Research, Society and Development, v. 11, n. 12, e152111234270, 2022
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i12.34270

A bibliometric analysis of the relationship between Digital Twins and Health Management: based on the Web of Science (WoS) platform

Uma análise bibliométrica da relação entre Gêmeos Digitais e Gestão em Saúde: com base na plataforma Web of Science (WoS)

Un análisis bibliométrico de la relación entre Digital Twins y Health Management: basado en la plataforma Web of Science (WoS)

Received: 08/19/2022 | Reviewed: 08/29/2022 | Accept: 09/01/2022 | Published: 09/09/2022

Anderson de Oliveira Ribeiro
ORCID: https://orcid.org/0000-0003-3460-4374
Centro Universitário Geraldo Di Biase, Brazil
Universidade Federal Fluminense, Brazil
E-mail: andersonribeiro@ugb.edu.br
Francisco Santos Sabbadini
ORCID: https://orcid.org/0000-0002-7018-5982
Universidade do Estado do Rio de Janeiro, Brazil
Universidade Federal Fluminense, Brazil
E-mail: franciscosabbadini@gmail.com
Kelly Alonso Costa
ORCID: https://orcid.org/0000-0002-7018-5982
Universidade Federal Fluminense, Brazil
E-mail: kellyalonso@id.uff.br
Bruna Sacramento de Souza Cruz
ORCID: https://orcid.org/0000-0002-9600-9434
Universidade Federal Fluminense, Brazil
E-mail: brunasacramento@id.uff.br

Abstract
Amidst the development of Industry 4.0, the appropriation of digital tools applied to production and manufacturing of activities represents a challenge for managers in other areas. Digital Twin (DT) technology is based on the integration of different "traditional" tools, such as simulation modeling and sensors, and aims to increase the performance of any process that can be represented virtually. With the increase in population, the demand for more efficient and universal Health Management (HM) has become a challenge of the 21st century. This study aims to analyze the relationship between the field of knowledge DT and HM and their interactions. A bibliometric review was performed using the Web of Science database through the Bibliometrix package and the VOSviewer application to evaluate studies, applications and identify research clusters and future trends. Our study indicates that the applications of DT in HM are focused on the diagnosis and monitoring of chronic diseases and that, so far, there is not a critical mass of knowledge that consolidates a general theory of application of DT and HM. This study identifies a relational hotspot between the integration of a DT in the optimization of resource management and patient care.
Keywords: Digital twin; Digital healthcare; Industry 4.0; Cyber-physical systems; Internet of things.

Resumo
Em meio ao desenvolvimento da Indústria 4.0, a apropriação de ferramentas digitais aplicadas à produção e fabricação de atividades representa um desafio para gestores de outras áreas. A tecnologia Digital Twin (DT) baseia-se na integração de diferentes ferramentas "tradicionais", como modelagem de simulação e sensores, e visa aumentar o desempenho de qualquer processo que possa ser representado virtualmente. Com o aumento da população, a demanda por Gestão em Saúde (GS) mais eficiente e universal tornou-se um desafio do século XXI. Este estudo tem como objetivo analisar a relação entre o campo de conhecimento DT e HM e suas interações. Foi realizada uma revisão bibliométrica utilizando a base de dados Web of Science por meio do pacote Bibliometrix e do aplicativo VOSviewer para avaliar estudos, aplicações e identificar clusters de pesquisa e tendências futuras. Nosso estudo indica que as aplicações da TD em HM estão voltadas para o diagnóstico e acompanhamento de doenças crônicas e que, até o momento, não existe uma massa crítica de conhecimento que consolide uma teoria geral de aplicação de TD e HM. Este estudo identifica um hotspot relacional entre a integração de um DT na otimização da gestão de recursos e atendimento ao paciente.
Palavras-chave: Gêmeo digital; Saúde digital; Indústria 4.0; Sistemas ciberfísicos; Internet das coisas.

Resumen
En medio del desarrollo de la Industria 4.0, la apropiación de herramientas digitales aplicadas a la producción y fabricación de actividades representa un desafío para los gestores de otras áreas. La tecnología Digital Twin (DT) se basa en la integración de diferentes herramientas "tradicionales", como el modelado de simulación y sensores, y tiene como objetivo aumentar el rendimiento de cualquier proceso que pueda representarse virtualmente. Con el aumento de la población, la demanda de una Gestión Sanitaria (GS) más eficiente y universal se ha convertido en un reto del siglo XXI. Este estudio tiene como objetivo analizar la relación entre el campo de conocimiento DT y HM y sus interacciones. Se realizó una revisión bibliométrica utilizando la base de datos Web of Science a través del paquete Bibliometrix y la aplicación VOSviewer para evaluar estudios, aplicaciones e identificar clusters de investigación y tendencias futuras. Nuestro estudio indica que las aplicaciones de DT en HM están enfocadas al diagnóstico y seguimiento de enfermedades crónicas y que, hasta el momento, no existe una masa crítica de conocimiento que consolide una teoría general de aplicación de DT y HM. Este estudio identifica un punto de acceso relacional entre la integración de un DT en la optimización de la gestión de recursos y la atención al paciente.
Palabras clave: Gemelo digital; Sanidad digital; Industria 4.0; Sistemas ciberfísicos; Internet de las cosas.

1. Introduction

The development of Industry 4.0 tools promotes a convergence of health, artificial intelligence, big data, cloud computing, internet of things, digital twin, as well as information and communication technologies (Huang et al., 2022). This convergence has brought a rapid digitalization of processes to health management, such as in prevention and treatment of diseases, economy reduction, patient autonomy and freedom, and equality of treatment (Popa et al., 2021).

The concept of digital twins has a great potential to transform the system, particularly when it comes to healthcare. Although some applications and relationships between the applications of digital twins are already known by researchers working in digital health (Khan et al., 2022), there is currently no comprehensive review that maps the main applications of digital twins in health management and health administration.

The concept development around Digital Twins began in the early 2000s. Since then, its definition has undergone constant changes (Barricelli et al., 2020). The first terminology was given by Grieves in a 2003 presentation and later documented in a white paper that laid a foundation for the development of Digital Twins (Grieves, 2014).

