of bibliometric review vs practical aspects.*

As a digital twin is a real-time virtual representation of a product or ecosystem that can be used to model, visualise, predict and provide feedback on product properties and functionality, they can be created virtually: simulate variables, predict outcomes and iterate the process, all with high accuracy. The idea is to save time, money and resources, as well as improve safety, compliance and productivity.

Digital twins allow the user to simulate the product as a whole, in different conditions and contexts. This means getting not only immediate feedback on whether the functional requirements of the product are met, but also key information about non-functional requirements. This approach can lead to better results at several stages: manufacturing, assembly, testing, maintenance and even disassembly and disposal. The latter is particularly valuable when thinking about sustainability and the need to maximise the reuse of materials recovered during disassembly.

Virtual or digital twins are used to model complex systems, from cars to cities, and mimic their functioning with accuracy that allows the user to go directly from the virtual model to the creation of a product or solution (Ibrahim et al., 2022; Mamchur et al., 2025). There is no need to spend years on getting a prototype and gradually improving it. The speed of bringing products to the market and reducing the risks of complex projects explains why digital twin technologies have been used in the development of 85% of electric vehicles in the world, involved in more than 75% of projects in the global wind energy industry and in breakthrough pilot projects such as the world's first solar-powered aircraft and new biomaterials.

Digital twins can receive real-world data, which creates feedback and leads to design improvements over time. This significantly speeds up the product update process. It is necessary to collect large amounts of data and build the right analytics to get a real-time view of what is happening. For this purpose, cloud technologies should be used (Shen et al., 2025; Nag et al., 2025). In summary, digital twins are a real-time virtual representation of a product, process or entire system used for modelling, visualisation, forecasting and providing feedback on product properties and functional characteristics.

Digital twins are therefore a digital technology that allows the user to model a product or a system or subsystem, create, produce and decommission these elements. A digital twin is not just a model of a factory or a car, but an environment where the user can constantly make new data and changes in real time, see what happens, what can be improved and conduct various product simulations. It is also a combination of digital and physical environments. In doing so, the user can also utilise other emerging technologies such as artificial intelligence and machine learning, big data and cloud computing, enabling the optimisation of existing products or making of innovative products.

4 DISCUSSION

The analysis allowed us to examine scientific views on the implementation of digital twins. The key role was assigned to both the shared and unique features between the scientific and practical aspects of the functioning of digital twins within the scope of the Sustainable Development Goals.

A dataset of 2883 scientific publications from the Scopus database identified during the study indicates the scientific interest in the field of digital twin technology, which is confirmed by the visualisation map of 16 clusters.

With the rise of Web 3.0, the concept of digital twins is becoming not only relevant but also high-demand (Zhang et al., 2022). It offers powerful support for businesses across sectors to enhance their products, processes and services. Through the creation of a digital twin of a physical product or system, companies can derive critical insights into real-world performance. Digital twins also enable testing of different scenarios and identification of potential problems, as evidenced by the algorithms described in the papers by Jamwal et al. (2021) and Pylianidis et al. (2021).

The study found that thanks to digital twins, businesses can quickly respond to potential complications, while gaining some insight into how to further innovate products or services (Velusamy et al., 2024). This technology is rapidly becoming an important tool for many businesses seeking to innovate their processes and meet customer needs as efficiently as possible. For example, internal logistics in healthcare facilities are complex and important for providing medical services and high-quality patient care (Smutny & Svandova, 2024). The solutions found by the authors as a result of their research should be developed further through the implementation of a digital twin. This will speed up and optimise logistics.

However, as Web 3.0 technologies have evolved, digital twins have taken on a whole new meaning. By creating personalised simulations, businesses can better understand customer preferences and develop customised services that meet their needs. Digital twins can also support the analysis of supply chain and logistics operations, increasing operational efficiency and helping organisations save time and money (Wanganoo & Tripathi, 2023).

Digital twins can revolutionise how businesses evolve and grow (Bessenbacher et al., 2023). They combine real-time analytics with forecasting technology. This allows businesses to create virtual models of systems and processes which in turn, optimise labour productivity and open up new opportunities for growth and capitalisation. This is confirmed by the scientific interest of representatives of many countries as evidenced by the bibliometric analysis.

