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ADVANCEMENTS IN 3D PRINTING FOR METAL BIO-IMPLANTS: A COMPREHENSIVE BIBLIOMETRIC AND SCIENTOMETRIC ANALYSIS

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Abstract

The growth trend and increasing global population are leading to new healthcare challenges that require prompt and effective solutions to meet the clinical demands. Currently, three-dimensional (3D) printing is emerging as a rapidly advancing technology to produce metal implants and other biomedical applications. This method creates intricate designs with biomimetic characteristics in a shorter timeframe, enabling healthcare providers to meet the needs of their patients better. This study thoroughly analyzes the demand and manufacturing methods for biomedical implants, particularly metal bio-implants. It also delves into biomaterials used in additive manufacturing, accompanied by a comprehensive bibliometric study covering scientific production by country, highly cited nations, productive authors, collaboration networks, and source rankings. The paper further investigates top author contributions, affiliations, and trends, featuring various analytical tools, such as co-citation networks, keyword co-occurrence analysis, and reference publication year spectroscopy, culminating in presenting key findings through insightful field plots. The current study uses network analysis and scientometric methodologies to analyze data taken from the Scopus journal database, which includes articles from the period between 2014 and 2023, to accomplish this goal. Through this analysis, the article aims to offer valuable insights into the relevance and real-world implications of previous research on the additive manufacturing of metal bio-implants.

Keywords: Biomedical implant, Bibliographical analysis, 3D-printing, literature review, RStudio.

I. Introduction

Osteoporosis and osteoarthritis, along with an aging population, are contributing to the growing importance of bio-implants in modern times (Al-Shalawi et al., 2023; Everton et al., 2016). As people age, the prevalence of these conditions increases and more surgeries are necessary (Lawrence E. Murr et al., 2012). To meet the rising demand for effective treatments, researchers are constantly seeking to improve and optimize the biomaterials used in bioimplants. Additionally, by minimizing micromotion at the bone-implant interface, bio-implants also assist in the biological components of bone repair (Lewandowski & Seifi, 2016; Sridhar et al., 2016; Yadav et al., 2022). As a result, bio-implants play a crucial role in the treatment of conditions that affect bone health in an aging population (Pandey et al., 2020; Zwawi, 2022).

An inventive and rapidly developing method for creating biomedical implants is additive manufacturing (AM) which has several advantages over traditional and non-traditional manufacturing methods (Mehrpouya et al., 2019). One major advantage is its unique manufacturing process, which leads to reduced production time and lower costs. Additionally, AM allows for the biomimicry of delicate biological implant features, offering great potential for developing implants that closely resemble natural structures (Bandyopadhyay et al., 2021; Wang et al., 2021; Zhou et al., 2023). Many medical experts are interested in employing metal-based AM for biomedical implants owing to its high corrosion resistance and superior fatigue strength characteristics. Individualized implants created through metal AM have proven to be effective alternatives to amputation, enabling faster healing times (Li et al., 2020; L.E. Murr, 2020; Tilton et al., 2018). Bioimplants are typically produced in small quantities and have specific requirements. These implants are designed for use in clinical and medical contexts; -examples include porous implants, prosthetics, drug delivery systems, and biosensors. Owing to the nature of their applications bio-implants are usually manufactured over a long period. Biologized, bio-functional, and biological implants are the three primary subcategories of bio-implants (Paul et al., 2021). Figure 1 shows the production of the 3d printed biomedical implants over time. Through this analysis, the article aims to offer valuable insights into the relevance and real-world implications of previous research in additive manufacturing of metal bio-implants. Bibliometric evaluation is a popular and accurate method for investigating and analyzing vast amounts of scientific data. It opens the boundaries of a discipline while allowing us to investigate various aspects of its evolutionary history.

