Integration of generative AI models and Digital Twin with Lean Manufacturing Principles: Bibliometric study

Mariannys Rodríguez Gasca[1*[0000-0001-7948-6135]], Marcos Alexandre Galdino [2[0000-0003-2454-5964]] and Sanderson César Macêdo Barbalho [1[0000-0003-1664-4866]]

[1] University of Brasilia, Technology Faculty, Research Group in Innovation, Projects and Process - GPIPP, Brasilia DF, Brazil.

[2] WZL | RWTH Aachen University, Chair of Production Metrology and Quality Management & Institute for Information Management in Mechanical Engineering, Aachen, GERMANY.

*mariannys.rgasca@gmail.com

Abstract. The evolution of production systems towards flexibility, customization, and traceability of processes, driven by the demands of the global market, has led companies to adopt technological and organizational tools to improve productivity, boost economic growth, and guarantee industries' sustainability and operational excellence. Industry 4.0 and Lean Manufacturing, although they are two approaches that use different strategies, share common principles and objectives that, combined, seem to satisfy the aforementioned requirements. The article develops a bibliometric study that explores theoretical frameworks and research trends of two specific Industry 4.0 technologies, i.e., generative Artificial Intelligence models and Digital Twin, in Kaizen. The study's objective is to find the existing associations between applications of generative Artificial Intelligence models and Digital Twin and Lean Manufacturing principles focused on kaizen. The results reveal significant contributions from leading countries such as China, the United States, and Germany. Additionally, periods of research growth and prominent authors with diverse interests aligned with the study's focus are identified. Finally, the findings suggest that the concept of digital twin has been progressing in practical applications in the industry, while the concept of generative Artificial Intelligence models is still in a phase where studies focus on analyzing technological solutions.

Keywords: Industry 4.0, Lean manufacturing, Generative Artificial Intelligence Models, Digital Twin, Kaizen, generative models, Bibliometric study.

1 Introduction

The demands of the global market, added to some challenges such as the individualization of customer requirements and the decrease of repetitive tasks, have been driven the evolution of production systems towards increasingly flexible, adaptable, customizable, and traceable processes [1], [2]. As a response to these challenges, the Industry 4.0 (I4.0) paradigm emerged, which has its roots in the idea that companies can establish intelligent networks and autonomously control production modules by interconnecting machines, systems, and assets [3].To make it possible to achieve these objectives, I4.0 provides some technological enablers for new production systems, such as Big Data, Cloud Computing, Artificial Intelligence (AI), Industrial Internet of Things (IIoT), and Cybersecurity [4]. However, to guarantee success in smart manufacturing environments, these technological enablers require a certain degree of maturity in organizational and process terms within the company [4], [5].

Based on that, companies have opted for implementing methodologies that allow greater rationalization of processes and even a contribution to their technology maturity level [6]. In that sense, the techniques associated with the Lean Manufacturing (LM) concept seem to be a logical evolutionary advance to promote I4.0 practices and direct results toward excellence in industrial operation [7]. LM focuses on minimizing losses in manufacturing systems and improving employee satisfaction, communication, and decision-making to maximize productivity [8].

The literature considers a strong interdependence between the I4.0 and LM paradigms. For example, Ciano MP et al. (2020) conducted a multiple case study

investigation to examine the enabling effect of LM on I4.0 and the potentiating effect of I4.0 on LM. When analyzing the results, they found specific effects of I4.0 technologies or characteristics on Kaizen and Teamwork, and, in general, the companies' knowledge supports the idea that the gaming atmosphere led by I4.0 can enhance and make more enjoyable the adoption of all LM techniques and practices [8]. Tortorella & Fettermann (2020) examined the relationship between lean production (LP) practices and implementing Industry 4.0 in Brazilian manufacturing companies. The findings indicated that LP practices are positively associated with I4.0 technologies, and their simultaneous implementation leads to greater performance improvements [9]. Kamble S. et al. (2019) tested the indirect effects of I4.0 on sustainable organizational performance with LM as a mediating variable in Indian manufacturing companies [10].

