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a bibliometric analysis

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Applications of Cobots in manufacturing: A bibliometric analysis

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ABSTRACT

In recent years, Collaborative Robots (Cobots) have gained traction. It is categorized as a special type of robot that is capable of working safely alongside humans. Cobots are used in a variety of industrial applications, including assembling, manufacturing, quality inspection, and packaging products. Cobots use smart technologies to work alongside humans, making work easier and more efficient. The presented research deeply explores the emerging field of human-robot collaboration, particularly focusing on Cobots and their integration into manufacturing, production planning, and control. It discusses the prevailing perceptions of Cobots while highlighting their potential benefits in enhancing workplace efficiency and safety. We explored the Scopus database in the initial phase and applied inclusion and exclusion criteria to obtain the relevant research articles. Next, a bibliometric analysis was performed via VosViewer and the R Package-Biblioshiny to investigate trends, patterns, and key research focus areas. This study reveals a growing interest in Cobots, emphasizing their applications in various industrial settings. Notable findings include distinctions between traditional robots and Cobots, the evolution of Cobots technology, and prevalent research themes such as production control, planning, human-robot collaboration, and Industry 5.0. To conclude, the presented study discusses theoretical, practical implications, and future scope of research.

1. Introduction

Rapid development and technological innovations have tremendously affected manufacturing processes (Hang and Chen, 2021; Liu and Son, 2024). In today's market landscape, industries must be highly agile and flexible to respond to changing customer requirements. In this context, human-robot collaboration is an innovative research discipline that strives to create a context where humans and robots may work together safely and effectively to accomplish a task. This field introduces a novel type of robot, i.e., collaborative robots (Cobots). Simões et al. (2020) analyzed the factors that impact managers' intentions to adopt Cobots in manufacturing firms. The authors divide the factors into three major categories: internal, external, and technological. The first Cobot was introduced in 1996 by Prof. J.E. Colgate and Prof. Peshkin 1996 (Javaid et al., 2022), which could automate and expedite repetitive industrial processes. The advantage of Cobots over Robots is that the former can work in proximity with employees without requiring a safety fence. Cobots are a key driver in the fourth industrial revolution, enhancing safety and operational efficiency (Faccio and Cohen, 2024). Cobots find applications in a variety of industries, including healthcare (Rahman et al., 2024), manufacturing

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(Javaid et al., 2022), construction (Reinhardt et al., 2020), and electronics (Bogue, 2023). Djuric et al. (2016) and El Makrini et al. (2018) discussed that Cobots contain features of both Robots and Humans: strength and endurance like Robots, and decision-making abilities like Humans. In addition, Bi et al. (2021) discussed that, as robots cannot make critical decisions, Cobots have the advantage of being highly responsive, agile, and adaptive. Additionally, traditional robots are considered unsafe and operate behind fences (Bharti and McGibney, 2022). To address these issues, Cobots are attracting attention worldwide. Additionally, Bi et al. (2021) stated that the usage of Cobots has risen exponentially in recent years, and the market size is estimated to be \$649 million, with a 45 % growth rate. Additionally, Statista reports (2024) revealed that the market's value is \$1.2 trillion, which is expected to increase many-fold quickly, reaching over \$7 billion by 2030.

Additionally, Bharti and McGibney (2022) reported that Cobots are receiving attention because of their reduced costs, increased programming simplicity, and easier installation capabilities. Keshvarparast et al. (2024) conducted a systematic literature review (SLR), discussed the applications of Cobots in manufacturing and assembly processes, and categorized the research studies into three areas: design, programming, and operation. Moreover, Cobots are equipped with features that enable accessible communication because they are meant to work alongside human employees. While traditional robots require complex computer programming abilities, Cobots are easy to program. Cobots can manage a variety of tasks, including machining (Liu and Son, 2024), palletizing & packaging (Comari et al., 2022), assembling (Keshvarparast et al., 2024), and much more. Moreover, Cobots are an ideal option for carrying out various tasks and other automated services due to their high flexibility, reduced size, and weight. Additionally, Cobots handle a variety of labour-intensive and repetitive duties, freeing human operators to work on more innovative and creative tasks. Amirnia and Keivanpour (2024) used reinforcement learning to enhance the feedback quality of Cobots in the disassembly process, hence facilitating robust decision-making capabilities.

In a globalized market landscape, improving efficiency, optimizing resources, and increasing market share have become urgent (Chand et al., 2024). A study by Liu and Son (2024) discussed that Cobots enhance profitability and investment returns. Cobots are expected to reach \$603.8, with a 47.2 % compound annual growth rate from 2021 to 2026 (Bhat, 2023). Most manufacturing industries are looking to deploy Cobots in the coming years. Maruti Suzuki, an automobile manufacturer, plans to open a gigafactory, promoting technological innovations along with sustainability (Barooah and Hussain, 2024). The Cobots will be used to monitor and control the production system. Moreover, according to Kupper et al. (2022), Cobots can sense more nuanced alterations in response to human movements, allowing them to attain high speed even in the presence of nearby humans. Therefore, the research questions are as follows:

- RQ1.** What are the publication trends, most influential publications, top contributing authors, and countries publishing in Cobots?
- RQ2.** How have the Cobots' applications evolved in the scholarly literature?
- RQ3.** What are the future research directions for adopting Cobots?

This study is the first attempt to conduct a bibliometric analysis of the applications of Cobots in industrial settings. Also, it identifies existing research gaps by reviewing the scholarly literature and discusses the scope of future work. The remaining sections of the paper are as follows: Section 2 presents the research methodology, Section 3 presents the analysis and results, and Section 4 discusses the application of Cobots. Section 5 presents implications and future scope, followed by conclusions in Section 6.

2. Research methodology

The research methodology is bifurcated into three steps.

2.1. Step 1: Literature search

The research articles were explored using the Scopus database because it conforms to the required standards and indexing, and it is quite comprehensive (Kumar et al., 2021). Moreover, it is the preferred research database for performing bibliometric analysis (Donthu et al., 2021). Additionally, Baas et al. (2020) reported similar findings and noted that Scopus is one of the highest quality databases for extracting bibliometric data. Moreover, Scopus research databases provide wider coverage and comprehensive indexing (Pham-Duc et al., 2023). The Boolean operators used were “OR”, “AND”, and “*”. The study analyses the Scopus data retrieved using various keywords, i.e., “Cobot” OR “Cobots” OR “Humanoid” OR “Robot*” OR “human centric*” OR “robot-assisted*” OR “work-force-augmentation” OR “Collaborative-robot” OR “Human-in-the-Loop” OR “Human-Robot Collaboration” AND “manufacturing*”. The data is analyzed using bibliometric tools with the help of “R package- Biblioshiny” and “VosViewer”.