The greatest scientific attention in the thematic area of digital twins is concentrated in China, the United States, Germany, the United Kingdom and Italy. The future of digital twins appears quite promising. Businesses in many sectors or industries are paying attention to their potential as a forecasting tool, and the possible uses for it continue to grow. There are already digital twins capable of accurately predicting the behaviour of complex systems (from power grids to mechanical systems).

As computational models become more complex, so will the capabilities of digital twins. In the future, these technologically advanced tools will become an integral part of monitoring and managing all types of economic activity, which will further optimise operations with greater efficiency.

With the advancement of technologies such as digital twins, the need for security and reliability is growing rapidly. With the advent of twin technology, businesses need to guarantee that their digital assets remain secure, resilient and adaptable to changing market dynamics. Consumers need to be convinced that there will be no software hacks, as all data traffic is carefully monitored by both qualified personnel and artificial intelligence (Biliavska et al., 2025). Due to combined multiple layers of authentication, including biometrics and one-time passwords, customer information is always safe when using a digital twin product.

This paper differs from previous studies in that it contains elements of scientific novelty: (1) the advantages, tools and risks of implementing a digital twin have been identified; (2) for the first time, a thematic map of digital twins has been created in the context of a bibliometric review and the practical aspects of the SDGs. This builds upon the concept introduced by Mayer et al. (2025), developed by forming scientific clusters where the focus is on digital technologies. Moreover, we further developed the research of Hassani et al. (2022), who considered the current trajectory of digital twin applications to support overall sustainability within the scope of the 17 UN SDGs.

This study has certain limitations. The evolution of digital twins is presented in a rather generalised manner. It should be noted that digital twins are a trend of Industry 4.0, but one based on the developments of previous industrial revolutions. The features of digital twins are justified, taking into account their advantages, tools and risks.

In addition, certain limitations can be identified in conducting the bibliometric review. For the analysis, works presented in the Scopus scientometric database were selected, which created certain limitations in the selection of information. However, this made it possible to avoid double calculations and to form more accurate research results. During the study, restrictions were imposed on the type of document and language, which affected the total number of documents. The final number of works selected and processed (n = 2883) is representative for obtaining reliable bibliometric results and formulating practical aspects of the application of digital twins. The subjective biases of the authors of scientific works may influence the interpretation of the keyword visualisation map data and may not significantly alter the content of scientific clusters. The research methodology section identified the risks of conducting a bibliometric review, which proved to be insignificant. This is confirmed by the results of the processed data in the form of tables and figures.

The thematic map of digital twins in the context of bibliometric review versus practical aspects is a generalised opinion of the authors and a scientific novelty on how to combine scientific clusters on the path to achieving the SDGs in economic, social and environmental aspects.

The contribution of this study lies in its ability to improve scientific approaches to the formation of a digital twin in an enterprise, taking into account the advantages, opportunities and risks. It is proved that digital twins are a powerful technology that provides enterprises with a comprehensive view of their performance. Therefore, with the help of digital twins, businesses can modernise their operations for new achievements. Thanks to digitalisation, digital twins have become an integral part of business processes. After all, it is an exact copy or replica of a real system that acts as a virtual model suitable for purposes such as testing, monitoring and troubleshooting.

The application of scientific approaches to the implementation of digital twins in the context of SDGs will enable optimal management decisions to be made in the process of applying digital technologies. This will lead to the development of digital literacy and the possibility of implementing the 17 SDGs. The results obtained can be used by managers of industrial enterprises to analyse and build design models, taking into account the advantages and risks. This will contribute to the establishment of cooperation between enterprises and stakeholders, as well as the sustainable development of countries.

5 CONCLUSION

In today's Web 3.0 world, digital twins are becoming a business imperative, covering the entire asset life cycle and forming the basis for the digitalisation of all enterprise processes, products and services to enable businesses to survive in a constantly changing environment. The four stages of digital twin development have made it possible to trace the path from the initial conceptualisation to confident application in various industries. Such evolutionary changes require more detailed attention to define the benefits, tools and possible risks of using digital twins. Adherence to the defined model will help improve decision-making by modelling various application scenarios with minimal risks, optimising business processes and increasing efficiency in solving complex problems. Special attention is paid to the framework of the UN Sustainable Development Goals (SDGs), where the integration of digital technologies can be traced in all 17 goals in three areas: economy, social aspects and biosphere. The availability of such advanced technologies as digital twins reduces the time, money and resources required to solve problems, providing access to effective solutions for businesses in any sector within the economy.