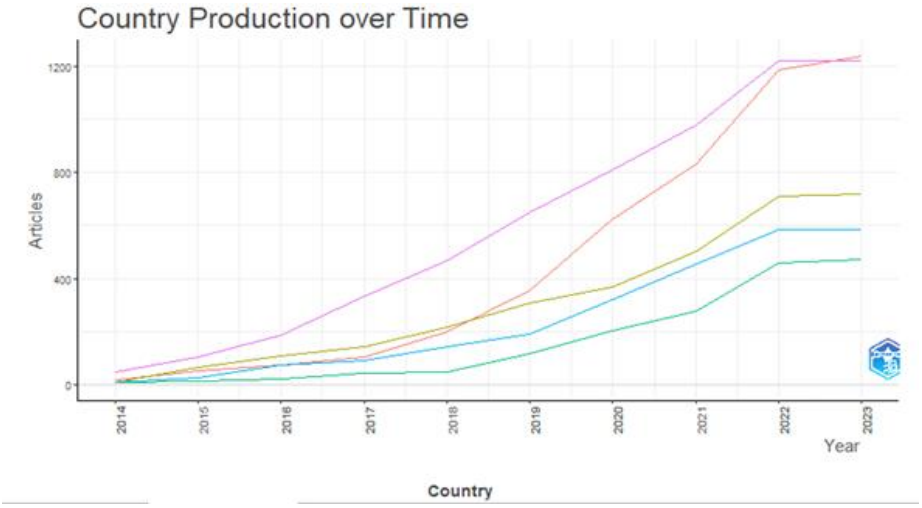

Fig. 1. Country Production Over Time on Additive Manufacturing Biomedical Implants

II. Methodology

Figure 2 illustrates this procedure in detail. The Scopus database served as a source of bibliometric data for this study. Scopus is the world's largest database of abstracts and citations by other researchers' articles, book portions, and conference reports (Al-Khoury et al., 2022; Meho & Yang, 2007; Pranckutė, 2021). Along with extensive monitoring, analysis, and visualization tools, it offers a comprehensive picture of the global research output in the humanities, philosophy, medicine, and science. Since indicators of citation and bibliography visualization are difficult to execute in collection reports, bibliometric studies frequently employ a single source. A significant portion of the PubMed database was integrated into Scopus, which also contains a similar number of indexed journals as the World Wide Web of Science (Gutiérrez-Salcedo et al., 2017; Singh et al., 2021). As a result, it is regarded as comprehensive and contains works that have been published in PubMed and the Web of Science. The source data are used to produce the title of the study, publication period, publication title, writer's name, as well as key phrases, corporations, and nation. Bibliometrics were used to assess the data obtained from the Scopus database. Additionally, RStudio for Windows was used to carry out a combination evaluation (for country, organization, and publisher), keyword combination, and evaluation of co-citations (for publication, writer, and reference) (Sakata et al., 2013). The word appeared more frequently when the node was larger. Significant terms, such as nations, organizations, or keywords, are shown as components in keyword combination research frameworks (Mejia et al., 2021; Zhu & Guan, 2013). According to co-citation analysis (journals and, references), two writers who are cited simultaneously by the same person have a connection. For each nation presented, the collaboration of the countries' total link strength (TLS) was computed. The TLS characteristic reveals the general strength of a nation's author/researcher relationship with other countries. Each color represents a distinct cluster. The minimum size is found to be ten clusters.

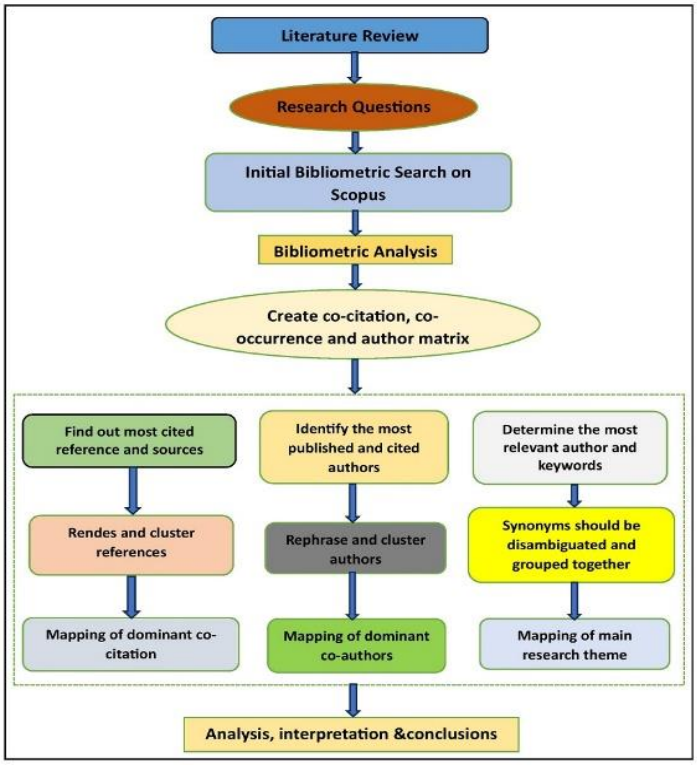

Fig. 2. Flow chart of research methodology

III. Bibliometric Analysis

For investigating and analyzing vast amounts of scientific data, a bibliometric evaluation is a popular and accurate method. It opens the boundaries of a discipline while allowing us to investigate various aspects of its evolutionary history.