2.2. Step 2: Setting criteria for inclusion and exclusion

To finalize the research database, we used inclusion and exclusion criteria. We considered only scholarly research articles in the initial phase and screened conference proceedings, book chapters, blogs, and magazine articles. Additionally, research papers published in languages other than English were not considered. Moreover, we analyzed the articles thoroughly, primarily from a business management perspective.

2.3. Step 3: Tools used for analysis

Bibliometrics is a renowned method for mapping science (Khanuja et al., 2024). Moreover, bibliometric studies have the advantage of overcoming sample selection bias in systematic literature studies (Khan et al., 2022). Also, bibliometric analysis helps analyze both quantitative and qualitative aspects of scholarly literature.

Fig. 1 presents the study structure, where we analyzed performance and scientific diagramming. The performance analysis assessed several common factors, such as the publication pattern, leading contributing journals, leading authors, and top contributing institutions, co-occurrence of keywords, and much more. The automation industry has been completely transformed by Cobots, the most powerful type of robot technology. As previously stated, "Cobot" derives from the term "collaborative robot." These robots can work safely with humans. This is possible because the Cobots are fitted with built-in safety features. Moreover, Adriaensen et al. (2022) discussed the socio-technical safety aspects of deploying Cobots, which facilitate the design of human factors and trigger aspects for training and development.

Most scholarly literature highlights the anticipated barriers and makes significant contributions to this domain. Additionally, the following research gaps have been identified: lack of comprehensive integration of Cobots in Industry 5.0 context, lack of interdisciplinary studies to overcome issues of Cobots integration, and lack of legal and ethical solution frameworks (Rahman et al., 2024). Therefore, a bibliometric analysis will examine various aspects, including overall publication patterns, trends, key research studies, and key authors. Additionally, the present study highlights the scope for future researchers, providing budding researchers and practitioners with food for thought to work in this direction. Moreover, literature review studies help to explore this area and obtain deep insights into theoretical contributions (Patriotta, 2020).

Furthermore, Post et al. (2020) discussed the power of reviewing articles in theory advancement, encouraging researchers to explore innovative and creative ideas in a particular domain. In our analysis, to confirm the inter-rater reliability of article inclusion and exclusion, Krippendorff's alpha (K-alpha) was used (Marzi et al., 2024). For this purpose, the articles were coded after going through the full-length text, and the value of K-alpha was computed as 0.8124.

3. Analysis and findings

The present research selected 360 articles for final analysis based on keywords and applying filters. To answer RQ1 (What are the publication trends, most influential publications, top contributing authors, and countries publishing in Cobots?), we assessed publication patterns year-wise and country-wise. Also, we analyzed the top contributing authors and institutions.

3.1. Publication pattern

As shown in Fig. 2, the number of publications is increasing rapidly in the domain of Cobots. In 2024, the highest number of articles was recorded (60), compared to the previous year, which showed a 62 % increase. Therefore, there has been a sharp increase in publications, particularly during the last five years, although there was a slight slowdown from 2001 to 2014. Ciccarelli et al. (2024) reported that applying Cobots in handicraft manufacturing minimizes work-associated risk while maximizing overall organizational performance. Similarly, a study by Huang et al. (2023) reported that Cobots enhance productivity and improve ergonomic aspects; moreover, the authors optimize the usage of Cobots on the production line, thus maximizing their utilization. Another similar study by Riedelbauch et al. (2023) discussed how cognitive load causes stress and anxiety, significantly impacting productivity and performance; therefore, it must be considered while designing Cobots.

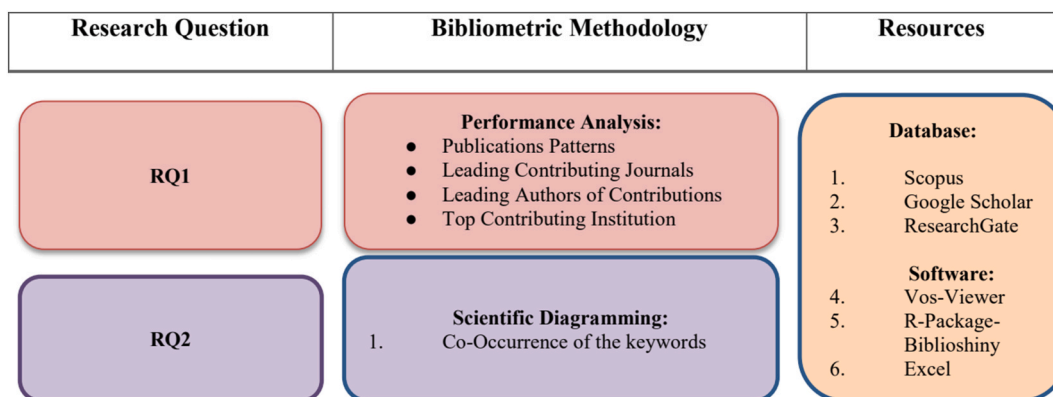


Fig. 1. Structure of the study.

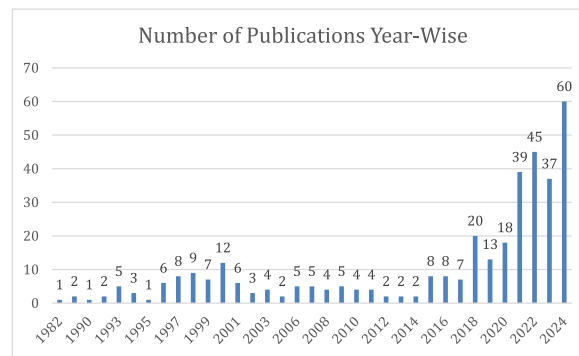


Fig. 2. Number of publications year-wise.