Similarly, Rossi F. et al. (2019) developed a study analyzing a scenario of European manufacturing companies. According to the findings, achieving higher levels of I4.0 adoption may be easier when LM practices are widely implemented in the company. On the contrary, when processes are not robustly designed, and continuous improvement practices are not established, companies' readiness to adopt novel technologies may be lower [11]. On the other hand, Torre et al. (2023) state that adopting LM combined with I4.0 has improved asset availability and reduced waste in a steel manufacturing plant. This, in turn, has contributed to a substantial decrease of approximately 58.5% in production losses and costs associated with corrective maintenance [12].

In this sense, the utilization of certain Industry 4.0 (I4.0) technologies, such as Artificial Intelligence (AI) and Digital Twin, in manufacturing operations could enhance the aforementioned synergy [13], [14]. This has recently gained further relevance with the potential integration of Generative AI models (GAIM) into manufacturing. GAIM can produce responses resembling human language in response to user queries, drawing on extensive datasets for knowledge acquisition, which is believed to facilitate decision-making by workers [15]. In this context, Digital Twins (DT), characterized by seamless integration between the physical and virtual worlds, could serve as a valuable data source for GAIM [16]. Therefore, the Kaizen philosophy, a fundamental concept of Lean, which promotes a culture of continuous experimentation and learning, could benefit from insights provided by systems incorporating these technologies and drive the continuous improvement process of intelligent industrial systems [17], [18].

This motivated me to carry out this work to understand and analyze the recent evolution in the field of integrating digital twin models and generative artificial intelligence models with continuous improvement methodologies to drive operational excellence in various industries. The importance of identifying emerging trends, current challenges and potential research areas at an early stage is highlighted as a central motivation. For this, a bibliometric study was proposed that explored qualitative and quantitative data from scientific documents published in the last six years on Digital Twin, generative AI, generative model, lean manufacturing, continuous improvements, and Kaizen. The rest of this article is divided into three sections: section 2 details the methodology applied to this study, section 3 presents the most relevant results obtained and discusses the main findings, and section 4 concludes the article.

2 Methodology

This study focuses on developing a bibliometric analysis that allows identifying central research, authors and other characteristics of interest and the relationships between them, detailing quantitative aspects of the topic of interest. This analysis was based on some recommended guidelines to obtain a high-quality review, including bibliographies with characteristics such as newer publication dates, high frequency of citations, and publications with high impact factors Uemura Reche et al. (2020).

2.1 Database Selection

The first step in this bibliometric analysis was the platform or database selection to extract a collection of scientific papers related to a subject. As such, the platforms and databases used in this article were Elsevier’s Scopus and Clarivate’s Web of Science

databases. These databases were chosen because they are reliable sources of worldwide scientific documents and have many publications indexed.

2.2 Search Protocol

Following the platform and database selection, defining a query string that relates keywords associated with the subject of interest is essential. It is also done through the search engines made available by selected platforms. In this case, the query string is constructed by assembling a set of words connected to operators (AND and OR). In addition to these operators, the query string was also instructed to return documents that included the search terms in their structure (Title, Abstract, or Keywords). The resulting constructed query string was:

TITLE-ABS-KEY("generative artificial intelligence" OR "generative model" OR "digital twin") AND TITLE-ABS-KEY("lean manufacturing" OR "kaizen" OR continuous improvement).

The objective of the research was to explore the panorama of the last six years on the antecedents of synergy between kaizen of Lean Manufacturing and industry 4.0 technologies, specifically the generative models of artificial intelligence and digital twin, for the operational excellence of the industries.

2.3 Filtering

Once the search protocol was defined, it was necessary to establish the inclusion criteria for selecting the documents. The resulting search string amounted to 358 documents after applying the inclusion filter of only articles published between 2018 and 2023. This period was selected because I wanted to limit the research to capturing the most recent technological developments in the field of study to gain an up-to-date understanding of trends and developments. Limiting the research to this period of time also facilitates the analysis and interpretation of the data by not covering an excessive amount of information. Of these documents, 176 came from the Scopus database and 182 from Web of Science. Then, bibliometric software called Data Blend Pro was used, combining the results from the two databases and eliminating duplicate documents, resulting in 274 documents.