III.i. Country Scientific Production

After searching the Scopus database, 1400 publications were identified, including journal articles, conference papers, and scientific reports. After carefully removing unrelated papers,500 documents were considered for the final bibliometric study. The results of a global study on AM-powered biomedical implants have indicated an upward trend. Currently, 54 nations are involved in this field of study. The overall strength of the co-authorship ties with other nations was evaluated for each nation. Forty40 nations produced more than 10 research publications in the field of 3D printed bio-medical implants between 2014 and 2023. The global geographic distribution of publications on 3D-printed biomedical implants is illustrated in Figure 3 shows the top 10 nations' outputs from 2014 to 2023.

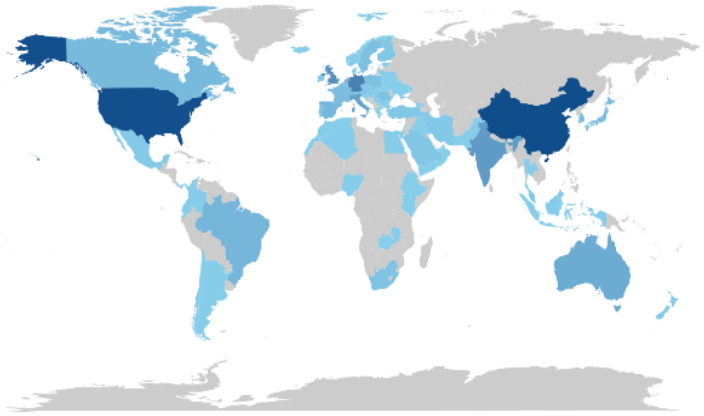

Fig. 3. Countries scientific production (2014-2023)

III.ii. Most Cited Countries

1400 publications, including journal articles, conference papers, and scientific reports, are discovered after searching the Scopus database. After carefully removing unrelated papers, a total of 500 documents were taken into account for the final bibliometric study. The results of the global study on AM-powered biomedical implants indicate an upward trend. 54 nations are known to be engaged in this field of study at the moment. For each of these nations, the overall strength of the co-authorship ties with other nations has been evaluated. According to the data, the USA is the top-ranking nation with 5372 citations. India ranked eighth with 1021 citations. The most significant nations in terms of 3D-printed bio-medical implant research are shown in Figure 4. The Network Analysis of the most-cited countries is shown in Figure 5.

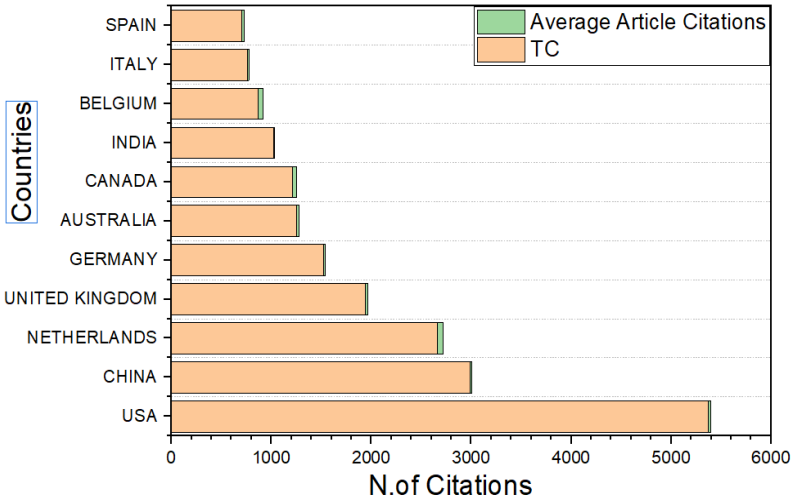

Fig. 4. Most cited countries (2014-2023)

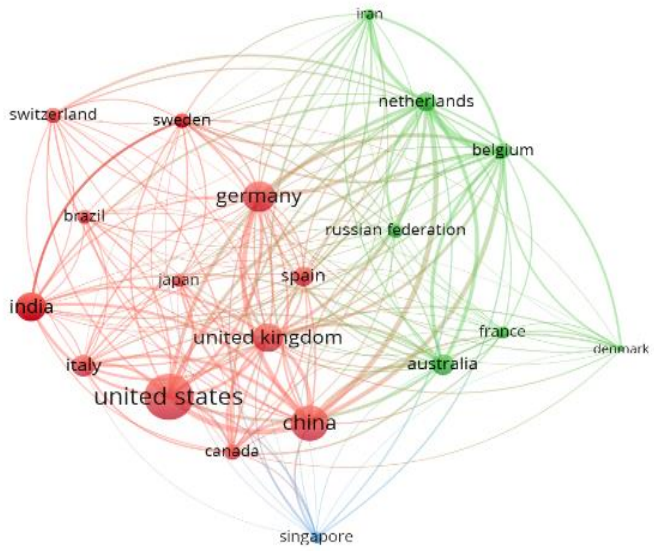

Fig. 5. Network Analysis of Most Cited Countries (2014-2023)