3.2. Top contributing journals

As shown in Fig. 3, the top contributing journals are robotics and autonomous systems, *Robots and Computer Integrated Manufacturing* (56 articles), *International Journal of Advanced Manufacturing Technology* (39 articles), *International Journal of Production Research* (32 articles), *Journal of Manufacturing Systems* (29 articles), *Industrial Robot* (27 articles), *IEEE Robotics and Automation Letters* (23 articles), *Computers and Industrial Engineering* (21 articles), *IEEE Transactions on Automation Science and Engineering* (21 articles), *IEEE Access* (18 articles), *International Journal of Computer Integrated Manufacturing* (15 articles), *Journal of Intelligent Manufacturing* (12 articles), *Manufacturing Letters* (11 articles), *IEEE/ASME Transactions on Mechatronics* (9 articles), *Journal of Mechanisms and Robotics* (9 articles), *IEEE Transactions on Robotics* (8 articles), *IEEE Transactions on Robotics and Automation* (8 articles), *International Journal of Production Economics* (8 articles), *Advanced Robotics* (7 articles), and *Computers in Industry* (7 articles). A study by Djogdom et al. (2024) reported that the use of Cobots reduces work-related musculoskeletal disorders (WMSD) and optimises production processes. Moreover, Chand et al. (2024) discussed that the advent of Industry 5.0 shifted from system-centric to human-centric manufacturing systems, resulting in increased sustainability and resilience.

As illustrated in Fig. 4, the analysis of documents by subject area reveals the distribution of published papers across various disciplines. Engineering papers represent the highest percentage, accounting for 32.4 % of the total publications, followed by Computer Science at 25.9 %. Conversely, the subject area with the lowest percentage of published papers is Energy, contributing only 2.3 %, with other fields comprising the remainder.

As shown in Table 1, the research paper concerning Cobots in manufacturing includes a timespan from 1982 to 2024. The paper was from 59 sources, with an annual growth rate of 10.24 %. The average number of citations per doc is 35.75, which signifies that the importance of Cobots is continuously increasing.

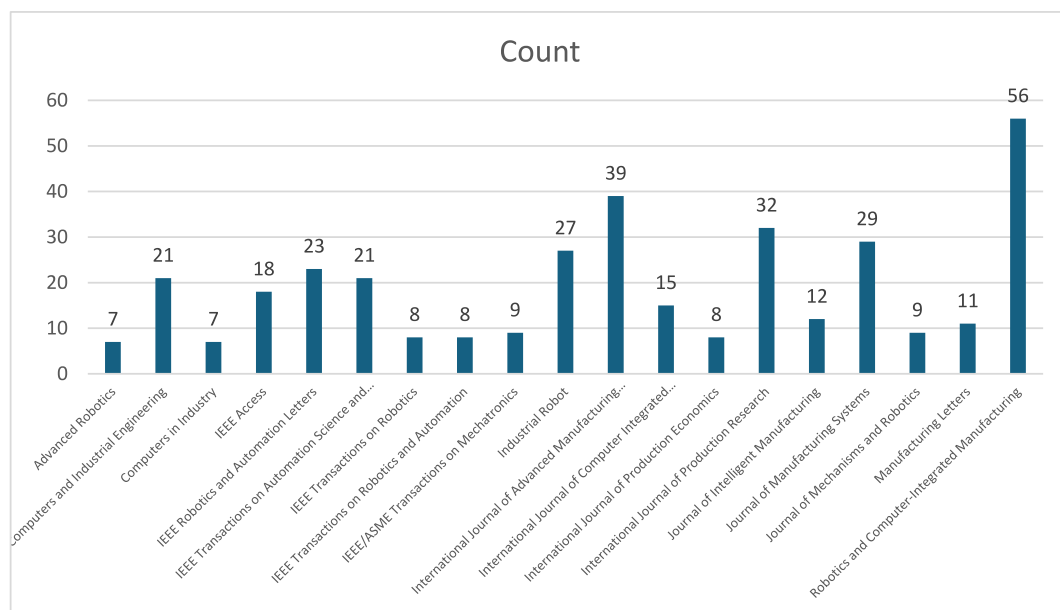


Fig. 3. Top contributing journals.

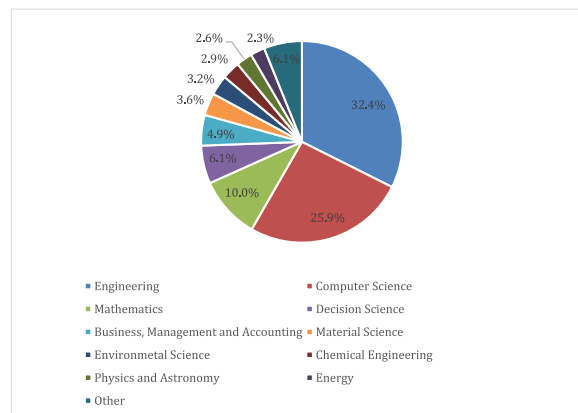


Fig. 4. Documents by subject area.

Table 1
Main Information about the data.

Timespan	1982–2024
Sources (Journals, Books, etc.)	59
Documents	360
Annual Growth Rate %	10.24
Document Average Age	8.52
Average citations per doc	35.75
References	13738
DOCUMENT CONTENTS	
Keywords Plus (ID)	2774
Author's Keywords (DE)	966
AUTHORS	
Authors	1160
Authors of single-authored docs	31
AUTHORS COLLABORATION	
Single-authored docs	34
Co-Authors per Doc	3.82
International co-authorships %	21.94
DOCUMENT TYPES	
Article	360

3.3. Leading universities

In terms of the top contributing universities, as shown in Fig. 5, Chalmers University of Technology is the leading university, which includes 16 articles, followed by the University Politehnica of Bucharest (10 articles), Tallinn University of Technology (6 articles), Federal University of VICOSA/UFV (7 articles), and Fraunhofer Institute for Machine Tools and Forming Technology IWU (6 articles).