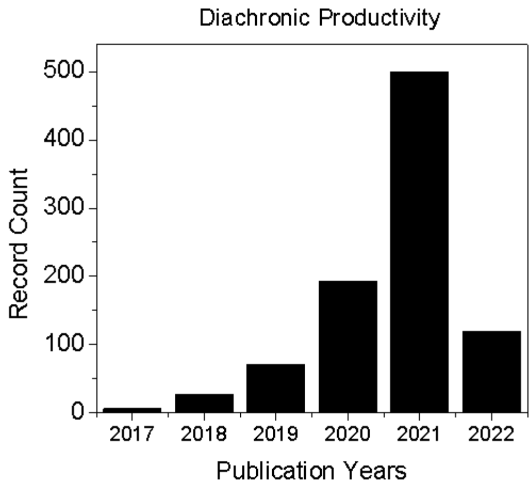
In this article, we will adopt the definition of Digital Twin as being "a virtual instance of a physical system (twin) that is continually updated with the latter's performance, maintenance, and health status data throughout the physical system's life cycle" (Chen, 2017).

In the healthcare field, Digital Twins have been applied primarily for predictive maintenance of medical devices and for optimizing their performance. This optimization focuses on increasing examination speed, reducing energy consumption and continuous improvement of the hospital life cycle (Barricelli et al., 2019). The advancement of medical technology has brought up the need to implement infrastructure of new technologies and the Digital Twins to deal with patient demand management, increase in clinical complexity, increase in the need for waiting, increase in space without supply of supplies, etc (Barricelli et al., 2019).

When applying the Digital Twin technology at the Mater Private Hospitals in Dublin (Scharff, 2010). it was shown that this application allows for the optimization of the digital process by using workflow simulations and testing new operational scenarios and new layouts. The Digital Twin technology allowed for predicting operational scenarios and instantly evaluating optimal solutions for care delivery.

The academic and market interest in the Digital Twin tool can be seen in the increased number of publications in the last five years, as seen in Figure 1, and this framework of knowledge allows us to perform a bibliometric analysis of the relationship between studies on Digital Twins and studies on Health Management. A bibliometric study is the study of the system of literature using mathematics, statistics, and other measurement methods to analyze the distribution, structure, quantity, relationships, laws, and the relationship between fields of study.

Figure 1 - Diachronic productivity of articles of the theme Digital Twin published in Web of Science since 2017.



Source: Authors.

Our literature review and bibliometric analysis was based on Lezzi et al. (Lezzi et al., 2018). to ensure the 'relevance' of the analyzed literature and accuracy in 'text mining'. The investigation objective is to carry out a search for the connection between the knowledge generated by publications referring to Digital Twins (henceforth DT) and the knowledge generated by publications referring to health management (henceforth HM). Specifically, the review seeks to identify (i) the relationships already established between DT-HM, (ii) identify the tools that support DT-HM integration, (iii) identify the potential for application of DT in HM and (vi) identify lines of research with potential for development.

The research performed for this article uses the Web of Science (WoS) citation database, which is the world's main article database used by many works to perform analyzes such as the one in this article (Gong et al., 2019), (Mansoori, 2018), (Soosaraei et al., 2018), (Sweileh et al., 2014), (Zyoud et al., 2017). The WoS platform is widely used by other scientific researchers in the field of bibliography, and covers more than 20,000 journals, books and conferences with more than 70 million (Sarkar et al., 2022) research materials.

This paper is organized as follows: Section I introduces the article's writing background. Section II explains the data source and research method. Section III analyses the basic characteristics of the database and their relationships, and finally, section IV presents discussions and conclusions.

2. Methodology for Sample Definition

The following conditions were adopted for the research: peer-reviewed articles, written in English, published between 2017 and 2022 and with at least 10 citations. With these conditions, a search for the terms HM and DT was performed. The definition of keywords for a bibliometric study representative of a given field of knowledge was the main step, as keywords usually illustrate the fundamental purpose of an article and can explain the main reason for any article in a detailed manner. Next, the construction structure of the HM and DT fields will be detailed. A similar approach to that used by Da Silva, A. F.C. et al (2022).

(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i12.34270

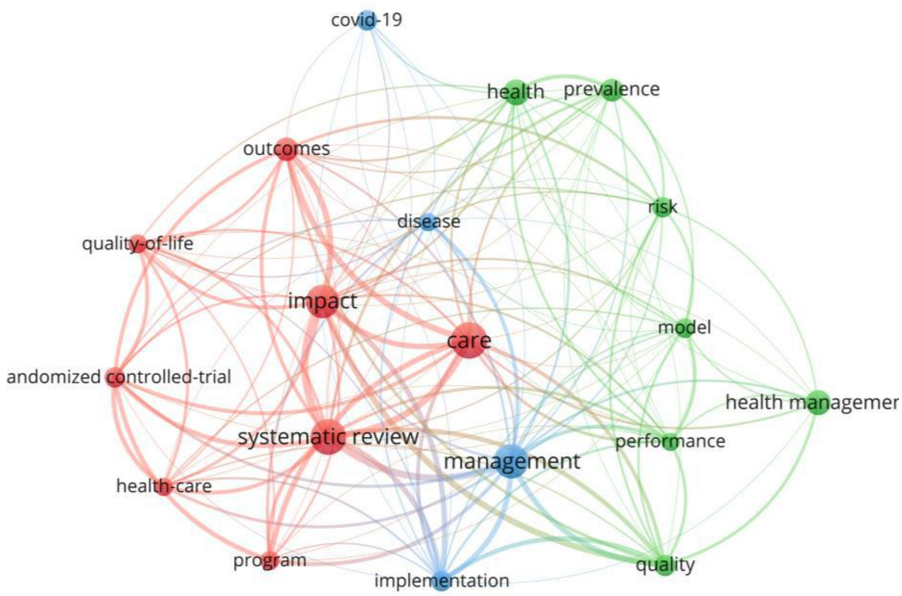
2.1 Definition of the Health Management Field

In order to define the HM field, a search was first carried out for all fields using the terms "health management", "healthcare", "healthcare management" and "health administration". This search resulted in 215 articles and, with this database and the Vosviewer software (van Eck, Waltman, 2009), a co-occurrence map of 7,485 keywords was generated. The study focused on the top 20 most common keywords, that is, with the highest co-occurrence. The result is shown in Figure. 2.

By interpreting the keyword cluster map, the VOSViewer software can examine the identifiers of various documents in detail and classify the field of study hotspots. In addition, the top 20 keywords were divided into 3 clusters according to the number of occurrences.