In the present paper, special attention was paid to a bibliometric review of research articles focused on digital twins, as indexed in the Scopus scientometric database. The keyword "digital AND twin AND industry" was used to identify 2883 publications from the period 1982-2025 in various subject areas.

Data processing by VOSviewer software formed 16 scientific clusters highlighting the connections between digital twins and the SDGs. This made it possible to create a thematic map and trace which scientific clusters are represented in the advancement of the social, economic and environmental areas. In summary, digital twins are a tool for improving operational efficiency, flexibility and effective decision-making. They allow managers to gain deep insights, optimise processes and respond effectively to market dynamics. Modern software efficiently connects source and target systems in just a few clicks, allowing the user to utilise the full potential of digital twins.

ADDITIONAL INFORMATION AND DECLARATIONS

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Statement on the Use of Artificial Intelligence Tools: The authors declare that they didn't use artificial intelligence tools for text or other media generation in this article.

Data Availability: The data that support the findings of this study are openly available in Zenodo at https://doi.org/10.5281/zenodo.17121712.

REFERENCES

Abad-Segura, E., Infante-Moro, A., González-Zamar, M.D., & López-Meneses, E. (2024). Influential factors for a secure perception of accounting management with blockchain technology. *Journal of Open Innovation: Technology, Market, and Complexity*, 10(2), 100264. https://doi.org/10.1016/j.joitmc.2024.100264

Andarwati Kunharyanto, S., Mayasari, R., & Oktaviana, D. (2025). Optimization in Routing and Vehicle Selection for E-commerce Last Mile Logistics: Bibliometric Analysis. *Acta Informatica Pragensia*, 14(1), 174–190. https://doi.org/10.18267/j.aip.257

Anitha, K., Ghosal, I., & Khunteta, A. (2024). Digital Twins AR and VR: Rule the Metaverse!. In *Emerging Technologies in Digital Manufacturing and Smart Factories* (pp. 193–204). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-0920-9.ch011

Bessenbacher, V., Schumacher, D. L., Hirschi, M., Seneviratne, S.I., & Gudmundsson, L. (2023). Gap-Filled Multivariate Observations of Global Land–Climate Interactions. *Journal of Geophysical Research: Atmospheres*, *128* (24), e2023JD039099. https://doi.org/10.1029/2023JD039099

Bhati, M., Goerlandt, F., & Pelot, R. (2025). Digital twin development towards integration into blue economy: A bibliometric analysis. *Ocean Engineering*, *317*, 119781. https://doi.org/10.1016/j.oceaneng.2024.119781

Biliavska, Y., Biliavskyi, V., Shestack, Y., Dyeyeva, N., Kolesnyk, M., & Tryvailo, A. (2025). Monitoring of cyber risks in the financial sector of the economy. *Financial and Credit Activity: Problems of Theory and Practice,* 3(62), 355–369. https://doi.org/10.55643/fcaptp.3.62.2025.4702

Biliavska, Y., Romat, Y., Biliavskyi, V., Ostapenko, T., & Sydorenko, O. (2024). Diagnosing category management in a pharmacy retail chain. *Eastern-European Journal of Enterprise Technologies*, 13(127), 22–32. https://doi.org/10.15587/1729-4061.2024.298093

Björnsson, B., Borrebaeck, C., Elander, N., Gasslander, T., Gawel, D. R., Gustafsson, M., ... & Swedish Digital Twin Consortium. (2020). Digital twins to personalize medicine. *Genome medicine*, 12, 1–4. https://doi.org/10.1186/s13073-019-0701-3

Brauner, P., Dalibor, M., Jarke, M., Kunze, I., Koren, I., Lakemeyer, G., ... & Ziefle, M. (2022). A computer science perspective on digital transformation in production. *ACM Transactions on Internet of Things*, 3 (2), 1–32. https://doi.org/10.1145/3502265

Casciani, D., Chkanikova, O., & Pal, R. (2022). Exploring the nature of digital transformation in the fashion industry: opportunities for supply chains, business models, and sustainability-oriented innovations. *Sustainability: Science, Practice and Policy*, 18 (1), 773–795. https://doi.org/10.1080/15487733.2022.2125640

