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The role of mechanical engineering in industry: Review and bibliometric analysis

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Abstract
Innovation has shown progress in many sectors, including mechanical engineering which is closely related to industry. Through a literature survey and bibliometric analysis of 1,920 articles sourced from the Scopus database from 2015 to 2024, this paper investigates the role that mechanical engineering plays in industrial progress. The analysis uses VOSviewer for network visualization, overlay, and density maps. According to the findings, mechanical engineering has significantly advanced several important areas, including advanced manufacturing processes, Industry 4.0 and digital transformation, sustainability and circular economy, educational advancement, use of new technologies, and biotechnology innovation. Some of the key findings of this review include the use of digital twins and integrating cyber-physical systems, the use of large-scale 3D printing technology, and the use of sustainable production methods in industry. According to the analysis, the number of publications and citations has increased, with a slight decrease during the COVID-19 pandemic. Visualizing this bibliometric map helps understand current trends, identify potential research areas, and highlight relationships between research issues.

Keywords: Mechanical engineering, Advanced manufacturing, Bibliometric analysis, VOSviewer

1. Introduction

Over the years, technological developments have played a significant role in driving innovation in various fields, including mechanical engineering in relation to industry. In fact, the first publication on mechanical engineering titled "mechanical engineering as applied to farm implements" published in the Journal of the Franklin Institute was found in the Scopus database in 1840 [1]. Furthermore, the publication on the role of mechanical engineering in industry in the Scopus database was found for the first time in 1926 titled "mechanical engineering in the cracking, heating, and cooling of oil" published in the Journal of Fluids Engineering, Transactions of the ASME and has been cited 1926 times [2].

The evolution of mechanical engineering continues with the rapid advancements brought by subsequent phases of the Industrial Revolution, including Industry 4.0 [3]–[6] and the emerging concepts of Industry 5.0 [7]. These phases emphasize the importance of integrating intelligent technologies, automation, and human-centered design approaches. Recent research has shown how mechanical engineering plays a role in developing adaptive manufacturing systems that leverage artificial intelligence (AI), robotics, and the Internet of Things (IoT) to improve efficiency, precision, and sustainability [8]–[12]. Innovations such as digital twins, which enable real-time monitoring and optimization of physical assets, and advances in additive manufacturing such as 3D printing, have transformed production processes by reducing waste and enabling customized manufacturing on demand [13]–[15].

In addition, research in mechanical engineering continues to make significant contributions to industrial development, in line with technological advances and the need for sustainability. For example, the exploration of biofuel as a renewable energy source shows great potential to reduce dependence on fossil fuels and support the sustainability of the energy industry [16]–[20]. Furthermore, improving the performance of wind turbines helps improve energy conversion efficiency in the renewable energy industry [21], [22]. Innovations in heat transfer are also seen in studies on the use of nanofluids, which contribute to improving the efficiency of cooling systems [23]–[27]. Experimental evaluation of the thermal storage power characteristics has also become

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an important focus for improving the efficiency of energy storage systems [28]. Research on the use of plastic waste fuel in internal combustion engines shows innovative solutions that can reduce waste and at the same time have a positive impact on the environment [29]. New approaches in milling to improve production efficiency in industry are also reviewed, supporting more sustainable practices [30]. The need to adopt sustainable energy sources for the future is also reviewed to highlight the importance of environmentally oriented industrial planning [31]. Complex steel forming technologies, such as deep drawing, have also been identified as important methods for improving production efficiency and manufacturing technology transfer [32]. Other studies on the optimal design of stator slots in electrical machines have also improved the efficiency and reliability of industrial equipment [33] and the use of nano calcium carbonate to strengthen composite materials has also been introduced [34]. In addition, research in mechanical engineering is rapidly advancing to support medical and health technology [35]–[40].

In order to further understand the contribution of mechanical engineering to industrial development, a systematic approach is needed in analyzing the available literature. This approach not only includes a quantitative assessment of the number of publications and citations, but also highlights the main themes and emerging research directions. Therefore, this article aims to examine the role of mechanical engineering in industry using a literature review and bibliometric analysis. Bibliometric analysis was chosen because of its effectiveness in assessing the impact and scope of the field of study [41]. This study also includes a mapping analysis, which is important for understanding research trends and visualizing the structure of the research field [42], [43].

2. Bibliometric Analysis and Mapping Visualization

This study employs bibliometric analysis and mapping visualization methods. Bibliometric analysis serves various purposes, including identifying research trends related to the number of documents and citations. In this study, 1,920 documents were obtained from the Scopus database (accessible at https://www.scopus.com/) using the keywords "Mechanical Engineering" AND "Industry." Data collection was taken on November 9, 2024, covering publications from 2015 to 2024. We used the "Result Analysis" feature in Scopus for preliminary statistical processing of the research data. Subsequently, we utilized the VOSviewer application to convert this data into map form. VOSviewer includes a viewer that allows for detailed examination of bibliometric maps and presents data as network, overlay, and density. The application of bibliometric analysis and VOSviewer has been described in detail in several of our previous studies [44]–[50].