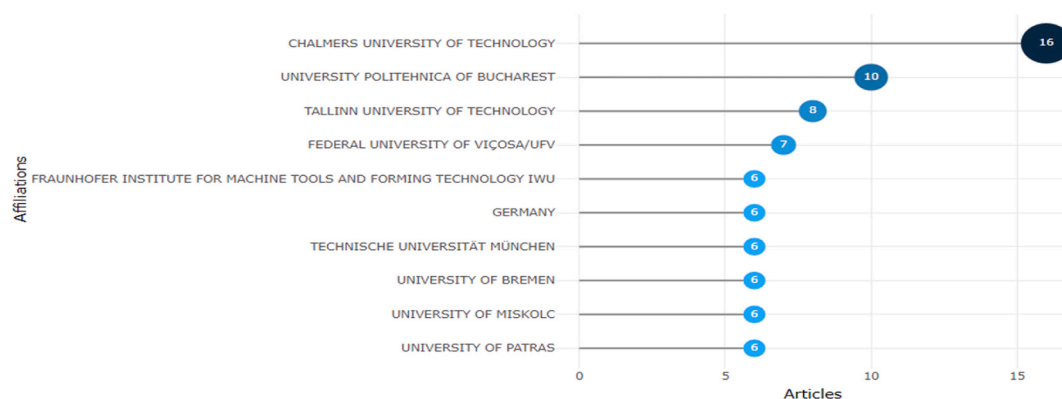


Fig. 5. Most relevant affiliations.

A study by Fager et al. (2020) discussed the applications of Cobots in kit preparation, thereby reducing time and enhancing efficiency. The authors further stated that Cobot-assisted kits are advantageous for diverse kits with smaller components per stock keeping unit (SKU). Moreover, Table 2 shows the top contributing countries identified as the USA, China, Italy, Japan, Germany, the UK, Spain, Greece, France, and Denmark.

3.4. Word cloud & tree map

Fig. 6 shows the word cloud of the top 25 words. The following terms appear most frequently in the literature: collaborative robots, human-robot interaction, robot programming, industrial robots, and manufacturers. Furthermore, as shown in Fig. 7 and Table 3, we examined the various words in the tree map based on the relative frequency of the top 25 keywords. The keyword frequency statistics are as follows: collaborative robots ranks first with 131 occurrences, followed by industrial robots (86), human robot interaction (81), robotics (81), robot programming (80), human-robot collaboration (69), manufacture (68), production control (65), robotic assembly (46), robots (46), production engineering (39), and social robots (39).

As shown in Fig. 8, the trend of publications in the context of Cobots applications in manufacturing has shifted from fixture (tooling) in the following chronological sequence: computer aided manufacturing, heuristic methods, robotic assembly, scheduling, production control, optimal control systems, optimization, calibrations, planning, automation, and eventually to human-robot interaction and smart manufacturing.

As shown in Fig. 9, cluster-1 has low centrality and low impact, and is placed at the bottom left corner. This cluster is characterized by pivotal keywords like agricultural robots (42.9 %), social robots (33.3 %), and human-robot collaboration (7.7 %). Cluster-2 has medium centrality and low impact, and the keywords include collaborative robots (38.6 %), human-robot collaboration (42.3 %), and human-robot interaction (38.5 %). Cluster-3 has high centrality and low impacts, including collaborative robots (18.2 %), assembly lines (80 %), and assembly machines (50 %).

Cluster-4 has high centrality and high impact and includes words like collaborative robots (15.9 %), collaborative assembly (55.6 %), and human-robot collaboration (19.2 %). Cluster-5 has medium centrality and high impact, with keywords such as collaborative robots (9.1 %), agricultural robots (42.9 %), and human-robot collaboration (11.5 %). Similarly, cluster-6 is described by low centrality and high impact, with keywords such as collaborative robots (15.9 %), human-robot interaction (38.5 %), and manufacturing (38.5 %).

The thematic evolution diagram (Fig. 10) shows that the focus of research has shifted over time. In the early years, the focus was on production control, robot applications, and production engineering from 1982 to 1995. However, in the middle period, i.e., between 1996 and 2010, the focus was primarily on automation agents, automation, planning, human computer interaction, machine design, genetic algorithms, and industrial applications. Moreover, in the last decade, the focus has shifted toward Industry 4.0, robotics, optimization, multi-agent systems, and human-robot interaction.

As shown in Fig. 11, the following clusters are obtained based on keyword co-occurrence. These are discussed below.

Cluster 1 (Red): keywords in this cluster include assembly, assembly line balancing, assembly machines, Cobots, robot programming, production line, scheduling, and human-robot collaboration.

Table 2
Countries' scientific production.

Country	Freq.
USA	235
China	194
Italy	171
Japan	94
Germany	92
UK	67
Spain	61
Greece	51
France	40
Denmark	33
Portugal	31
New Zealand	25
Sweden	25
South Korea	24
Singapore	22
Canada	20
Mexico	16
Finland	13
Belgium	12
Netherlands	12
Norway	11
Czech Republic	9
Brazil	8
Algeria	7
Australia	7

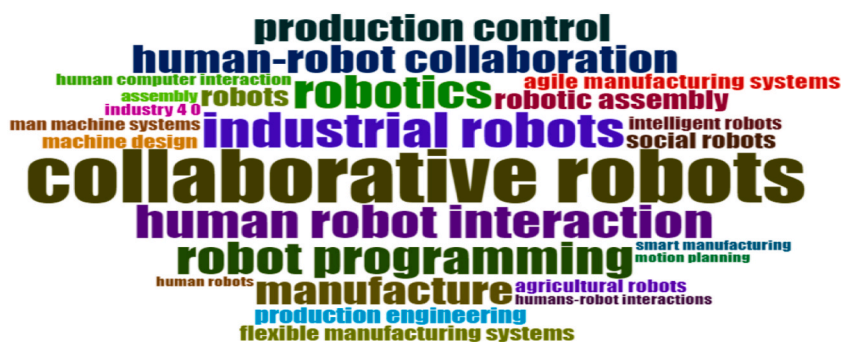


Fig. 6. Document Most relevant words.



Fig. 7. Word tree map.

Cluster-2 (Yellow): The keywords in this cluster include cobot, cobot selection, collaborative operation, collaborative robot, industrial robots, manufacturing efficiency, productivity, shared workplace, smart manufacturing, and sustainability.

Cluster 3 (Green): This cluster includes keywords such as 3D printing, additives, collaborative robots, industrial research, Industry 4.0, Internet of Things, Industry 4.0, investments, robotics, and machine design.

Cluster 4 (Blue): This cluster involves the following main keywords: behavioral research, decision making, ethics, human robots, Industry 5.0, manufacturing, production efficiency, qualitative analysis, and technology adoption.