The red cluster (CHM1) consists of eight items: care, health-care, impact, outcomes, program, quality-of-life, randomized controlled-trial, and systematic review. The green cluster (CHM2) comprises seven components: health, health management, model, performance, prevalence, quality and risk. The blue cluster (CHM3) consists of four items: covid-19, disease, implementation and management. CHM2 is the cluster that contains the co-occurring keywords that form the health management fields. The less space between the pair of nodes, the greater the proportion of corresponding co-occurrences. The green cluster represents the "Health management" knowledge field.

Figure 2 - Co-occurrence cluster map, the co-occurring keywords that form the health management fields. The size of the nodes stands out from the listing frequency. Co-occurrences in the same cluster derive the curvatures associated with the nodes.



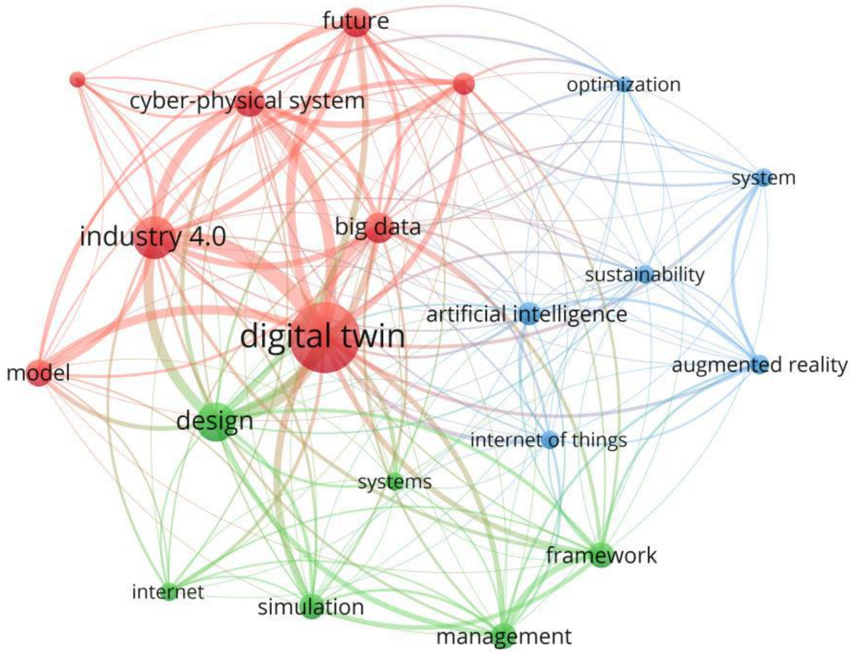
Source: Authors.

2.2 Definition of the Digital Twin

To define the DT field, a search was first performed for the terms "Digital Twin" and "Digital Twins", which resulted in 217 articles and, using the same procedure performed previously, a co-occurrence map of 640 keywords was generated. For an equitable analysis between the DT and HM fields, the map was limited to the top 20 most frequent keywords, as shown in Figure 3.

The red cluster (CDT1) is composed of eight items: digital twin, design, model, management, simulation, internet and systems. The blue cluster (CDT2) is composed of six items: industry 4.0, big data, cyber-physical system, future, smart manufacturing and smart factory. The green cluster (CDT3) is composed of six sites: artificial intelligence, augmented reality, internet of things, sustainability, system and optimization. CDT1 is the cluster that contains the co-occurring keywords that form the Digital Twin related field. In the next section, the relationship between the field defined by CHM1 and CDT2 and the other clusters directly connected to them will be presented.

Figure 3 - Co-occurrence cluster map, you can see the three clusters formed from the keywords. The red cluster represents the "Digital Twin" knowledge field.



Source: Authors.

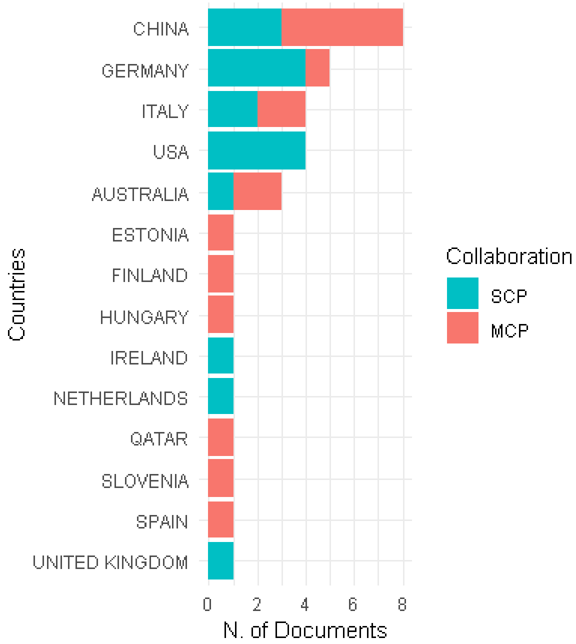
3. Analysis of the Relation Between Digital Twins and Health Management

To relate Health Management and Digital Twin, as presented, the fields of knowledge of these themes (delineated by the sets of keywords CHM2 and CDT1) were defined. In Figure 2 and 3 it is possible to observe the connections between these fields with the other items and, from the analysis of this scenario, a search for the intersection of the union between CHM2 and CDT1 and the other items, that will be called CF1, is proposed. The design, model, management, simulation, internet and systems were moved from CDT1 to the CF1 set, as these terms have a generalist character. This way, our search met the logic (CHM2) and (CDT1) and (CF1) such that: (("health management" or "health" or "risk" or "performance" or "prevalence") and ("digital twin" or "digital twins")) and ("design" or "simulation" or "internet management" or "systems" or "quality" or "implementation" or "artificial" or "intelligence" or "augmented reality" or "internet of things" or "optimization" or "sustainability" or "system" or "big data" or "cyber-physical" or "future" or "industry 4.0" or "smart factory" or "smart manufacturing" or "care" or "impact" or "outcomes" or "program" or "quality-of-life" or "randomized" or "controlled-trial" or "covid-19" or "disease" or "healthcare"or "model").

The only difference in the search parameters described on the first paragraph of section II is the removal of the filter and articles. The search shows a database of 33 items: 12 articles, 13 proceeding papers and 8 review articles. Even though the time interval used for the search is between 2017 and 2022, it results in five articles published in 2018, 17 in 2019 and 11 in 2021. The international scope is reflected on the participation of 14 countries, and the country of the corresponding author considered as outlined in Figure 4.