De Benedictis, A., Flammini, F., Mazzocca, N., Somma, A., & Vitale, F. (2023). Digital twins for anomaly detection in the industrial internet of things: Conceptual architecture and proof-of-concept. *IEEE Transactions on Industrial Informatics*, 19(12), 11553–11563. https://doi.org/10.1109/TII.2023.3246983

Dembski, F., Wössner, U., Letzgus, M., Ruddat, M., & Yamu, C. (2020). Urban digital twins for smart cities and citizens: The case study of Herrenberg, Germany. *Sustainability*, 12 (6), 2307. https://doi.org/10.3390/su12062307

Fan, C., Zhang, C., Yahja, A., & Mostafavi, A. (2021). Disaster City Digital Twin: A vision for integrating artificial and human intelligence for disaster management. *International journal of information management*, 56, 102049. https://doi.org/10.1016/j.ijinfomgt.2019.102049

Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital twin: enabling technologies, challenges and open research. *IEEE access*, 8, 108952–108971. https://doi.org/10.1109/ACCESS.2020.2998358

Garske, B., Holz, W., & Ekardt, F. (2024). Digital twins in sustainable transition: exploring the role of EU data governance. *Frontiers in Research Metrics and Analytics*, 9, 1303024. https://doi.org/10.3389/frma.2024.1303024

Giuffrè, M., & Shung, D. L. (2023). Harnessing the power of synthetic data in healthcare: innovation, application, and privacy. *Npj Digital Medicine,* 6 (1), 1–8. https://doi.org/10.1038/s41746-023-00927-3

Hassani, H., Huang, X., & MacFeely, S. (2022). Enabling digital twins to support the UN SDGs. *Big Data and Cognitive Computing*, 6(4), 115. https://doi.org/10.3390/bdcc6040115

Ibrahim, M., Rassõlkin, A., Vaimann, T., & Kallaste, A. (2022). Overview on digital twin for autonomous electrical vehicles propulsion drive system. *Sustainability*, 14 (2), 601. https://doi.org/10.3390/su14020601

Ivanov, D. (2020). Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case. *Transportation Research Part E: Logistics and Transportation Review*, 136, 101922. https://doi.org/10.1016/j.tre.2020.101922

Jamwal, A., Agrawal, R., Sharma, M., & Giallanza, A. (2021). Industry 4.0 technologies for manufacturing sustainability: A systematic review and future research directions. *Applied Sciences*, 11(12), 5725. https://doi.org/10.3390/app11125725

Jiang, B., Cheng, T., Tsou, M. H., Zhu, D., & Ye, X. (2025). Advancing translational human dynamics research: bridging space, mind, and computational urban science in the era of GeoAI. *Computational Urban Science*, 5(1), 1–9. https://doi.org/10.1007/s43762-025-00171-3

Jones, D., Snider, C., Nassehi, A., Yon, J., & Hicks, B. (2020). Characterising the Digital Twin: A systematic literature review. *CIRP journal of manufacturing science and technology*, 29, 36-52. https://doi.org/10.1016/j.cirpj.2020.02.002

Kagermann, H., & Wahlster, W. (2022). Ten years of Industrie 4.0. *Sci*, 4(3), Article 26. https://doi.org/10.3390/sci4030026

Krasnobayev, V., Yanko, A., Hlushko, A., Kruk, O-g, Kruk, O-r, & Gakh, V. (2023). Cyberspace protection system based on the data comparison method. In *Economic and cyber security*, (pp. 3–29). PC Technology Center. https://doi.org/10.15587/978-617-7319-98-5.ch1

Lim, K. Y. H., Zheng, P., & Chen, C. H. (2020). A state-of-the-art survey of Digital Twin: techniques, engineering product lifecycle management and business innovation perspectives. *Journal of Intelligent Manufacturing*, 31 (6), 1313–1337. https://doi.org/10.1007/s10845-019-01512-w

Liu, M., Fang, S., Dong, H., & Xu, C. (2021). Review of digital twin about concepts, technologies, and industrial applications. *Journal of manufacturing systems*, 58, 346–361. https://doi.org/10.1016/j.jmsy.2020.06.017

Lo, C. K., Chen, C. H., & Zhong, R. Y. (2021). A review of digital twin in product design and development. *Advanced Engineering Informatics*, 48, 101297. https://doi.org/10.1016/j.aei.2021.101297