Cluster 5 (Purple): The keywords in this cluster are assembly process, collaborative robotics, comparative analysis, human-robot collaboration, and manufacture.

Cluster 6 (Sky Blue): This cluster involves keywords like assembly operations, ergonomics, human operator, performance, robotic assembly, and workers.

4. Applications of Cobots in manufacturing

Pizoń et al. (2022) also analyzed the integration of Cobots with Industry 5.0, which resulted in reduced waste and enhanced problem-solving capabilities. Moreover, the authors stated that Cobots are different from robots because they collaborate with humans rather than work in silos. Cobots' main objective is to work with people to increase the automation of production activities in a way that is both profitable and secure.

Table 3
Most relevant words.

Relevant Words	Freq.
collaborative robots	131
industrial robots	86
human robot interaction	81
robotics	81
robot programming	80
human-robot collaboration	69
manufacture	68
production control	65
robotic assembly	46
robots	46
production engineering	39
social robots	39
agile manufacturing systems	37
flexible manufacturing systems	36
machine design	33
agricultural robots	31
intelligent robots	30
man machine systems	29
human computer interaction	28
industry 4 0	28
assembly	27
humans-robot interactions	25
smart manufacturing	25
human robots	24
motion planning	24

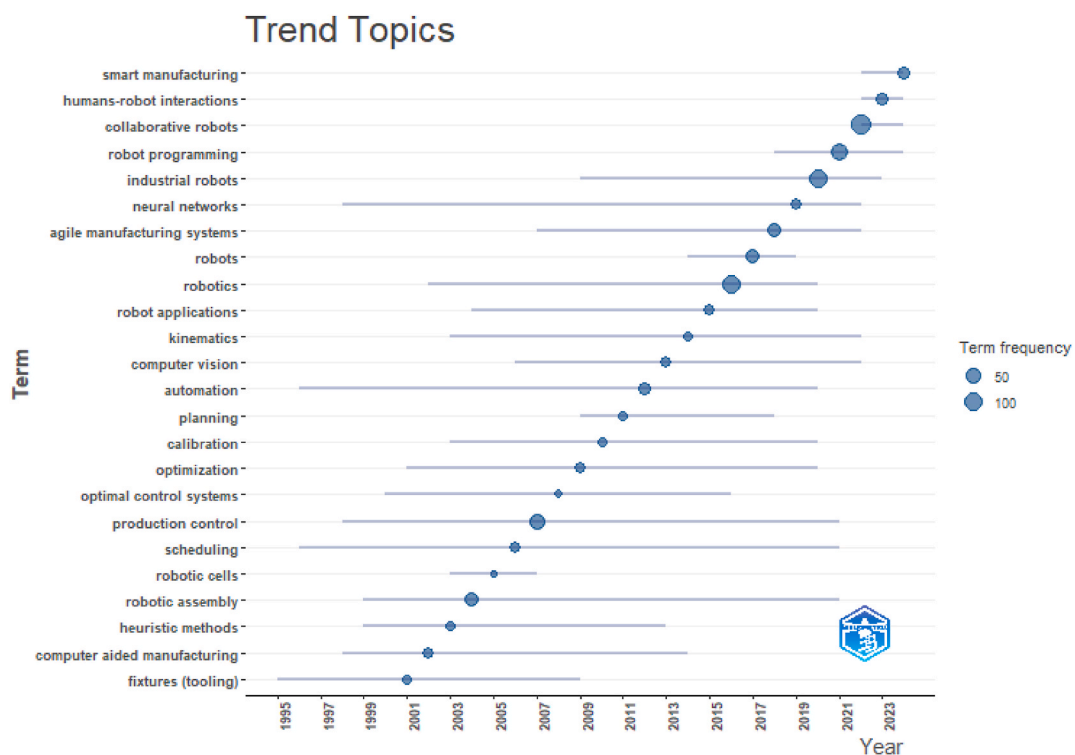


Fig. 8. Trend topic.

Unlike robots, which work in closed work environments, the usage of Cobots requires them to be equipped with certain extra safeguards to ensure their safety while working with humans. This will eventually help prevent collisions in industrial settings. However, humans' acceptance of Cobots has not been examined in the current literature. [Wessling \(2023\)](#) analyzed that applications of Cobots in the automobile industry are essential, as this sector involves a wide range of complexities. Cobots can offer significantly greater benefits than conventional robots and are quick to deploy. Moreover, as [Industrial Robots \(2021\)](#) report, Cobots are smaller in

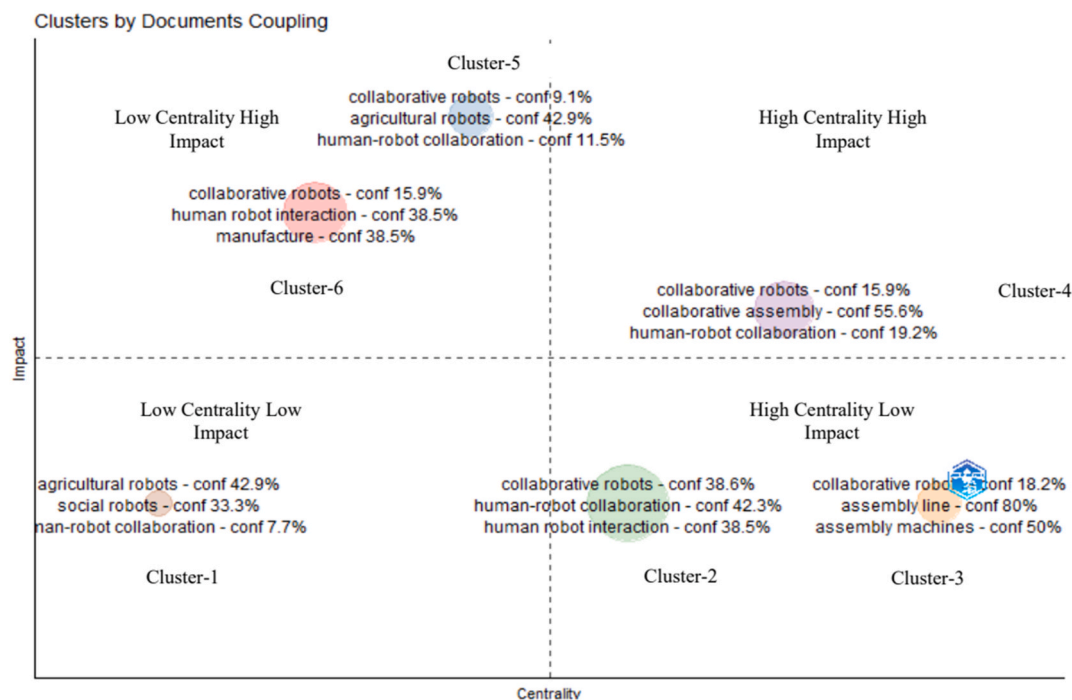


Fig. 9. Clustering by coupling.