Collaborations between several countries enable bridges that disseminate knowledge and access to resources between organizations and research groups that do not have the resources for cutting-edge technology and, as a result, this greater dissemination of knowledge improves the quality of research results (Moshobane et al., 2021). The use of research publication co-authorships (Ferligoj et al., 2015). is an efficient method to measure collaboration. Co-authorship is used because it is a sufficiently objective and direct way of evaluating scientific cooperation. Furthermore, Multiple Country Publications (MCP) and Single Country Publications (SCP) are two established indicators for this investigation (Moshobane et al, 2021), (Ferligoj et al, 2015).

Figure 4 - The global contribution by country of the corresponding author's country in the International Journal of Tropical Insect Science, 2017–2022. SCP = Single country publications (SCP) and MCP = Multiple country publications (MCP).



Source: Authors.

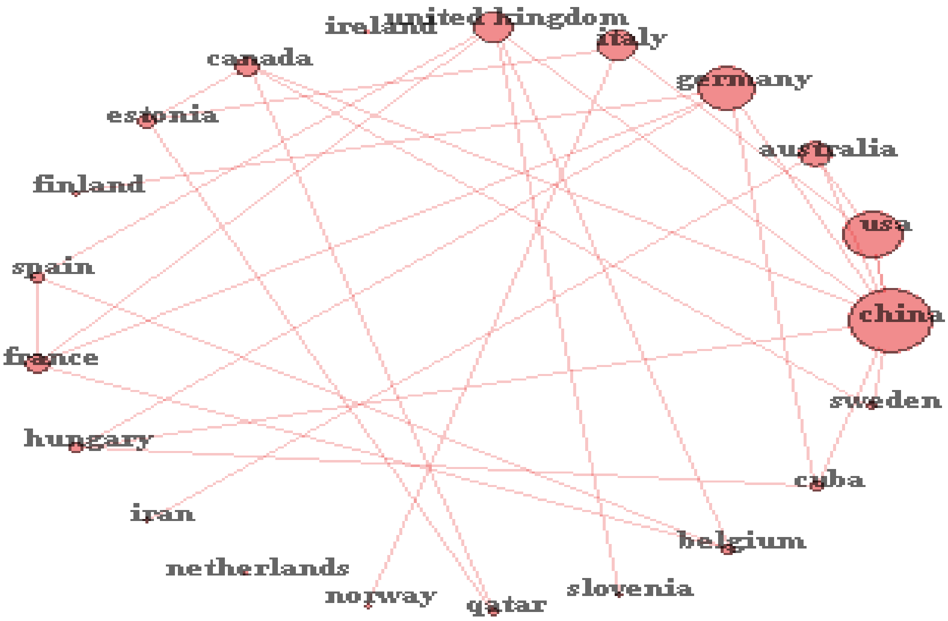
Figure 4 shows that there is a block formed by China (leading with 8 articles), Germany (5 articles), Italy (4 articles), USA (4 articles) and Australia (3 articles), and a second block formed by Estonia, Finland, Hungary, Ireland, Netherlands, Qatar, Slovenia, Spain and United Kingdom. China, Italy and Australia are the countries that show stronger collaboration. The USA does not have measured collaboration.

There are co-authorship connections between China and eight countries followed by the United Kingdom and Germany, with five connections. The countries on the second block have their publications linked to countries with a high publication volume, and this same block does not have a collaboration network (as seen in Figure 5).

The keyword illustrates the fundamental goals and can easily explain the main motive of any article. Table 1 shows the 30 most frequent keywords and their respective number of links. With the VOSViewer layout resource, the interaction between these words can be observed, as outlined in Figure 6. The keyword ''digital twin'' occurred 29 times with 78 links; meanwhile, it was noted a significantly lower occurrence of other keywords and number of links.

Research, Society and Development, v. 11, n. 12, e152111234270, 2022
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i12.34270

Figure 5 - Co-author network map showing linkages and collaboration between various countries.



Source: Authors.

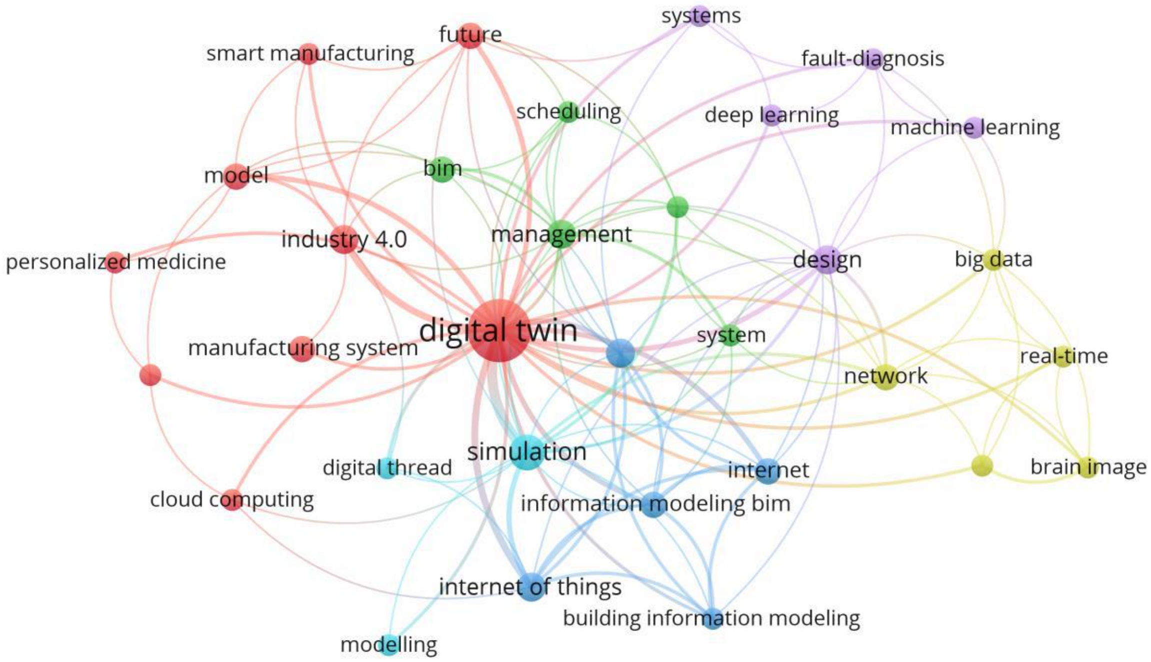
Table 1 - The 33 keywords that define the relationship between the HM and DT fields.