3. Current Trends in Mechanical Engineering Research Related to Industry

In this analysis, we observed that publications related to "Mechanical Engineering" AND "Industry" increased from 2015 to 2019 but showed a decline in 2021 and 2022, as depicted by the blue bar chart in **Figure 1**. However, there is an increasing trend again from 2022 to 2023 and 2024, despite 2024 being incomplete. We suspect that the decline in 2021 and 2022 was due to the impact of COVID-19, which indirectly hampered the research process during 2020 and 2021. Meanwhile, citations of articles discussing mechanical engineering in relation to industry have shown a consistent increase, as represented by the black line in **Figure 1**. From the 1,920 documents, we conducted an analysis using VOSviewer to generate network and overlay maps. We set a threshold of at least five occurrences for keywords, and the results are shown in **Figure 2** and **Figure 3**.

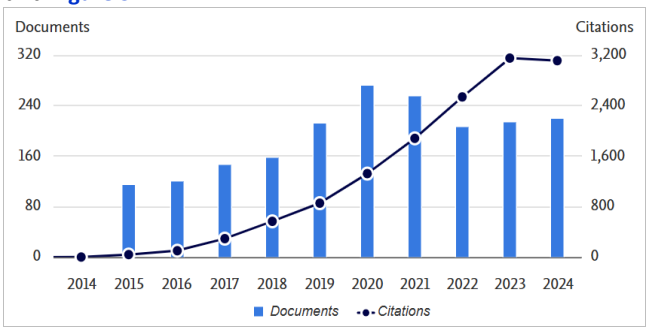

Figure 1. Publication and citation trends related to "mechanical engineering" and "industry" from 2015 to 2024

The analysis continued with the aim of identifying academic articles that have scientific contributions based on the number of citations. The use of the number of citations as a metric provides an idea of the impact and relevance of an article in an academic field. Articles with a high number of citations indicate that the work is re-

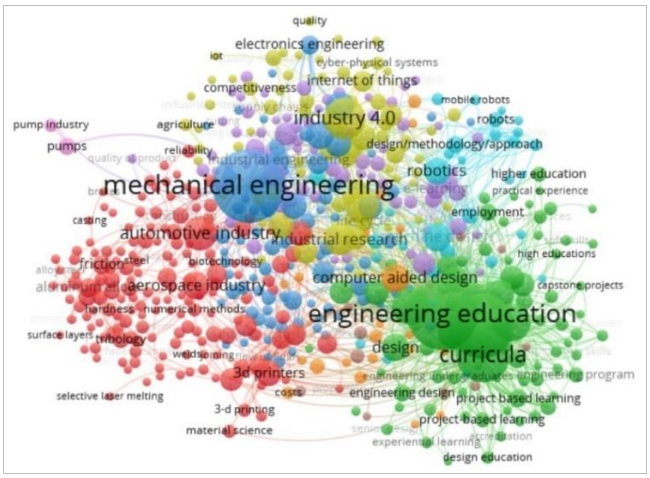

Figure 2. Keyword network map (cluster) from 2015 to 2024

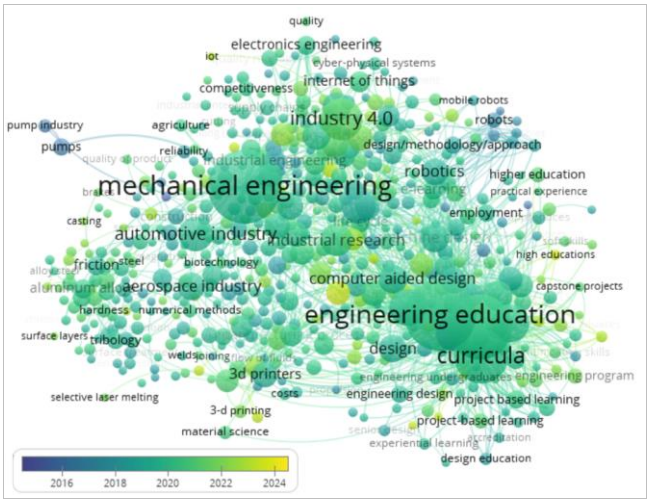

Figure 3. Keyword network map (overlay) from 2015 to 2024

cognized and frequently referenced by other researchers, reflecting an important contribution to the scientific literature. In this analysis, we only used scientific articles that have been published in journals and proceedings and did not include books, chapters, or other types of publications to maintain the focus on peer-reviewed works. The results of this analysis are sorted by the number of citations each article has, from highest to lowest. The 20 most highly cited articles are presented in **Table 1**.