III.iii. Most Productive Authors

Figure 6 shows the most productive authors in terms of 3d printed bio-medical implants. ZADPOOR AA produced 39 publications. The other three authors (WANG L, LI Y, BANDYOPADYAY A) produced 21,19 and 17 publications, respectively. The other six authors comprising the top ten produce more than 10 publications each. The findings of numerous authors as a whole indicate that this is a developing topic with major potential for future investigations. Figure 7 represents the network visualization of the most productive authors and the table represents the most relevant authors from maximum to minimum articles.

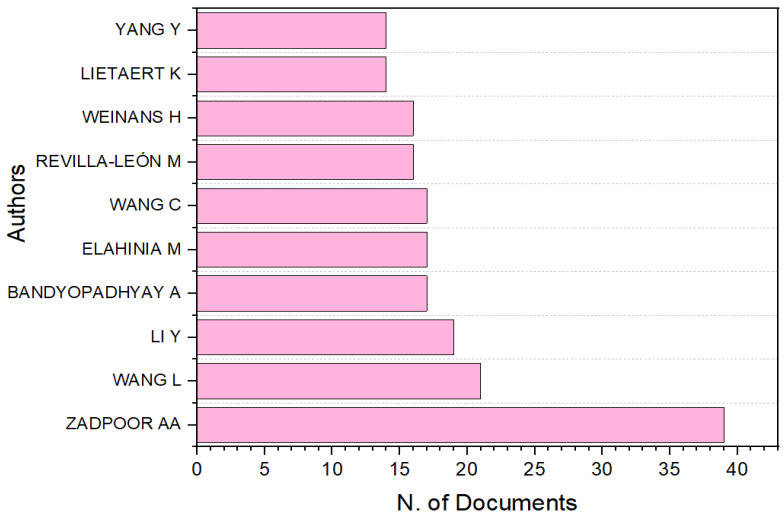

Fig. 6. Most Productive Authors

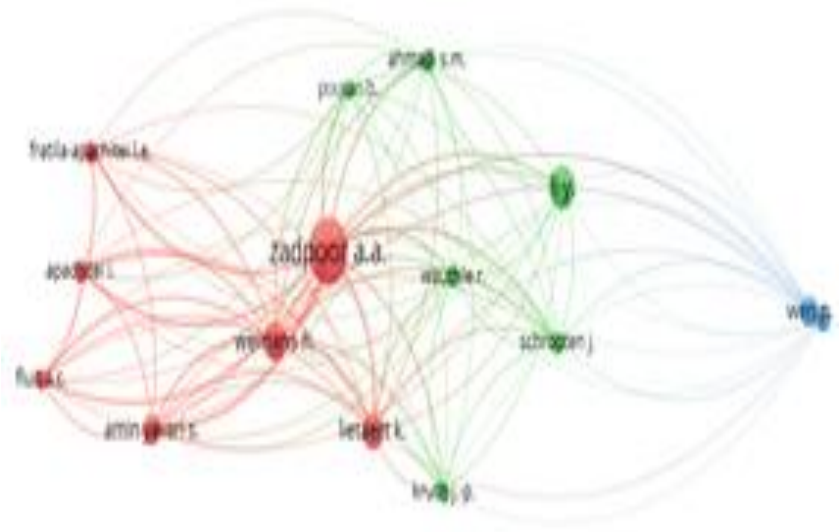

Fig. 7. Network Visualization of Most Productive Authors

III.iv. Corresponding Author's Country

Figure 8 shows the countries of the related authors. The corresponding writer is the person who submits the article to the article publisher and oversees all communications concerning it. Additionally, the corresponding author serves as a point of contact for other interested researchers by providing their email address, which is typically found on the first page of the article. Among the top three, the USA comes first with 187 articles published. CHINA ranks second with 163 papers published, and INDIA ranks third with 93 papers published. Figure 9 shows the co-authorship countries network based on published documents.