Keywords	Occurrences	Total link strength
digital twin	29	78
simulation	7	27
design	4	19
industry 4.0	4	14
internet of things	4	19
management	4	17
performance	4	20
bim	3	9
future	3	12
information modeling bim	3	17
internet	3	16
manufacturing system	3	3
model	3	12
network	3	13
big data	2	10
brain image	2	7
building information modeling	2	13
cloud computing	2	5
deep learning	2	6
digital thread	2	6
fault-diagnosis	2	8
genetic algorithm	2	9
image segmentation	2	7
machine learning	2	6
modelling	2	3
personalized medicine	2	4
precision medicine	2	5
real-time	2	6
scheduling	2	8
smart manufacturing	2	6

Source: Authors.

Thus, it can be said that the main hotspot between the Digital Twin and Health Management fields is the Digital Twin field itself, and that it concatenates the main technological tools with applications. An example can be seen in the connection of ‘’management - digital twin - internet of things’’ in the work of Y. Liu (Liu et al., 2019). It presents an integration in computing and cloud, digital twin and health resource management and medical care, in which the merger result is the CloudDTH. This tool provides a new mode of healthcare that achieves the goals of disseminating and coordinating decentralized resources, rationalizing healthcare services, and optimizing large-scale processes for healthcare institutions and patients.

Figure 6 - Co-occurrence cluster map of the relationship between HM and DT fields. It can be noticed the formation of 6 clusters. The red cluster is composed of the terms: cloud computing, digital twin, future, industry 4.0, manufacturing system, model, personalized medicine, precision medicine, smart manufacturing. The green cluster is composed of: bim, genetic algorithm, management, scheduling and system. The blue cluster is composed of: Building Information Modeling, Information Modeling bim, internet and internet of things. The light blue cluster is composed: digital thread, modeling and simulation. The purple cluster is composed of: deep learning, design, fault-diagnosis, machine learning and systems. Finally, the yellow cluster is defined by: big data, brain image, image segmentation, network and real-time



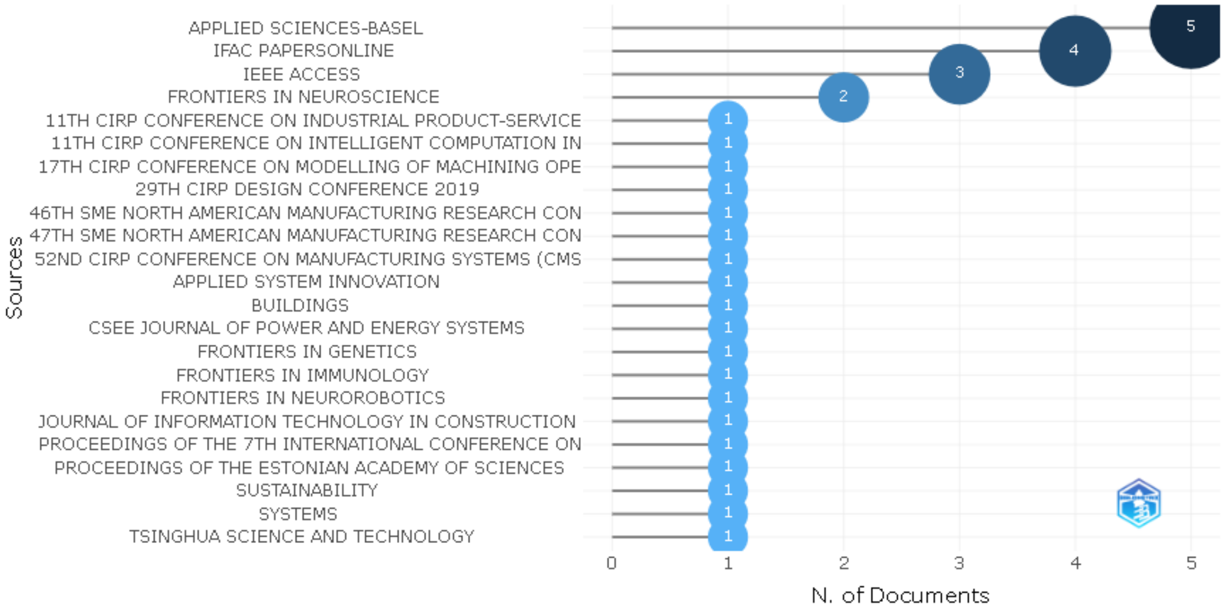
Source: Authors.

The Co-occurrence cluster map (Figure 6) brings an interesting result; the red cluster concentrates the subjects focused on the personalization and precision medicine in association with smart manufacturing. (Voigt et al., 2021). shows that Digital Twins will help make precision medicine and patient-centered care a reality in everyday life and have expanded the offer of medical care, both by reducing cost and increasing efficiency in its distribution.

In Figure 7 the journals that concentrate the publications resulting from the relationship between HM and DT can be observed. The journals APPLIED SCIENCES-BASEL (Impact Factor of 2,679), IFAC PAPERSONLINE (Impact Factor of 1,130), IEEE ACCESS (Impact Factor of 3,367) and FRONTIERS IN NEUROSCIENCE (Impact Factor of 4,501) are those that have more than one publication, while the others have only one publication each.

The analysis of the web of science categories shows that the structuring areas of publications related to the relationship between HM and DT are: engineering, science, computer automation, chemistry, control, materials, physics, systems, telecommunications, neurology, neuroscience and technology. This result, along with the result shown in Figure 7, will allow us to demonstrate the paths for the DT-HM consolidation.

Figure 7 - Most relevant sources of the relationship between HM and DT fields.



Source: Authors.

4. Discussions

The results of the research presented reveal a quantitative and qualitative profile of the 33 articles that constitute the representative database of the relationship between HM and DT. The first topic researched was HM and, based on it, it was possible to determine a set of keywords CHM2 that defined what we call the field of knowledge. The same was done for DT, which was determined by the keywords CDT1. The other CF1 keywords were treated as integration tools between the two fields.

There is still no consolidation of national research groups and international collaborations that represent the application of DT in HM, or even the appropriation of the DT tool for HM processes. This is evidenced by the very low international collaboration (Figure 4 and Figure 5) and by the pulverization of publications in international journals (Figure 7).

China is the most advanced country in terms of number of publications within our database. Of the eight published articles, four are directly related to health and present a way of implementing DT to improve diagnoses (Liu et al, 2019), (Hu et al.,2021), (Pang, Huang, Xie, Li, Cai, 2021), (Wan et al., 2021), mapped in Figure 6 as the connection between the red and yellow clusters. The other works from China provide possible applications manufacturing (Qiao et al., 2019), (Mazhar Shah et al., 2021). service (Zhou et al., 2019) and construction (Hou et al., 2020), of DT that can be used in HM.