Mamchur, V., Osetskyi, V., Biliavska, Yu., Umantsiv, H., & Biliavskyi, V. (2025). Strategic vectors of agribusiness development in Ukraine. *Ekonomika APK,* 32(1), 33–46. https://doi.org/10.32317/ekon.apk/1.2025.33

Mandolla, C., Petruzzelli, A. M., Percoco, G., & Urbinati, A. (2019). Building a digital twin for additive manufacturing through the exploitation of blockchain: A case analysis of the aircraft industry. *Computers in industry*, 109, 134–152. https://doi.org/10.1016/j.compind.2019.04.011

Marinagi, C., Reklitis, P., Trivellas, P., & Sakas, D. (2023). The impact of industry 4.0 technologies on key performance indicators for a resilient supply chain 4.0. *Sustainability*, 15 (6), 5185. https://doi.org/10.3390/su15065185

Mayer, A., Greif, L., Häußermann, T. M., Otto, S., Kastner, K., El Bobbou, S., ... & Ovtcharova, J. (2025). Digital Twins, Extended Reality, and Artificial Intelligence in Manufacturing Reconfiguration: A Systematic Literature Review. *Sustainability*, 17 (5), 2318. https://doi.org/10.3390/su17052318

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

Moufid, O., Praharaj, S., & Oulidi, H.J. (2024). Digital technologies in urban regeneration: A systematic review of literature. *Journal of Urban Management,* 14(1), 264–278. https://doi.org/10.1016/j.jum.2024.11.002

Nag, D., Brandel-Tanis, F., Pramestri, Z.A., Pitera, K., & Frøyen, Y.K. (2025). Exploring digital twins for transport planning: a review. *European Transport Research Review*, 17(1), Article 15. https://doi.org/10.1186/s12544-025-00713-0

Negri, E., Fumagalli, L., & Macchi, M. (2017). A Review of the ROLES OF Digital Twin in CPS-based Production Systems. *Procedia manufacturing*, 11, 939–948. https://doi.org/10.1016/j.promfg.2017.07.198

Nguyen, H. X., Trestian, R., To, D., & Tatipamula, M. (2021). Digital Twin for 5G and Beyond. *IEEE Communications Magazine*, 59 (2), 10–15. https://doi.org/10.1109/MCOM.001.2000343

Nishant, R., Kennedy, M., & Corbett, J. (2020). Artificial intelligence for sustainability: Challenges, opportunities, and a research agenda. *International Journal of Information Management,* 53, https://doi.org/10.1016/j.ijinfomgt.2020.102104

Osama, Z. (2024). The digital twin framework: A roadmap to the development of user-centred digital twin in the built environment. *Journal of Building Engineering*, 98, 111081. https://doi.org/10.1016/j.jobe.2024.111081

Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & McKenzie, J. E. (2021). PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. BMJ, 372, Article 160. https://doi.org/10.1136/bmj.n160

Pylianidis, C., Osinga, S., & Athanasiadis, I. N. (2021). Introducing digital twins to agriculture. *Computers and Electronics in Agriculture*, 184, 105942. https://doi.org/10.1016/j.compag.2020.105942

Qi, Q., & Tao, F. (2018). Digital twin and big data towards smart manufacturing and industry 4.0: 360 degree comparison. *IEEE Access*, 6, 3585–3593. https://doi.org/10.1109/ACCESS.2018.2793265

Rasheed, A., San, O., & Kvamsdal, T. (2020). Digital twin: Values, challenges and enablers from a modeling perspective. *IEEE Access*, 8, 21980–22012. https://doi.org/10.1109/ACCESS.2020.2970143

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*, 9, 32030–32052. https://doi.org/10.1109/ACCESS.2021.3060863

Rehman, S.U., Giordino, D., Zhang, Q., & Alam, G.M. (2023). Twin transitions & industry 4.0: Unpacking the relationship between digital and green factors to determine green competitive advantage. *Technology in Society*, 73, 102227. https://doi.org/10.1016/j.techsoc.2023.102227

Ren, J., Ahmad, R., Li, D., Ma, Y., & Hui, J. (2025). Industrial applications of digital twins: A systematic investigation based on bibliometric analysis. *Advanced Engineering Informatics*, 65, 103264. https://doi.org/10.1016/j.aei.2025.103264

Schleich, B., Anwer, N., Mathieu, L., & Wartzack, S. (2017). Shaping the digital twin for design and production engineering. *CIRP Annals*, 66(1), 141–144. https://doi.org/10.1016/j.cirp.2017.04.040