2.4 Bibliometric Analysis

The selected articles extracted information of statistical interest, such as authors, periodicals of publication, year of publication, country of origin, citations, and occurrence of keywords, among other data capable of contributing to a bibliometric study. First, the analysis begins with the number of publications per year and documents by country or territory. Then, the ten most cited documents were classified using the bibliometric software mentioned above, which facilitates extracting information from two documents due to the volume of data. This is to identify the impact and importance of individual articles. Finally, a qualitative analysis was carried out using the bibliometric software VOSviewer. Such analysis helps identify patterns and trends in given data, highlighting the most relevant information, such as networks of words and the most influential authors. This analysis of bibliometric maps was also used to establish categories that represented the main trends in the lines of research in the the selected documents. It is believed that the results obtained through this exploration can be used to promote research and guide decision-making in this field of study.

3 Results

The main findings related to the proposed methodology are discussed in this section. The results of the 274 documents provide quantitative and qualitative information on the topic studied and an overview of the development between 2018 and 2023.

3.1 Evolution of publication by year

Figure 1 shows how the number of documents published on the topic has behaved from 2018 to 2023. It was observed that during this period the number of publications has always been increasing. However, the highest growth percentage occurred from 2019

to 2020 and from 2022 to 2023. In addition, 2023 has been the year in which the most publications have been made, with 86 documents out of the total of 275 analyzed.

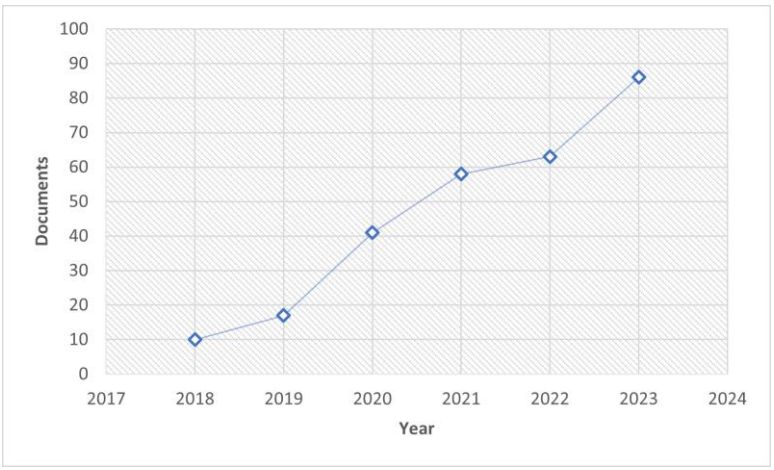

Fig. 1. Evolution of publication between 2018-2023

This graph suggests that since 2020, research on the synergy between generative artificial intelligence, digital twins, and continuous improvement has gained great relevance. It could even be said that the significant increase in publications observed in 2023 could be influenced by the launch of ChatGPT in November 2022 because it triggered the possibility of incorporating Generative AI models (GAIM) in manufacturing, engineering, and business management [13].

3.2 Publication by Country/territory

Figure 2 shows the distribution of documents according to the geographical location from which the scientific contributions studied came. As a geographical location, the affiliation of the authors and co-authors for each document was taken as a reference. To construct this graph, the first ten countries with the most publications were selected from 46 countries that contributed at least one publication. The minimum number for classification was eight publications.

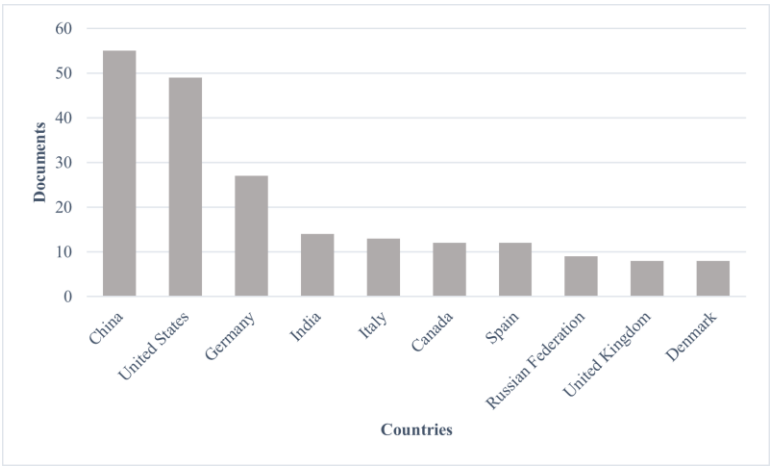

Fig. 2. Number of publications by country (Affiliations)