Publications linked to Germany, second country in number of publications with a total of five articles, present DT applications in improving the supply chain and logistics. The application to the supply chain seeks to control and mitigate the cascading effect in cases of severe interruption (Ivanov, Dolgui, 2019). In logistics (Wagner et al., 2019), DT is used in the sector of assistance to the dispatch of trucks operator in search of actions that optimize the dispatch by using performance predictions based on computer simulation. Other areas are being explored for DT implementation such as Product Engineering (Hofmann, Branding, 2019) and Manufacturing (Talkhestani et al., 2018). In our analysis, it can be speculated that these applications can be transported to HT practices and processes, whether in the administrative management of resources or in the management of patients.

A German publication from our database (Voigt et al.,2021) applies DT in an innovative way in the treatment of multiple sclerosis. As it is a highly complex and multidimensional disease, DT has proved to be an adequate solution. Through analysis based on artificial intelligence of several disease parameters obtained by pairing a DT with the patient, several characteristics of the disease can be analyzed, allowing health professionals to intervene accurately, contributing to an individual and effective patient-focused care and supporting decision-making.

The Italian and American publications present the same pattern observed above, with elements of industry 4.0 linked to DT and possible transfer of these to HM. Among the Italian publications (Negri et al., 2019), (Macchi, Roda, Negri, Fumagalli, 2018), (Agnusdei et al., 2021), (Schimanski et al., 2019) the work of E. Negri et al. (2019) proposes a DT application for the industry in order to manage the maintenance of scheduling through a structure to include equipment health forecasts and incorporate an Equipment Health indicator module synchronized in a DT simulation field. The proposed architecture can be adapted for HM in the field of predictive therapies for chronical patients and treatments that the framework requires periodic adjustments.

Curiously, North American publications (Madni et al., 2019) (Hu et al., 2018) (Deng, Menassa, Kamat, 2021), (Baskaran et al., 2019) are not part of international collaborations (Figure. 4). American works seek to expand the use of DT in areas such as: applications in model-based system engineering, and the benefits of integrating DT with system simulation and the Internet of Things in support of model-based system engineering; applications aimed at integrating DT in productive systems of manufacturing in cyber-physical cloud in the search for reduction of overheads and saving of resources; applications in an avant-garde area of the civil construction, life cycle of built environments; and, finally, creation of DT for the automotive manufacturing processes seeking not only the pairing of processes but also the human element within the production process.

The articles from the other countries combined follow the same trend as those presented (Zhang et al., 2019), (Sepasgozar et al., 2019), (Pang et al., 2021), (Kaurene et al., 2021), (Singh et al., 2021), (Khajavi et al., 2019), (Bruynseels et al., 2018), (Vrabičet al., 2018), (Armendia et al., 2019), (Pizzolato et al., 2019), (Bányai et al., 2019), (Kuts et al., 2019), the use of new technologies in the implementation of DT in processes, management and service. From our analysis, it is possible to indicate that the consolidation of a wide application of DT in HM undergoes the appropriation and adaptation of the applications that are being carried out and the adjustment to the specificities of HM. Initiatives to integrate medical care management with hospital management through a DT concept were not observed in this analysis. It is possible to say that the hotspot of the DT and HM relationship is the use of DT for diagnosis and treatment follow-up.

5. Final Considerations

This work presented a study of the relationship between the field of knowledge related to the Digital Twin and Health Management, seeking to understand its main axes of development and explore connections between the areas not yet identified. The results obtained indicate: (i) the study of the application of DT in HM has not yet reached an international collaborative development and, among the nations, China is at the forefront of these studies; (ii) the DT in HM applications analyzed are limited to automated diagnoses and monitoring of complex treatments or resource optimization. An application that fully integrates HM was not observed; and (iii) it was identified the existence of DT applications in industry and service processes that can be transported to HM processes with minor adjustments.

This work outlines numerous applications of Digital Twins to be transported to Health Management and, as an extension of this work, it will focus on cataloging processes with potential for immediate application in the integration of HM. An interesting perspective of the results presented is the opportunity for international collaborations with countries that already have consolidated academic relationships, such as the United States of America, Italy and France. This work contributes with markers for the characterization of the critical success factors of the units of the health system and thus facilitating the adoption of measures for the implementation of Digital Twins.

Acknowledgments

This work is part of the Graduate Program in Production Engineering at Universidade Federal Fluminense in collaboration with Centro Universitário Geraldo Di Biase UGB-FERP/PROPPEX and Universidade do Estado do Rio de Janeiro - Faculty of Technology. This article is dedicated in memory of Ademostano Ribeiro and Nanci do Carmo de Oliveira Ribeiro

References

Agnusdei, G. P., Elia, V., & Gnoni, M. G. (2021). Is Digital Twin Technology Supporting Safety Management? A Bibliometric and Systematic Review. *Applied Sciences*, 11(6), 2767. https://doi.org/10.3390/app11062767

Armendia, M., Cugnon, F., Berglind, L., Ozturk, E., Gil, G., & Selmi, J. (2019). Evaluation of Machine Tool Digital Twin for machining operations in industrial environment. *Procedia CIRP*, 82, 231–236. https://doi.org/10.1016/j.procir.2019.04.040

Bányai, Á., Illés, B., Glistau, E., Machado, N. I. C., Tamás, P., Manzoor, F., & Bányai, T. (2019). Smart Cyber-Physical Manufacturing: Extended and Real-Time Optimization of Logistics Resources in Matrix Production. *Applied Sciences*, 9(7), 1287. https://doi.org/10.3390/app9071287.