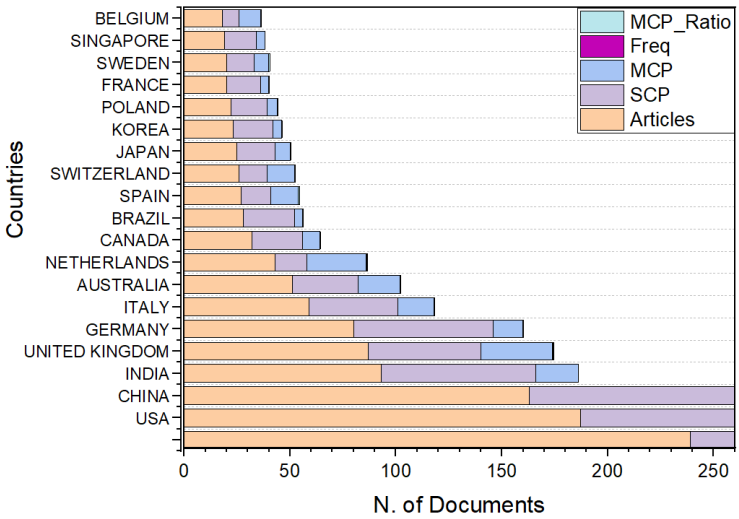

Fig. 8. Nation of the corresponding author. Collaboration between countries (SCP and MCP) between 2014 and 2023

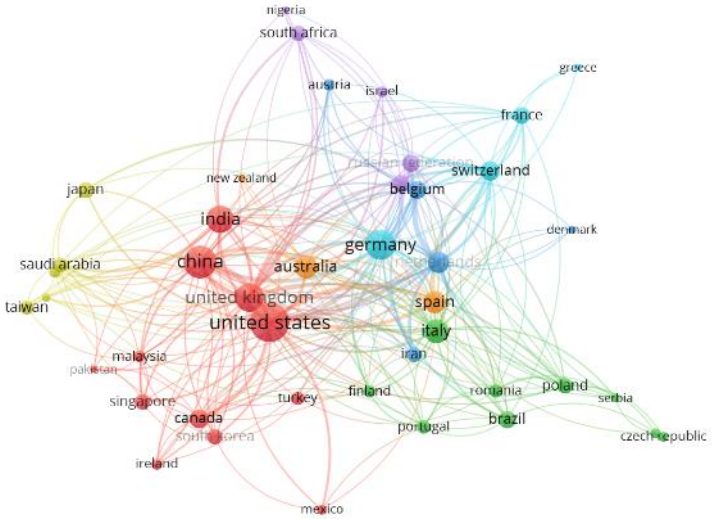

Fig. 9. Co-authorship countries Network visualization based on published documents

III.v. Keywords

Keywords are crucial elements in defining a topic of study and reflecting trends in science. This study focuses on the terms associated with biomedical implants in AM-related papers (Schmitt et al., 2021). The keyword identified the articles' most significant areas of expertise (Weismayer & Pezenka, 2017). Using nodes, the keyword co-occurrence network measurement shows the links between a variety of terms. The Scopus database was used to collect 1498 keywords in total. The keyword network and keyword count in the articles were used to analyze the research content. The association between phrases is shown using a top-keyword correlation matrix. When two keywords appear in the same article or record, the correlation value is one; otherwise, it is zero. Therefore, the correlations showed how frequently these two terms were used together during the investigation (Chang & Huang, 2012; Kalantari et al., 2017; van Raan, 2006). If there are several connections, it is clear that the two terms are often used in conjunction. If the value is low, there is a chance that the terms will change in the future. The possibility of merging top-appearing keywords in the future is increased by the low correlation number in the matrix. Figure 10 displays the terminology related to 3D-printed biomedical implants. 3D printers, titanium, porosity, and biocompatibility were the most frequently used phrases. Access control and distributed ledger technology are two words that have been used less frequently.

Keywords are crucial elements in defining a topic of study and reflect trends in science. The investigation places particular attention on the keywords that are utilized in papers on metallic biological implants in relation to AM. Keywords indicate each journal's primary expertise in the relevant topic field. Keyword combination analysis of networks uses nodes to show the relationships between multiple phrases.

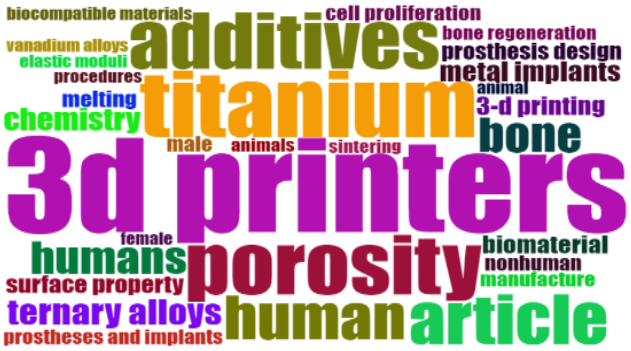

Fig. 10. Keyword Analysis

III.vi. Social Structure: Network of Collaboration

3D printed biomedical implants and their network structure is shown in Figure 11. As several nations write on the topic, only a narrow collaborative cluster can be identified. The following nations were included in the cluster: The United Kingdom of Great Britain and Northern Ireland, the United States of America, China, Canada, India, Australia, and Brazil. The analysis shows that, despite the greatest number of nations constructing the topics under consideration, there is no discernible pattern of interactive trends among them.