Next, the collected data was processed and exported to VOSviewer to produce a comprehensive network visualization. VOSviewer was chosen because it can visualize the relationship between elements in academic research, such as citation networks, co-occurrence between keywords, and overlay analysis, which helps understand the dynamics of research in the selected field. This software gives us a clearer picture of the relationship and density between various articles and related research topics.

We used the co-occurrence method for the analysis process based on keywords selected from the articles. The minimum limit of keywords used in this analysis was set at two occurrences, meaning that the keyword must appear at least twice to be included in the visualization. The results showed that 16 keywords appeared together, indicating key topics that are often studied together and are relevant to each other in the analyzed literature. The network visualization map resulting from this co-occurrence analysis is shown in **Figure 4**, where the relationship between keywords can be clearly identified. In addition, the overlay visualization provides insight into the temporal development of research themes, thus showing the latest trends in the field. Meanwhile, density visualization allows us to identify the densest and frequently discussed research areas, which are indicated by different colors and intensities on the map.

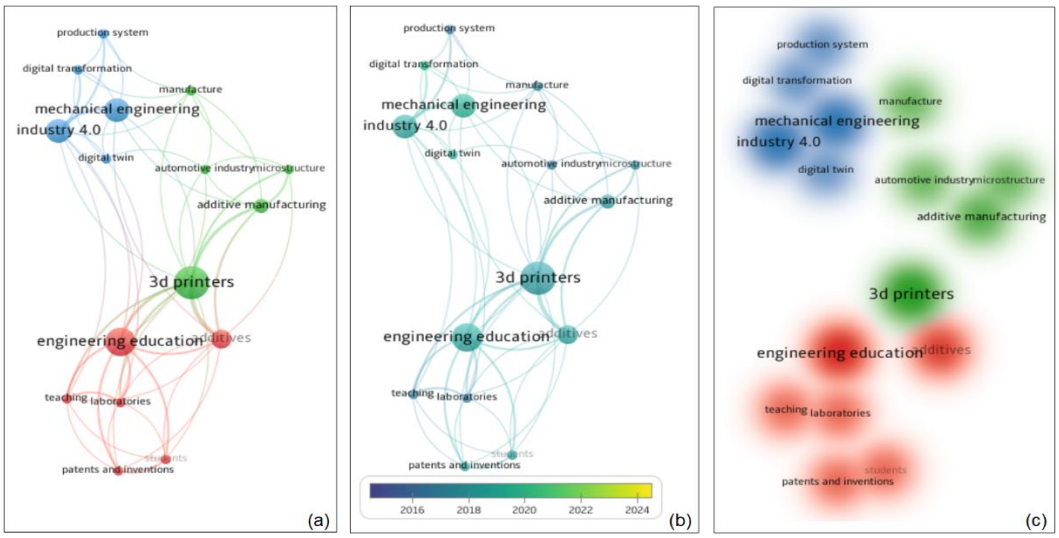

Figure 4. Vizualisation data on VOSviewer: (a) Network, (b) overlay, and (c) density

Table 1. The most cited research articles on mechanical engineering in industry

No	Title	Ref.	Year	Cited by
1	Microstructural features of Sc- and Zr-modified Al-Mg alloys processed by selective laser melting	[51]	2017	422
2	Electron beam welding - Techniques and trends - Review	[52]	2016	310
3	Large-scale digital concrete construction – CONPrint3D concept for on-site, monolithic 3D-printing	[53]	2019	298
4	The digital twin of an industrial production line within the industry 4.0 concept	[54]	2017	256
5	Digitization, Digital Twins, Blockchain, and Industry 4.0 as Elements of Management Process in Enterprises in the Energy Sector	[55]	2021	235
6	Making existing production systems Industry 4.0-ready: Holistic approach to the integration of existing production systems in Industry 4.0 environments	[56]	2015	228
7	XJTU-SY Rolling Element Bearing Accelerated Life Test Datasets: A Tutorial	[57]	2019	192
8	Enterprise Architectures for the Digital Transformation in Small and Medium-sized Enterprises	[58]	2018	168
9	Remote and Virtual Labs for Engineering Education 4.0: Achievements of the ELLI project at the TU Dortmund University	[59]	2018	153
10	Nitsche's method for a coupling of isogeometric thin shells and blended shell structures	[60]	2015	150
11	Developing a framework for using structure-from-motion techniques for road distress applications	[61]	2020	89
12	A framework for a hydrogen economy	[62]	2021	82
13	The green competitiveness of enterprises: Justifying the quality criteria of digital marketing communication channels	[63]	2021	79
14	New trends on digitisation of complex engineering drawings	[64]	2019	75
15	Organ Bioprinting: Are We There Yet?	[65]	2018	74
16	The first step towards intelligent wire arc additive manufacturing: An automatic bead modelling system using machine learning through industrial information integration	[66]	2021	69
17	A framework for teaching the fundamentals of additive manufacturing and enabling rapid innovation	[67]	2016	68
18	Innovative processes in managing an enterprise from the energy and food sector in the era of industry 4.0	[68]	2021	63
19	Micromechanical analysis of the effective properties of lattice structures in additive manufacturing	[69]	2018	62
20	Methodologies of knowledge discovery from data and data mining methods in mechanical engineering	[70]	2016	58

From the results of the bibliometric analysis, we found that the 20 top cited articles that we collected can be grouped into six main topics, as explained as follows.