As seen in Figure 2, China leads the chart with 19% (56 documents) of all articles, followed by the United States with 16% (49 documents) and Germany with 9% (27 documents). These three are responsible for 44% of all documents in the collection. The remaining 56% is divided between other countries: Italy, Canada, Spain, Russia, United Kingdom, Denmark, Brazil, South Korea, Japan, France, Finland, Austria, Poland, Netherlands, Australia, Norway, Portugal, Malaysia, Israel, Marocco, Ireland, Sweden, United, Arab Emirates, Slovenia, Vietnam, Pakistan, Romania, Saudi Arabia, Belgium, Malta, Oman, South Africa, Grecia, Latvia, Estonia, Mexico, Hungary,

Taiwan, Colombia, Egypt, Croatia, Iceland, Nigeria, North Macedonia. Although Brazil does not appear in the graph of the ten countries with the most contributions in the study area, it has published a total of 6 documents, which is equivalent to 2% of the total production of the analyzed collection. Regarding collaboration links between countries, it was observed that Germany, the United States, and France tend to collaborate on publications with other countries.

3.3 Author analysis

For the analysis of authors, the ones with more than one document in the total collection were selected to identify the most relevant authors in the area. Figure 3 shows a bar graph that organizes the authors with the most documents from left to right. In addition, it also shows the number of citations each of these authors obtained with those publications within the two databases analyzed.

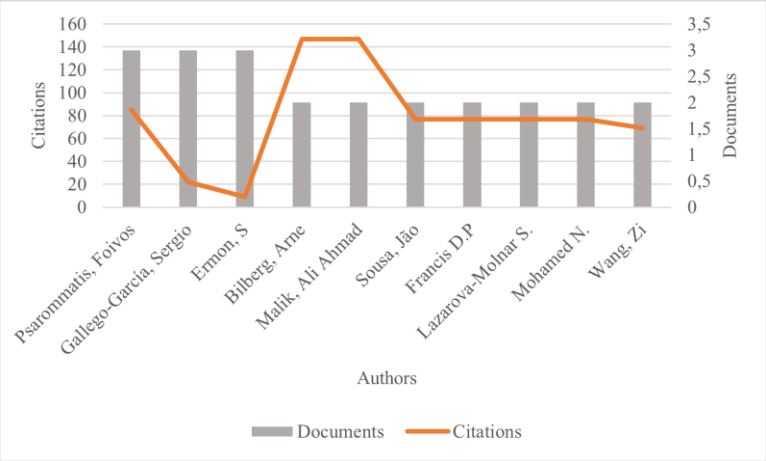

Fig. 3. Graph of the top 10 most relevant authors

Figure 3 shows that although the collection of documents obtained with our search protocol was significant, the number of individual publications in the author network is quite limited, with three being the largest number of documents by the author. The one who leads the group with the most documents related to the searched topic has been "Psarommatis, Foivos" with three publications in the last six years, adding up to 85 in SCOPUS and Web of Science.

After analyzing the research profile of each of these authors, we found some trends related to the study of applications of artificial intelligence, digital twin, robots, machine learning, and data analysis for the management of manufacturing systems and processes, supply chain, quality assurance, schedule, factories of the future and product innovation.

3.4 Publications by citation

The ten most cited articles correspond to just over 50% of the total citations in the collection. The observed metrics associated with each article are shown in Table 3. Within these ten selected documents, 5 are research articles, 3 are conference papers, and 2 are reviews. The journals in which these documents were published have a high impact factor, and most fit into quartile 1, according to the Scimago Journal Ranking classification.