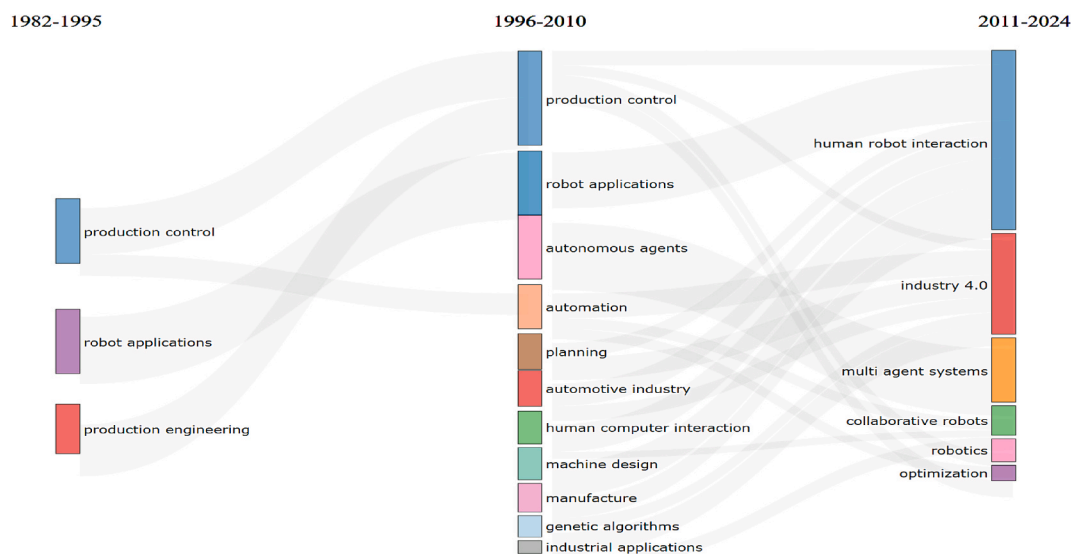


Fig. 10. Thematic evolution.

size, making it easier to relocate, and cost-effectiveness helps improve return-on-investment (ROI).

The purpose of the Cobots is to facilitate flexibility in manufacturing and other critical tasks. A single collaborative robot can handle several requests quickly, making it more efficient and less costly than its industrial robot counterpart (Javaid et al., 2022). Conventional industrial robots were intended to replace operators at several points in the manufacturing process to improve output and prevent health hazards for workers.

El Zaatari et al. (2019) bifurcated Cobots into four major categories depending on the level of engagement between humans and Cobots: independent, simultaneous, sequential, and supportive. The authors further stated that the overall objective of deploying Cobots is to improve ergonomics. Weiss et al. (2021) discussed the applications of Cobots in Industry 4.0 based on individual, team, and organization narratives; rather than considering the dichotomous relationship between humans and Cobots, Cobots must be

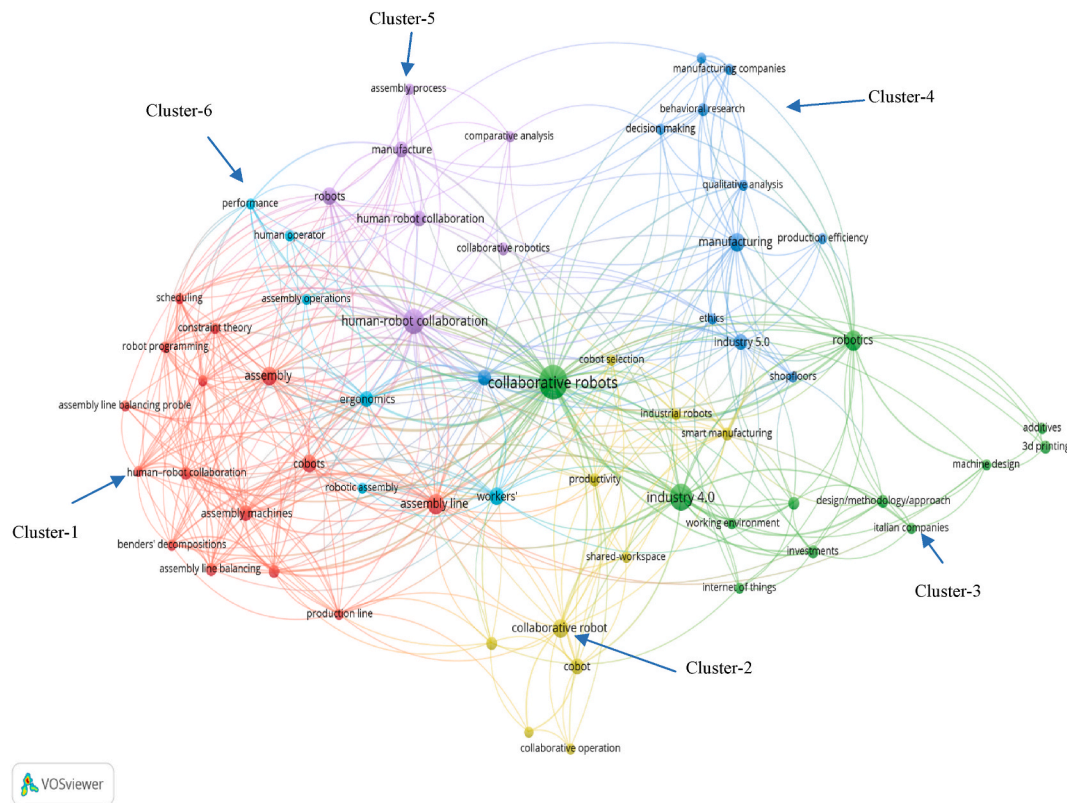


Fig. 11. Keywords co-occurrence network.

considered as human and non-human contributors. In continuation with this, [Zafar et al. \(2024\)](#) discussed Cobots in Industry 5.0 as a heterogeneous team of robots and humans. [Amirnia and Keivanpour \(2024\)](#) discussed the application of Cobots in the disassembly process, thereby enhancing operational efficiency, ensuring quality, maximizing the utilization of resources, and hence achieving sustainability.