Fig. 11. Social Structure collaboration network (countries)

III.vii. Most Relevant Affiliations and Institutions

Figure 12 represents the graph between the Affiliation production over time to year of different institutes. Based on the number of publications they have produced this graph. In this top most scientifically productive institute is the Delft University of Technology.

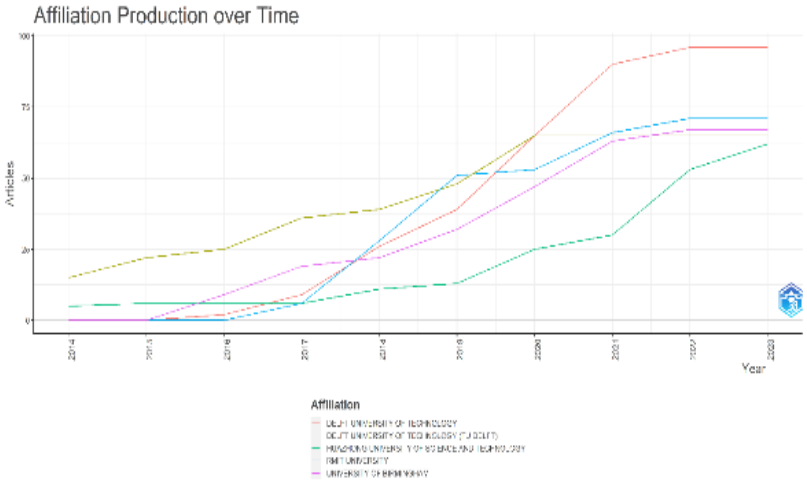

Fig. 12. Affiliation of the institutes

III.viii. Source Evaluations and Dynamics

After determining which sources had the largest influence on the scientific community with regard to 3D printing subjects in the construction sector, to examine how the top five sources varied from 2014 to 2023, a line chart displaying the current state of those sources was developed. The data for various source dynamics are included in Figure 13.

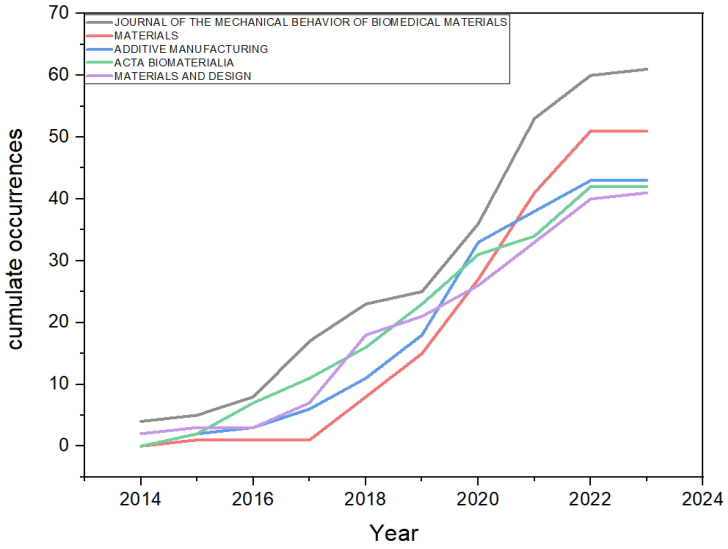

Fig. 13. Source trend dynamics

III.ix. Correspondence and Cluster Analysis: Word chart

Two primary groups can be observed on the factorial bidimensional map. The biomedical implant keywords in Figure 14 are used to identify the blue cluster, and the 3D printing process keywords were used as the secondary keywords.