Barricelli, B. R., Casiraghi, E., & Fogli, D. (2019). A Survey on Digital Twin: Definitions, Characteristics, Applications, and Design Implications. *IEEE Access*, 7, 167653–167671. https://doi.org/10.1109/access.2019.2953499

Barricelli, B. R., Casiraghi, E., Gliozzo, J., Petrini, A., & Valtolina, S. (2020). Human Digital Twin for Fitness Management. *IEEE Access*, 8, 26637–26664. https://doi.org/10.1109/access.2020.2971576

Baskaran, S., Niaki, F. A., Tomaszewski, M., Gill, J. S., Chen, Y., Jia, Y., Mears, L., & Krovi, V. (2019). Digital Human and Robot Simulation in Automotive Assembly using Siemens Process Simulate: A Feasibility Study. *Procedia Manufacturing*, 34, 986–994. https://doi.org/10.1016/j.promfg.2019.06.097

Bruynseels, K., Santoni de Sio, F., & van den Hoven, J. (2018). Digital Twins in Health Care: Ethical Implications of an Emerging Engineering Paradigm. *Frontiers in Genetics*, 9, 31. https://doi.org/10.3389/fgene.2018.00031

Chen, Y. (2017). Integrated and intelligent manufacturing: Perspectives and enablers (Engineering, Ed.; Vol. 3, pp. 588–595) Engineering.

da Silva, A. F. C., de Oliveira Ribeiro, A., de Souza Cruz, B. S., de Almeida, C. P., Costa, K. A., & Sabbadini, F. S. (2022). Análise da integração da indústria 4.0 e economia circular para consolidação do conceito da remanufatura 4.0: um estudo bibliométrico. *Research, Society and Development*, 11(7), e9511729687-e9511729687.

Deng, M., Menassa, C. C., & Kamat, V. R. (2021). From BIM to digital twins: a systematic review of the evolution of intelligent building representations in the AEC-FM industry. *Journal of Information Technology in Construction*, 26, 58–83. https://doi.org/10.36680/j.itcon.2021.005

Ferligoj, A., Kronegger, L., Mali, F., Snijders, T. A. B., & Doreian, P. (2015). Scientific collaboration dynamics in a national scientific system. *Scientometrics*, 104(3), 985–1012. https://doi.org/10.1007/s11192-015-1585-7

Gong, R., Xue, J., Zhao, L., Zolotova, O., Ji, X., & Xu, Y. (2019). A Bibliometric Analysis of Green Supply Chain Management Based on the Web of Science (WOS) Platform. *Sustainability*, 11(12), 3459. https://doi.org/10.3390/su11123459

Grieves, M. (2014). Digital twin: Manufacturing excellence through virtual factory replication: Vol. White Paper 1. NASA.

Hofmann, W., & Branding, F. (2019). Implementation of an IoT- and Cloud-based Digital Twin for Real-Time Decision Support in Port Operations. *IFAC-PapersOnLine*, 52(13), 2104–2109. https://doi.org/10.1016/j.ifacol.2019.11.516

Hou, L., Wu, S., Zhang, G. (Kevin), Tan, Y., & Wang, X. (2020). Literature Review of Digital Twins Applications in Construction Workforce Safety. *Applied Sciences*, 11(1), 339. https://doi.org/10.3390/app11010339

Hu, L., Nguyen, N.-T., Tao, W., Leu, M. C., Liu, X. F., Shahriar, M. R., & Al Sunny, S. M. N. (2018). Modeling of Cloud-Based Digital Twins for Smart Manufacturing with MT Connect. *Procedia Manufacturing*, 26, 1193–1203. https://doi.org/10.1016/j.promfg.2018.07.155

Hu, M., Zhong, Y., Xie, S., Lv, H., & Lv, Z. (2021). Fuzzy System Based Medical Image Processing for Brain Disease Prediction. *Frontiers in Neuroscience*, 15. https://doi.org/10.3389/fnins.2021.714318

Huang, P., Kim, K., & Schermer, M. (2022). Mapping the Ethical Issues of Digital Twins for Personalised Healthcare Service (Preprint). *Journal of Medical Internet Research*. https://doi.org/10.2196/33081

Ivanov, D., & Dolgui, A. (2019). New disruption risk management perspectives in supply chains: digital twins, the ripple effect, and resileanness. *IFAC-PapersOnLine*, 52(13), 337–342. https://doi.org/10.1016/j.ifacol.2019.11.138

Kaewunruen, S., Sresakoolchai, J., Ma, W., & Phil-Ebosie, O. (2021). Digital Twin Aided Vulnerability Assessment and Risk-Based Maintenance Planning of Bridge Infrastructures Exposed to Extreme Conditions. *Sustainability*, 13(4), 2051. https://doi.org/10.3390/su13042051

Khajavi, S. H., Motlagh, N. H., Jaribion, A., Werner, L. C., & Holmström, J. (2019). Digital Twin: Vision, Benefits, Boundaries, and Creation for Buildings. *IEEE Access*, 7, 147406–147419. https://doi.org/10.1109/ACCESS.2019.2946515

Khan, S., Arslan, T., & Ratnarajah, T. (2022). Digital Twin Perspective of Fourth Industrial and Healthcare Revolution. *IEEE Access*, 10, 25732–25754. https://doi.org/10.1109/access.2022.3156062.

Kuts, V., Modoni, G. E., Otto, T., Sacco, M., Tähemaa, T., Bondarenko, Y., & Wang, R. (2019). Synchronizing physical factory and its digital twin through an IIoT middleware: a case study. *Proceedings of the Estonian Academy of Sciences*, 68(4), 364. https://doi.org/10.3176/proc.2019.4.03

Lezzi, M., Lazoi, M., & Corallo, A. (2018). Cybersecurity for Industry 4.0 in the current literature: A reference framework. *Computers in Industry*, 103, 97–110. https://doi.org/10.1016/j.compind.2018.09.004

Liu, Y., Zhang, L., Yang, Y., Zhou, L., Ren, L., Wang, F., Liu, R., Pang, Z., & Deen, M. J. (2019). A Novel Cloud-Based Framework for the Elderly Healthcare Services Using Digital Twin. IEEE Access, 7, 49088–49101. https://doi.org/10.1109/access.2019.2909828

Macchi, M., Roda, I., Negri, E., & Fumagalli, L. (2018). Exploring the role of Digital Twin for Asset Lifecycle Management. *IFAC-PapersOnLine*, 51(11), 790–795. https://doi.org/10.1016/j.ifacol.2018.08.415

Madni, A., Madni, C., & Lucero, S. (2019). Leveraging Digital Twin Technology in Model-Based Systems Engineering. *Systems*, 7(1), 7. https://doi.org/10.3390/systems7010007

Mansoori, P. (2018). 50 years of Iranian clinical, biomedical, and public health research: a bibliometric analysis of the Web of Science Core Collection (1965-2014). *Journal of Global Health*, 8(2). https://doi.org/10.7189/jogh.08.020701

Mazhar Rathore, 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, 1–1. https://doi.org/10.1109/access.2021.3060863