Table 1. Top 10 most cited documents in the collection

Authors	Title	N. Citations	Source
Barricelli B.R.; Casiraghi E.; Fogli D.	Survey on digital twin: Definitions, characteristics, applications, and design implications.	578	IEEE Access
Nweke, HF; Teh, YW; Al-Garadi, MA; Alo, UR	Deep learning algorithms for human activity recognition using mobile and wearable sensor networks: State of the art and research challenges.	478	EXPERT SYSTEMS WITH APPLICATIONS
Belghazi M.I.; Baratin A.; Rajeswar S.; Ozair S.; Bengio Y.; Courville A.; Hjelm R.D.	Mutual information neural estimation	199	35th International Conference on Machine Learning, ICML 2018
Malik A.A.; Bilberg A.	Digital twins of human-robot collaboration in a production setting	125	Procedia Manufacturing
Sacks, R ; Brilakis, I; Pikas, E ; Xie, HS ; Girolami, M	Construction with digital twin information systems	123	DATA-CENTRIC ENGINEERING
Kingma D.P.; Salimans T.; Poole B.; Ho J.	Variational Diffusion Models	101	Advances in Neural Information Processing Systems
Ciano, MP; Dallasega, P; Orzes, G; Rossi, T	One-to-one relationships between Industry 4.0 technologies and Lean; Production techniques: a multiple case study	91	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH
Ramu S.P.; Boopalan P.; Pham Q.-V.; Maddikunta P.K.R.; Huynh-The T.; Alazab M.; Nguyen T.T.; Gadekallu T.R.	Federated learning enabled digital twins for smart cities: Concepts, recent advances, and future directions	90	Sustainable Cities and Society
Psarommatis, F; Sousa, J; Mendonça, JP; Kiritsis, D	Zero-defect manufacturing the approach for higher manufacturing; sustainability in the era of industry 4.0: a position paper	77	INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH
Friederich J.; Francis D.P.; Lazarova-Molnar S.; Mohamed N.	A framework for data-driven digital twins for smart manufacturing	71	Computers in Industry

Analyzing the content of these ten publications in more detail, we observed some trends among the key terms used. Regarding technologies, terms such as artificial intelligence, digital twin, internet of things, machine learning, deep learning, assembly system, generative models, and simulation appear together in these documents. On the other hand, the applications involve supervised learning, zero defect manufacturing, quality assurance, quality improvement, quality management, sustainable manufacturing, and the study of applications that involve the concept of Lean, which is also highlighted.

Additionally, among the authors of these 10 most cited documents, the appearance

of "Psarommatis, Foivos", "Francis D.P", "Lazarova-Molnar S", "Mohamed N.", "Sousa, J", "Bilberg, Arne " and "Malik, Ali Ahmad" who are part of the list of the 10 most relevant authors according to their number of contributions, corroborating the findings shown above. Furthermore, this analysis shows us other names to be considered as relevant authors since citations can also indicate the importance and quality of the research.

3.5 Keyword Occurrence

A keyword co-occurrence map is built using the data collected to find the most frequent keywords correlated to the terms applied in the initial search. This keyword co-occurrence map was built with a minimum number of keyword occurrences set to 5. This first analysis covers the last six years, from 2018 to 2023. As shown in Figure 4, the node size is proportional to the number of keyword occurrences, while the links represent the times some words have been used together. The colors of the nodes represent clusters of the terms that appear together in the documents analyzed a greater number of times. From this map, a reconstruction of the most frequently used author keywords can be obtained, detailing mainly the query search terms described in Section 2.2 and keywords often used alongside them, revealing current research trends and topics of interest.