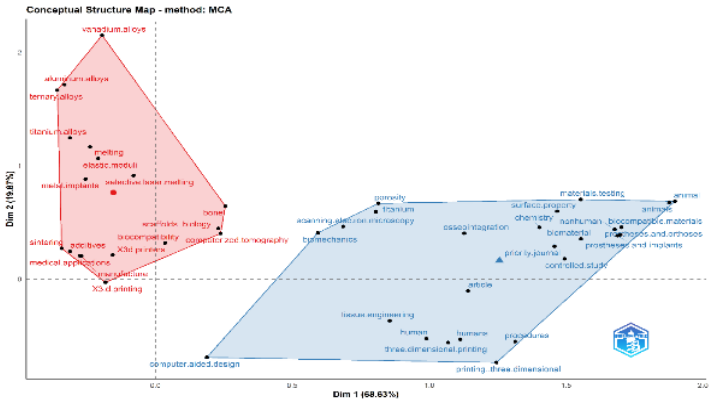

Fig. 14. Factorial analysis

III.x. Map of Themes: Strategic Diagram

The organizational structure of the strategy diagram from the analysis is shown in Figure 15. The quantity, shown on the x-axis, is the proportion of existing relationships to all potential ties. The density of each group's network runs from 0 to 1, where a value of 0 denotes the absence of any ties between individuals in the group and a value of 1 denotes the strongest level of linkage conceivable between every member of the group. The ordinate axis shows the significance, a property that identifies the nodes in a network with the most connections. In that they have more options for meeting their requirements, more opportunities to obtain resources, are seen as less reliant than others, and more central players may be in a better position than others. Four quadrants are shown in the strategic diagram: primary topic, secondary and tertiary themes, new or evaporating themes, and general and transverse themes.

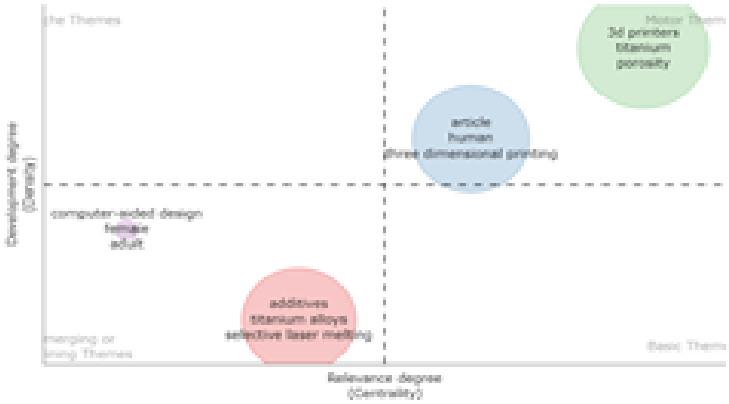

Fig. 15. Strategic diagram

III.xi. Local Effects on the Source (H index).

Figure 16 shows the research publications with the highest influence considering the H-Index as a standard for effect comparison. When it comes to publications among the top five publications, "JOURNAL OF THE MECHANICAL BEHAVIOUR OF BIOMEDICAL MATERIALS" is at the top of the list with an H-Index of 27, meaning it has 27 research articles with at least 27 citations, for a total of 2820 citations and 61 publications. "ACTA BIOMATERIALIA" (24 H-Index, 3158 citations, and 42 documents) was in second place, followed by "MATERIALS AND DESIGN" (also 24 H-Index, 1960 citations, and 41 documents), and "ADDITIVE MANUFACTURING" (22 H-Index, 1390 citations, and 43 documents) in fourth place. Finally, the MATERIALS SCIENCE AND ENGINEERING (18 H-Index, 1426 citations, and 26 publications) came in fifth place.

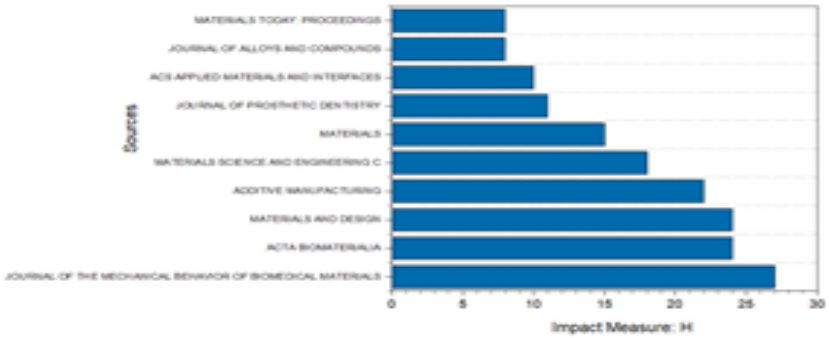

Fig. 16. Source local impact by H index

III.xii. Author Local Impact by H index

The authors with the greatest impact are included in Figure 17 using the H-Index as a measuring stick for impact. The top author in the ranking, ZADPOOR AA, has an H-Index of 26 (2990 citations and 39 documents), followed by WEINANS H in second place (16 H-Index, 2087 citations and 16 documents), ELAHINIA M in third place (13 H-Index, 814 citations and 17 documents), LIETAERT K in fourth place (13 H-Index, 1212 citations and 14 documents), and AMIN YAVARI S in fifth place.