Moshobane, M. C., Khoza, T. T., & Niassy, S. (2021). The period of insect research in the tropics: a bibliometric analysis. *International Journal of Tropical Insect Science*, 42(1), 989–998. https://doi.org/10.1007/s42690-021-00616-2

Negri, E., Ardakani, H. D., Cattaneo, L., Singh, J., Macchi, M., & Lee, J. (2019). A Digital Twin-based scheduling framework including Equipment Health Index and Genetic Algorithms. *IFAC-PapersOnLine*, 52(10), 43–48. https://doi.org/10.1016/j.ifacol.2019.10.024

Pang, J., Huang, Y., Xie, Z., Li, J., & Cai, Z. (2021). Collaborative city digital twin for the COVID-19 pandemic: A federated learning solution. *Tsinghua Science and Technology*, 26(5), 759–771. https://doi.org/10.26599/tst.2021.9010026

Pang, T. Y., Pelaez Restrepo, J. D., Cheng, C.-T., Yasin, A., Lim, H., & Miletic, M. (2021). Developing a Digital Twin and Digital Thread Framework for an "Industry 4.0" Shipyard. *Applied Sciences*, 11(3), 1097. https://doi.org/10.3390/app11031097

Pizzolato, C., Saxby, D. J., Palipana, D., Diamond, L. E., Barrett, R. S., Teng, Y. D., & Lloyd, D. G. (2019). Neuromusculoskeletal Modeling-Based Prostheses for Recovery After Spinal Cord Injury. *Frontiers in Neurorobotics*, 13. https://doi.org/10.3389/fnbot.2019.00097

Popa, E. O., van Hilten, M., Oosterkamp, E., & Bogaardt, M.-J. (2021). The use of digital twins in healthcare: socio-ethical benefits and socio-ethical risks. *Life Sciences, Society and Policy*, 17(1). https://doi.org/10.1186/s40504-021-00113-x

Qiao, Q., Wang, J., Ye, L., & Gao, R. X. (2019). Digital Twin for Machining Tool Condition Prediction. *Procedia CIRP*, 81, 1388–1393. https://doi.org/10.1016/j.procir.2019.04.049

Sarkar, A., Wang, H., Rahman, A., Memon, W. H., & Qian, L. (2022). A bibliometric analysis of sustainable agriculture: based on the Web of Science (WOS) platform. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-022-19632-x

Scharff, S. (2010). From Digital Twin to Improved Patient Experience. (Siemens Healthineers, Ed.) [Review of From Digital Twin to Improved Patient Experience.]. https://www.siemens-healthineers.com/news/mso-digitaltwin-mater.html

Schimanski, Pasetti Monizza, Marcher, & Matt. (2019). Pushing Digital Automation of Configure-to-Order Services in Small and Medium Enterprises of the Construction Equipment Industry: A Design Science Research Approach. Applied Sciences, 9(18), 3780. https://doi.org/10.3390/app9183780

Sepasgozar, S. M. E., Karimi, R., Shirowzhan, S., Mojtahedi, M., Ebrahimzadeh, S., & McCarthy, D. (2019). Delay Causes and Emerging Digital Tools: A Novel Model of Delay Analysis, Including Integrated Project Delivery and PMBOK. Buildings, 9(9), 191. https://doi.org/10.3390/buildings9090191

Singh, M., Fuenmayor, E., Hinchy, E. P., Qiao, Y., Murray, N., & Devine, D. (2021). Digital Twin: Origin to Future. Applied System Innovation, 4(2), 36. https://doi.org/10.3390/asi4020036

Soosaraei, M., Khasseh, A. A., Fakhar, M., & Hezarjaribi, H. Z. (2018). A decade bibliometric analysis of global research on leishmaniasis in Web of Science database. Annals of Medicine and Surgery, 26, 30–37. https://doi.org/10.1016/j.amsu.2017.12.014

Sweileh, W. M., Al-Jabi, S. W., Sawalha, A. F., & Zyoud, S. H. (2014). Bibliometric analysis of nutrition and dietetics research activity in Arab countries using ISI Web of Science database. SpringerPlus, 3(1). https://doi.org/10.1186/2193-1801-3-718

Talkhestani, B. A., Jazdi, N., Schlögl, W., & Weyrich, M. (2018). A concept in synchronization of virtual production system with real factory based on anchor-point method. Procedia CIRP, 67, 13–17. https://doi.org/10.1016/j.procir.2017.12.168

van Eck, N. J., & Waltman, L. (2009). Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, 84(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

Voigt, I., Inojosa, H., Dillenseger, A., Haase, R., Akgün, K., & Ziemssen, T. (2021). Digital Twins for Multiple Sclerosis. Frontiers in Immunology, 12. https://doi.org/10.3389/fimmu.2021.669811

Vrabič, R., Erkoyuncu, J. A., Butala, P., & Roy, R. (2018). Digital twins: Understanding the added value of integrated models for through-life engineering services. Procedia Manufacturing, 16, 139–146. https://doi.org/10.1016/j.promfg.2018.10.167

Wagner, R., Schleich, B., Haefner, B., Kuhnle, A., Wartzack, S., & Lanza, G. (2019). Challenges and Potentials of Digital Twins and Industry 4.0 in Product Design and Production for High Performance Products. Procedia CIRP, 84, 88–93. https://doi.org/10.1016/j.procir.2019.04.219

Wan, Z., Dong, Y., Yu, Z., Lv, H., & Lv, Z. (2021). Semi-Supervised Support Vector Machine for Digital Twins Based Brain Image Fusion. Frontiers in Neuroscience, 15. https://doi.org/10.3389/fnins.2021.705323

Zhang, C., Xu, W., Liu, J., Liu, Z., Zhou, Z., & Pham, D. T. (2019). A Reconfigurable Modeling Approach for Digital Twin-based Manufacturing System. Procedia CIRP, 83, 118–125. https://doi.org/10.1016/j.procir.2019.03.141

Zhou, M. Yan, J. Feng, D. (2019). Digital twin and its application to power grid online analysis. CSEE Journal of Power and Energy Systems. https://doi.org/10.17775/cseejpes.2018.01460

Zyoud, S. H., Waring, W. S., Al-Jabi, S. W., & Sweileh, W. M. (2017). Global cocaine intoxication research trends during 1975–2015: a bibliometric analysis of Web of Science publications. Substance Abuse Treatment, Prevention, and Policy, 12(1). https://doi.org/10.1186/s13011-017-0090-9