Schrotter, G., & Hürzeler, C. (2020). The digital twin of the city of Zurich for urban planning. *PFG-Journal of Photogrammetry, Remote Sensing and Geoinformation Science*, 88 (1), 99–112. https://doi.org/10.1007/s41064-020-00092-2

Shen, J., Hu, L., Yang, Y., Li, Y., & Lou, P. (2025). Real-time update algorithms for digital twin models of distribution network equipment under internet of things and optical imaging technology. *Scientific Reports*, 15(1), 5910. https://doi.org/10.1038/s41598-025-85457-6

Shihabi, R., Liu, Y., Kusaibati, A.M., Maraabeh, F., Zhan, J., Zhang, J., & Hu, L. (2025). Three-dimensional analysis of mandibular and condylar growth using artificial intelligence tools: A comparison of twin-block and Frankel II Appliances. *BMC Oral Health,* 25(1), 254. https://doi.org/10.1186/s12903-025-05624-z

Smutny, Z., & Svandova, K. (2024). An Overview of Improving Logistics Processes in Health Facilities: Issues, Solutions, and Challenges. *Journal of Engineering and Technology for Industrial Applications,* 10(50), 191–196. https://doi.org/10.5935/jetia.v10i50.1315

Tan, J. K. N., Law, A. W. K., Kumar Maan, A., & Cheung, S. H. (2023). Digital-twin-controlled ventilation for real-time resilience against transmission of airborne infectious disease in an indoor food court. *Building Services Engineering Research & Technology*, 44(6), 641–658. https://doi.org/10.1177/014362442312044

Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018a). Digital twin-driven product design, manufacturing and service with big data. *The International Journal of Advanced Manufacturing Technology*, 94, 3563–3576. https://doi.org/10.1007/s00170-017-0233-1

Tao, F., Zhang, H., Liu, A., & Nee, AY (2018b). Digital Twin in Industry: State-of-the-Art. *IEEE Transactions on industrial informatics*, 15(4), 2405–2415. https://doi.org/10.1109/TII.2018.2873186

Tao, F., Zhang, M., Cheng, J., & Qi, Q. (2017). Digital twin workshop: A new paradigm for future workshop. *Computer integrated manufacturing systems*, 23 (1), 1–9. https://doi.org/10.13196/j.cims.2017.01.001

Velusamy, S., Raguvaran, S., Kumar, S. V., Kumar, B. S., & Padmapriya, T. (2024). From Industry 4.0 to 5.0: Digital Management Model of Personnel Archives Based on Transition from Digital Manufacturing. In *Emerging Technologies in Digital Manufacturing and Smart Factories* (pp. 1–25). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-0920-9.ch001

Wanganoo, L., & Tripathi, R. (2023). "Reverse Logistics: Rebuilding Smart and Sustainable Transformation Based on Industry 4.0". In *Fostering Sustainable Development in the Age of Technologies,* (pp. 129–143). Emerald. https://doi.org/10.1108/978-1-83753-060-120231011

Yi, H. (2023). Improving cloud storage and privacy security for digital twin based medical records. *Journal of Cloud Computing,* 12(1), 151. https://doi.org/10.1186/s13677-023-00523-6

Yu, H., He, Z., Peng, L., & Zhou, A. (2024). Verification of 3D electrical equipment model based on cross-source point cloud registration using deep neural netwo. *Information Technology and Control,* 53(4), 983–996. https://doi.org/10.5755/j01.itc.53.4.37475

Yun, Y., & Lee, M. (2019). Smart city 4.0 from the perspective of open innovation. *Journal of Open Innovation: Technology, Market, and Complexity*, 5 (4), 92. https://doi.org/10.3390/joitmc5040092

Zhang, C., Yang, H., Zhang, C., Zhang, J., Yao, Q., Wang, Z., & Vasilakos, A. V. (2025). Federated cross-chain trust training for distributed smart grid in Web 3.0. *Applied Soft Computing*, 180, 113313. https://doi.org/10.1016/j.asoc.2025.113313

Zhang, R., Wang, F., Cai, J., Wang, Y., Guo, H., & Zheng, J. (2022). Digital twin and its applications: A survey. *The International Journal of Advanced Manufacturing Technology*, 123 (11), 4123–4136. https://doi.org/10.1007/s00170-022-10445-3

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