1. Advanced Manufacturing Processes

This topic includes research that discusses advanced manufacturing processes that combine modern technologies to improve production efficiency and quality. Węglowski [52] highlights recent developments in electron beam welding techniques, combining new technologies to enhance weld results. Mechtcherine et al. [53] describes the application of 3D printing technology to large-scale construction, with a focus on material efficiency and labor. Meanwhile, Souza et al. [69] explores the micromechanical analysis of lattice structures used in lightweight designs to improve mechanical performance.

2. Digital Transformation and Industry 4.0

Research in this topic highlights the use of digital technologies to improve industrial processes and data management. Vachalek et al. [54] explores the use of digital twins for real-time monitoring and decision-making. Then, Schlechtendahl et al. [56] discusses how traditional production systems can be adapted to meet Industry 4.0 standards with cyber-physical system integration. Additionally, Goerzig & Bauernhansl [58] describes how enterprise architectures can support real-time data integration and operational flexibility.

3. Sustainability and Circular Economy

Articles on this topic focus on sustainability strategies in management and production. Borowski [68] discusses innovative approaches to adopting circular economy principles in production processes, aiming to optimize resource use and reduce waste through more efficient and sustainable production systems. Yang et al. [63] reveal how companies can improve their competitiveness by implementing green strategies, showing that sustainable practices are not only good for the environment but also provide a competitive advantage in the market. Majumdar et al. [62] offer a comprehensive view of the potential application of the hydrogen economy as a sustainable energy solution, highlighting a framework that supports the use of hydrogen as a clean and reliable alternative energy source to reduce dependence on fossil fuels.

4. Educational Advancements in Engineering

In this topic, research focuses on educational methods adapted to modern technologies. Research by Go and Hart [67] offers a guide to teaching the basic principles of additive manufacturing, including a combination of theoretical modules and laboratory activities. This study highlights the importance of an integrated approach to ensure students' understanding of modern manufacturing technologies. Meanwhile, Grodotzki et al. [59] discuss the use of virtual laboratories for engineering education in the Industry 4.0 era. This study shows how virtual laboratories can provide a learning experience that is close to hands-on practice, overcome the limitations of traditional classrooms, and increase students' learning flexibility.

5. Emerging Technologies and Data Applications

This topic covers the exploration of new technologies and applications of data in engineering. Rogalewicz and Sika [70] discuss data mining approaches and machine learning algorithms used for knowledge discovery in engineering applications. Moreno-García et al. [64] explore the latest methods and technologies used in the digitization process of complex engineering drawings, providing insight into the growing trend of digitization in this field. Roberts et al. [61] propose a framework that uses photogrammetric technologies, such as structure-from-motion, to assess road conditions, with the aim of improving efficiency and accuracy in infrastructure monitoring.

6. Biotechnological Innovations

This topic covers technological innovations in the medical field. Gao et al. [65] discuss the developments in organ bioprinting technology and the challenges that remain to achieve the production of functional organs that can be used in medicine. Bioprinting has emerged as a potential solution to engineer vascularized tissues, which was previously difficult to achieve with conventional tissue manufacturing methods. Although 3D printing technology has developed rapidly over the past decade, the expected progress in bioprinting has not been as rapid as the development of conventional 3D printing. This is due to the fundamental differences in principles between bioprinting and industrial 3D printing. Bioprinting must consider living components, while conventional 3D printing technology focuses more on non-living materials for biomedical applications.

4. Conclusion

Through research in areas such as advanced manufacturing, digital transformation, sustainability, education, and biotechnology innovation, mechanical engineering continues to grow and contribute to the industry. According to a bibliometric examination of 1,920 papers, sustainability approaches promote environmentally friendly practices, while subjects such as digital twinning, 3D printing, and electron beam welding contribute to improving manufacturing quality and efficiency. Furthermore, the use of mechanical engineering for education and medicine is expanded by data technology and organ bioprinting. By showing current trends and areas for future research, the bibliometric map visualization helps to explain the relationship between research issues. In conclusion, mechanical engineering is essential for the development of industrial technology, promoting sustainable practices, solving global problems, and providing sustainable research opportunities.

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