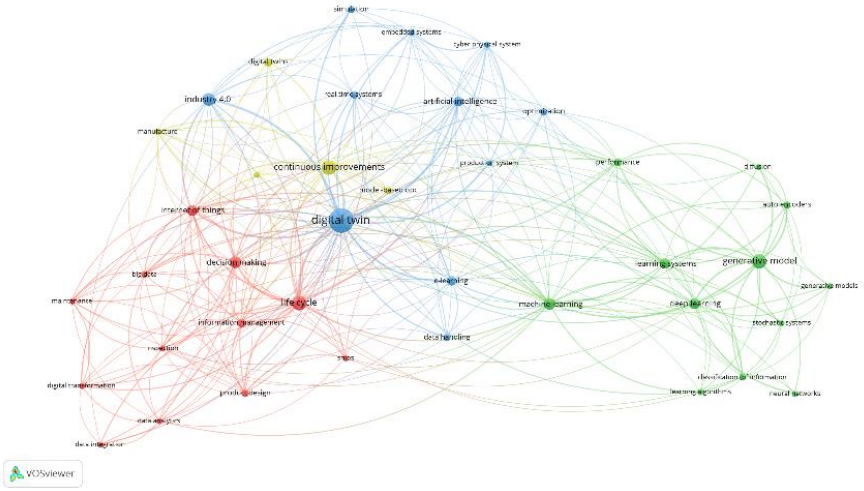

Fig. 4. Network graph of keyword occurrences

These keywords were selected based on their presence in documents from both the Scopus and Web of Science databases. Based on these co-occurrence relationships, the related keywords can be grouped into four groups, as presented in Table 2. The first group covers data management and analysis concepts, decision-making, digital transformation, and process optimization. The second group comprises keywords related to design, manufacturing, and management of products throughout their life cycle, focusing on maintenance and inspection. The third group encompasses a variety of concepts related to machine learning and data modeling. It includes aspects such as developing and applying machine learning algorithms, such as neural networks, learning algorithms, machine learning systems, autoencoders, and generative models. Finally, the fourth group encompasses a variety of concepts related to integrating advanced technologies in production and business management processes, focusing on improving efficiency, automation, and decision-making in production and manufacturing environments.

Table 2. Keyword Cluster Trends

Category	Keywords	Search query keywords with a link
Data and Process Management	Big data, data analytics, integrations, decision-making, digital transformation, information management, maintenance, and inspection.	Digital Twin, Continuous Improvement
Engineering and Product Life Cycle Management	Life cycle, maintenance, inspection, product design, ships, manufacture, architectural design, model-based OPC.	Digital Twin, Continuous Improvement
Learning and Modeling Technologies	Deep learning, learning systems, neural networks, learning algorithms, autoencoders, diffusion, machine learning, performance, stochastic systems.	Generative Model, Continuous Improvement, Digital Twin
Advanced Production Systems	Industry 4.0, simulation, real-time systems, production system, optimization, internet of things, embedded system, e-learning, data handling, cyber-physical system, artificial intelligence	Digital Twin, Continuous Improvement

These four groups suggest lines of research that relate generative and digital twin models with applications focused on the continuous improvement of industrial systems. The keywords related to each category, which are generally part of the same cluster, are shown, except the second category, which covers terms from the yellow and red clusters. The search query keywords are placed separately to analyze their relationship with each category. We observed that the term Digital Twin has links with all categories. However, it was observed that it is not related to all the terms in the "Learning and Modeling Technologies" category, especially since it does not seem to have any link with the term generative model.

Regarding the term continuous improvement, it was also observed that it has links with keywords from all categories. However, particularly with the category "Learning and Modeling Technologies," it has only appeared with the terms generative model and learning systems. Finally, the term generative model is the one that has the fewest links with keywords of the research categories identified within the network of occurrences. It is only related to artificial intelligence, optimization, and continuous improvement.

The term "Kaizen," despite being one of the keywords used for the search, had only five appearances, so it does not appear in the analyzed network of occurrences. Similarly, the term "Lean Manufacturing" had less than five occurrences. However, it was observed that other similar terms appeared, such as Lean production, Lean automation, lean 4.0 production, Lean thinking, and Lean assembly. Furthermore, a strong relationship was observed between these keywords and digital twins for applications in production systems.

It is also important to highlight that the term generative models is mostly concentrated in 2023, with a few occurrences in previous periods. The term digital twin could have been constant in almost all the analyzed periods. Furthermore, this graph allows us to corroborate that the studies associated with the term generative model are more focused on exploring technological solutions for improving the concept. In contrast, the studies associated with digital twins explore applications for the industry more broadly.