[Silva et al. \(2024\)](#) proposed a decision-making framework for the adoption of Cobots using the following criteria categories: financial, operational, technological, strategic, human, risk, environmental, and legal. The authors used weighted scoring methods to evaluate criteria ranking, which ultimately aids in a comprehensive decision-making process.

Table 4

Theoretical and practical implications.

Aspect	Theoretical Implications	Practical Implications
Cobots in Production	Challenges the traditional notion that automation can replace human beings rather than augmenting capabilities in manufacturing and production.	Proper integration of cobots results in improved output quality, saving money, and streamlining production processes.
Human-Robot Interaction	Extends current notions of human-robot interaction by highlighting the importance of smooth coordination and communication between human workers and Cobots.	Emphasizes the need for human workers to receive the right training and assistance to guarantee a seamless working relationship with Cobots.
Optimization of Processes	Investigate the hypothesis that Cobots can create more efficient production processes by bridging the gap between human skill and machine precision.	Suggests that by carefully structuring Cobots integration and considering both technology and human elements, businesses can realize efficiency advantages.
Workforce Dynamics	Raises concerns about how Cobots integration may affect labor dynamics over time, particularly skill development and job satisfaction.	Gives information about the applications of Cobots that work well, including assembly lines, quality control, and repetitive jobs.
Technology and Adaptation	Provides strong justification that technological innovations facilitate Cobots capabilities, making them more human-centric and autonomous. Users must train to make them comfortable while using Cobots.	Practitioners must focus upon contemporary tools and techniques and execute research and development activities for successful Cobots deployment.
Economic Feasibility	Highlights the need for extensive research on the sustainability of adopting Cobots for SMEs from an economic perspective.	Provides constructive advice with an emphasis on the financial and operational advantages of Cobots technology for companies thinking about implementing it.

5. Implications and future scope

5.1. Implications

For the adoption of Cobots, triple helix actors such as the government, industries, and educational institutes must work collaboratively to foster innovation. Introducing courses on digital transformations and technological innovations in academic institutions can help industries obtain the right skill sets for prospective employees. The government must facilitate by developing a supporting regulatory and policy framework that drives innovation and growth for the deployment of Cobots. Additionally, the availability of funds for small and medium enterprises (SMEs) and public-private partnerships can add significantly to the successful Cobots deployment. Furthermore, industries must conduct research and development activities rigorously to develop creative and innovative solutions for the integration of Cobots.

The manufacturing workplace has evolved, and due to recent technological advancements, it has become possible for humans and robots to collaborate and work alongside. In the present market landscape, there is a common notion that digital technologies will replace human beings, leading to unemployment. However, the role of human operators will change rather than replace them. Therefore, Cobots will augment human capabilities rather than substitute them. Moreover, in different aspects, the theoretical and practical implications are summarized in [Table 4](#). Additionally, the top 15 cited papers are shown in [Appendix A](#), [Table A1](#), and some key aspects of Cobots are shown in [Table A2](#).

5.2. Future scope

This analysis will help industry practitioners obtain more comprehensive knowledge of the potential and difficulties of adopting Cobots. Identifying and prioritizing the barriers to the adoption of Cobots can help managers and practitioners implement them successfully. Cobots research in manufacturing, production control, and planning has a wide future scope. To improve Cobots' decision-making and operational capabilities, key areas include integrating cutting-edge technology like artificial intelligence, machine learning, and the Internet of Things. Creating models for Cobots' interaction and enhancing efficiency and safety in cooperative settings are also emerging research areas.

Cobots are found to have several benefits. In the future, applications of Cobots can be explored and investigated in various other areas, including hospitality, agriculture, pharmaceuticals, and healthcare. Since Cobots are cost-intensive and in the development stage, systematic evaluation of ROI and cost-benefit analysis can help managers make quick decisions about their deployment and integration. Also, there is much scope for integrating and investigating the green and sustainability aspects for integrating Cobots. Although Cobots are safe to use and work alongside humans, there is still a need to work on these lines and reinforce the safety of workers. Since Cobots are not standardized, there is no set of working protocols; therefore, there is difficulty in integrating them into various industrial sectors, which provides an opportunity for researchers to work in this direction. Additionally, in recent years, some large organizations have already spent heavily on automation and robotics, so the question is whether the existing systems can be retrofitted to make them compliant with the Cobots requirements. Additionally, these initiatives can be cumbersome, costly, and time-consuming, so there is a scope to simplify these processes. Moreover, there are research gaps in analyzing ethical perspectives while deploying Cobots.

6. Conclusion

The presented research provides a comprehensive analysis of research potential, gaps, and the current state of research in deploying Cobots in manufacturing industries. Bibliometric analysis was conducted to identify key publications, prominent journals and authors, topmost countries, thematic evolution, and clustering. Exploring these perspectives can be highly helpful for understanding the present research status, gaps, and potential research areas. Therefore, the research results systematically evaluate existing scholarly studies, the dynamic capabilities of Cobots, and their practical implications in industry. There has been a significant increase in publications in recent years, primarily with studies focusing on making manufacturing processes collaborative and autonomous. Since the implementation of emerging technologies is subject to various challenges, there are multiple roadblocks in the pathway of the deployment and integration of Cobots. These include technological complexity, cybersecurity, skill gaps, and ethical concerns. It has been found that Cobots have many advantages in manufacturing and production, including enhancing efficiency and effectiveness, improving safety, increasing quality, and profitability.

Various research themes can be explored and investigated, such as human-robot collaboration and safety, intelligent and autonomous control systems, operations and supply chain integration, ethical perspectives, and digital twins for end-of-life assessment to integrate Cobots. Researchers must work meticulously and diligently to use Cobots for industrial applications successfully. Industry managers can use these insights to develop strategies, optimize manufacturing processes, and make informed decisions. It further helps organizations reduce lead time, enhance productivity, and maximize the utilization of resources.