4 Conclusions

This article presented a bibliometric study based on the analysis of documents from two databases (Scopus and Web of Science. The study identified important publications

related to the concept and applications of digital twin and generative Artificial Intelligence models in conjunction with continuous improvement methodologies for the operational excellence of industries. It also identified the most frequently used keywords related to the main query terms, mapping research from the last 6 years and related areas of interest, and challenges and approaches currently under investigation by academia. It provides opportunities to address vacancies in research areas in their early stages and highlights the trends and greatest contributions to date.

In addition, this study allowed us to identify that China, the United States, and Germany are, to date, the countries that have contributed the most with publications related to the keywords of this research, and we were able to observe the percentage of their contributions from the total documents in the analyzed collection.

The behavior of publications was analyzed from 2018 to 2023, and it was observed that there were two moments between 2019 and 2020 and 2022 and 2023 in which the growth of research increased compared to the others. years. This suggests that the emergence of new technology releases, such as Chat GPT, may have influenced this trend and attracted greater interest. However, it should be mentioned that this specific term did not have many occurrences within the documents analyzed.

The research also allowed us to identify a group of authors with relevant contributions. In this sense, an important observation is that the number of publications by each author has been quite limited, with three documents being the largest contribution per author, which the search protocol can explain. However, when analyzing the profiles of the group of relevant authors, it was possible to corroborate their wide range of research, mostly with topics related to the area of interest of this study. The profile of the authors suggests possible fields of application or lines of research that can be explored with the search keywords.

In other matters, it was possible to identify the terms that have been most frequently associated with the search keywords in the analyzed research. The clusters of keyword occurrences suggest lines of research focused on analyzing and managing data and processes to support decision-making within production systems. Life cycle management is also a strong trend of applications related to these Industry 4.0 technologies, especially the Internet of Things, big data, and digital twins. The integration of advanced technologies in production processes and business management focuses on improving efficiency and automation in production and manufacturing environments. It also highlights applications focused on supervised learning, zero defect manufacturing, quality assurance, quality improvement, quality management, sustainable manufacturing, and the study of various applications that involve the concept of Lean, mainly associated with the use of digital twins. Finally, the findings suggest that the concept of digital twins has a greater advance in terms of practical applications for implementations in the industry, while the concept of generative models is still in a phase where studies focus on analyzing associated technological solutions. to improve the concept.

The main contribution is a vision of the trends and significant contributions in the field of study during the last six years, as well as the emerging research areas and the practical applications of the analyzed concepts.

Limitations of this work include the exclusion of additional data sources beyond Scopus and Web of Science, which could have limited the comprehensiveness of the bibliometric analysis. Furthermore, restricting the study period to the last six years may have excluded relevant research prior to this period. Threats to the validity of this work include the possibility of bias in the selection of documents and the interpretation of results, as well as the limitation in the bibliometric metrics used. Can suggest for research future incorporate other databases into our sample or utilize some standardized protocols, such as PRISMA. Some practical frameworks to incorporate generative AI models into digital twins can also be proposed, or even as a tool for lean manufacturing programs once industry-based applications are lacking in current scientific literature.

References

1. A. Luque, M. E. Peralta, A. de las Heras, and A. Córdoba, "State of the Industry 4.0 in the Andalusian food sector," Procedia Manuf, vol. 13, pp. 1199–1205, 2017, doi: 10.1016/j.promfg.2017.09.195.
2. S. Thamm et al., "Concept for an augmented intelligence-based quality assurance of assembly tasks in global value networks," Procedia CIRP, vol. 97, pp. 423–428, 2021, doi:

10.1016/j.procir.2020.05.262.
3. G. R. D. N. Martins, L. F. P. Ramos, E. F. R. Loures, V. A. dos Santos, L. M. B. do Amaral, and F. Deschamps, “Prioritization of Industry 4.0 Technologies to Increase Maturity in Lean Manufacturing from the Perspective of Enterprise Interoperability,” 2023, pp. 379–386. doi: 10.1007/978-3-031-17629-6_39.
4. B. Felippes, I. da Silva, S. Barbalho, T. Adam, I. Heine, and R. Schmitt, “3D-CUBE readiness model for industry 4.0: technological, organizational, and process maturity enablers,” Prod Manuf Res, vol. 10, no. 1, pp. 875–937, Dec. 2022, doi: 10.1080/21693277.2022.2135628.
5. I. A. da Silva, S. C. M. Barbalho, T. Adam, I. Heine, and R. Schmitt, “Industry 4.0 Readiness: a new framework for maturity evaluation based on a bibliometric study of scientific articles from 2001 to 2020,” DYNA (Colombia), vol. 88, no. 218, pp. 101–109, Jul. 2021, doi: 10.15446/dyna.v88n218.92543.
6. F. Rosin, P. Forget, S. Lamouri, and R. Pellerin, “Impacts of Industry 4.0 technologies on Lean principles,” Int J Prod Res, vol. 58, no. 6, pp. 1644–1661, Mar. 2020, doi: 10.1080/00207543.2019.1672902.
7. K. Ejsmont, B. Gladysz, D. Corti, F. Castaño, W. M. Mohammed, and J. L. Martinez Lastra, “Towards ‘Lean Industry 4.0′ – Current trends and future perspectives,” Cogent Business & Management, vol. 7, no. 1, p. 1781995, Jan. 2020, doi: 10.1080/23311975.2020.1781995.
8. M. P. Ciano, P. Dallasega, G. Orzes, and T. Rossi, “One-to-one relationships between Industry 4.0 technologies and Lean Production techniques: a multiple case study,” Int J Prod Res, vol. 59, no. 5, pp. 1386–1410, Mar. 2021, doi: 10.1080/00207543.2020.1821119.
9. G. L. Tortorella and D. Fettermann, “Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies,” Int J Prod Res, vol. 56, no. 8, pp. 2975–2987, Apr. 2018, doi: 10.1080/00207543.2017.1391420.
10. S. Kamble, A. Gunasekaran, and N. C. Dhone, “Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies,” Int J Prod Res, vol. 58, no. 5, pp. 1319–1337, Mar. 2020, doi: 10.1080/00207543.2019.1630772.
11. M. Rossini, F. Costa, G. L. Tortorella, and A. Portioli-Staudacher, “The interrelation between Industry 4.0 and lean production: an empirical study on European manufacturers,” The International Journal of Advanced Manufacturing Technology, vol. 102, no. 9–12, pp. 3963–3976, Jun. 2019, doi: 10.1007/s00170-019-03441-7.
12. N. Torre, C. . Leo, and A. Bonamigo, “Lean 4.0: An analytical approach for hydraulic system maintenance in a production line of steel making plant.,” International Journal of Industrial Engineering and Management, vol. 14, no. 3, pp. 186–199, 2023.
13. A. K. Dogru and B. B. Keskin, “AI in operations management: applications, challenges and opportunities,” Journal of Data, Information and Management, vol. 2, no. 2, pp. 67–74, Jun. 2020, doi: 10.1007/s42488-020-00023-1.
14. M. Bordukova, N. Makarov, R. Rodriguez-Esteban, F. Schmich, and M. P. Menden, “Generative artificial intelligence empowers digital twins in drug discovery and clinical trials,” Expert Opin Drug Discov, vol. 19, no. 1, pp. 33–42, Jan. 2024, doi: 10.1080/17460441.2023.2273839.
15. A. Bandi, P. V. S. R. Adapa, and Y. E. V. P. K. Kuchi, “The Power of Generative AI: A Review of Requirements, Models, Input–Output Formats, Evaluation Metrics, and Challenges,” Future Internet, vol. 15, no. 8, p. 260, Jul. 2023, doi: 10.3390/fi15080260.
16. Q. Xu, G. Zhou, Z. Chao, F. Chang, Y. Cao, and D. Zhao, “Generative AI and digital twin integrated intelligent process planning：A conceptual framework,” he International Journal of Advanced Manufacturing Technology, 2023.
17. C. Angulo, A. Chacón, and P. Ponsa, “Towards a cognitive assistant supporting human operators in the Artificial Intelligence of Things,” Internet of Things, vol. 21, p. 100673, Apr. 2023, doi: 10.1016/j.iot.2022.100673.
18. H. Abdulmouti, “Benefits of Kaizen to Business Excellence: Evidence from a Case Study,” Industrial Engineering & Management, vol. 07, no. 02, 2018, doi: 10.4172/2169-0316.1000251