Ethics statement

Not applicable because this work does not involve the use of animal or human subjects.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table A1
Top 15 cited papers

No.	Publication Year	Document Title	Authors	Journal Title	Total Citations
1	2019	Human–robot interaction in industrial collaborative robotics: a literature review of the decade 2008–2017	(Hentout et al., 2019)	<i>Advanced Robotics</i>	480
2	2016	Learning physical collaborative robot behaviors from human demonstrations	(Rozo et al., 2016)	<i>IEEE Transactions on Robotics</i>	344
3	2018	Skill-based instruction of collaborative robots in industrial settings	(Schou et al., 2018)	<i>Robotics and Computer-Integrated Manufacturing</i>	168
4	2019	Introduction and configuration of a collaborative robot in an assembly task as a means to decrease occupational risks and increase efficiency in a manufacturing company	(Realyvásquez-Vargas et al., 2019)	<i>Robotics and Computer-Integrated Manufacturing</i>	114
5	2020	Haptic-based touch detection for collaborative robots in welding applications	(Tannous et al., 2020)	<i>Robotics and Computer-Integrated Manufacturing</i>	44
6	2021	A multimodal approach to human safety in collaborative robotic workcells	(Costanzo et al., 2021)	<i>IEEE Transactions on Automation Science and Engineering</i>	49
7	2019	Towards an optimal avoidance strategy for collaborative robots	(Zanchettin et al., 2019)	<i>Robotics and Computer-Integrated Manufacturing</i>	50
8	2021	Optimised Learning from Demonstrations for Collaborative Robots	(Wang et al., 2021)	<i>Robotics and Computer-Integrated Manufacturing</i>	31
9	2021	From manual operation to collaborative robot assembly: An integrated model of productivity and ergonomic performance	(Zhang et al., 2021)	<i>IEEE Robotics and Automation Letters</i>	32
10	2008	Improved control and simulation models of a tricycle collaborative robot	(Bi et al., 2008)	<i>Journal of Intelligent Manufacturing</i>	28
11	2021	On the development of a collaborative robotic system for industrial coating cells	(Arrais et al., 2021)	<i>International Journal of Advanced Manufacturing Technology</i>	21
12	2023	A general cost model to assess the implementation of collaborative robots in assembly processes	(Barravecchia et al., 2023)	<i>International Journal of Advanced Manufacturing Technology</i>	22
13	2023	Adaptive obstacle avoidance in path planning of collaborative robots for dynamic manufacturing	(Hu et al., 2023)	<i>Journal of Intelligent Manufacturing</i>	24
14	2021	Collaborative robotics in wire harnesses spot taping process	(Ibáñez et al., 2021)	<i>Computers in Industry</i>	19
15	2022	Analysis of assembly-time performance (ATP) in manufacturing operations with collaborative robots: a systems approach	(Chen et al., 2022)	<i>International Journal of Production Research</i>	19

Table A2
Some of the key Cobots aspects identified in the literature

No.	Theme	Key Aspects	References
1.	Co-existing, Cooperative & Cognitive	Tri-Co capabilities are intellectually demanding, which helps in developing exhaustive performance evaluation. A construction method using both subjective and objective aspects was considered and analyzed using text clustering and statistical tools. Class-1 evaluation indices analyzed structured quantitative data while Class-2 analyzed unstructured text data.	Yao et al. (2024)
2.	Human Factors	Both physical and cognitive ergonomics were explored and investigated. The human factors taken into consideration were physical ergonomics, mental workload, trust, acceptance, and usability. Cobots's capabilities include mobility, adaptability, connectivity, actuation, consistency, and safety.	Faccio et al. (2023)
3.	Avoid Over hyping Cobots	Humans will remain as central element. Avoiding unrealistic expectations, the true picture can help to overcome the workers' fear of losing their jobs. Therefore, rather than replacing human roles, Cobots will help to enhance workers' productivity and efficiency. Solving multiple dynamic problems with quality solutions is something that Cobots cannot achieve.	Sorell (2022)
4.	Automotive in SMEs production	Automation framework was proposed based on hybrid machine learning approaches, i.e., Convolutional Neural Network (CNN) and Support Vector Machine (SVM), to develop learning-based vision capabilities. The proposed framework can be used to analyze human	Yang et al. (2023)

(continued on next page)

Table A2 (continued)

No.	Theme	Key Aspects	References
		intentions by means of untouched human-robot collaborations, thus including humans in the control loop.	
5	Humna-Robot Teaming	Various metrics considered include efficiency, task flexibility, teaming flexibility, physical ergonomics, cognitive ergonomics, physical safety, and psychological safety.	Riedelbauch et al. (2023)
6	Improve human-robot collaboration	The manufacturing sector has an outstanding communal of researchers for integrating robots in various applications, and the construction sector has yet to be investigated. Moreover, assisting technologies like radio-frequency identification (RFID) and robotic vision are discussed as crucial enablers for Cobots deployment.	Burden et al. (2022)
7.	Assembly line	The application of Cobot in Biomedical assembly was investigated. Cobots are suitable to mimic human behavior and perform repetitive activities, and are helpful in providing customized solutions and products. Integration of additive manufacturing helps in reducing wastage and achieving lean automation by developing fast and cost-effective prototypes.	Rossi et al. (2020)
8	Minimizing the risk of Musculoskeletal Disorders (MSD)	The application of Cobot in manual mold assembly was analyzed, which resulted in mitigating the issue of MSD. Moreover, it resulted in optimum utilization of resources and cycle time was found to be reduced significantly. Mathematical models were developed for mold assembly using a genetic algorithm.	Liau and Ryu (2022)
9.	Retail Warehousing	Human-robotic collaborative behavior was explained using a longitudinal case study in retail warehousing. The control variables taken in the study include product weight, product volume, travel distance, and pick density. Moreover, the authors identified interaction dimensions in Industry 5.0 include social dynamics, trust, safety and support, supervision, and autonomy.	Koreis et al. (2025)
10	Automatic packaging	Cobot application for feeding raw material in the tea-packaging operation was discussed using custom mechanical components.	Comari et al. (2022)

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