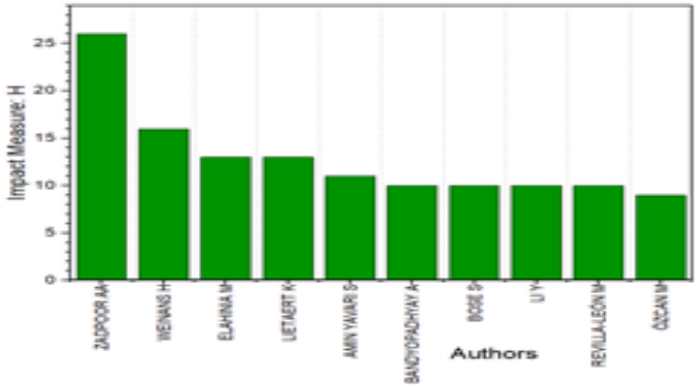

Fig 17. Author impact by H index

III.xiii. Annual Citation Count of Articles per Year

Figure 18 presents the average number of article citations per year, showing the fluctuation in citation counts over time. The year with the highest average citation count was 2014, which was primarily attributed to the publication of the most cited articles during that year. To provide more detailed information, that displays the annual article citations per year, offering a comprehensive breakdown of citation counts for each year.

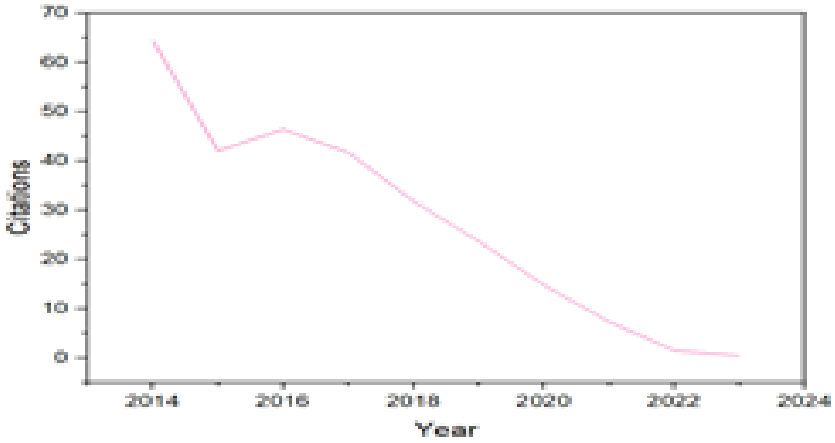

Fig. 18. Annual Citation Count of Articles per Year

III.xiv. Trend Topic

Figure 19 shows the trends from 2017 to 2022. 3D printing, power beds, and laser powders are the most trending topics in 2022.

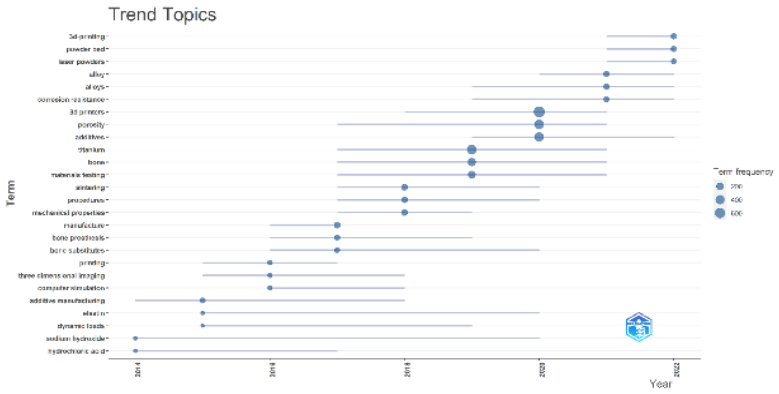

Fig. 19. Trend Topic

III.xv. Analysis of Most Cited Article Co-citation Network

Co-citation analysis is a commonly used technique in bibliometric analysis (Castanha et al., 2024; OSAREH, 1996). When two publications are cited in the same article, this is referred to as a co-citation. A prominent method in bibliometric analysis that focuses on the connections between these cited publications is the co-citation network. The co-

citation network revealed the most frequently co-cited references, indicating their strong influence within the field. The co-citation network of influential research articles is presented in the accompanying Figure. Each bubble in the diagram represents an individual research article, and the size of the bubble indicates the total number of citations received by that particular article. The thickness of the lines connecting two bubbles represents the strength of the co-citation ties between them. Additionally, the color of each bubble signifies the cluster or thematic grouping to which the article belongs. In Figure 20, each article is denoted by the author, year of publication, and journal in which it was published. The strength of the lines within the clusters indicates the intensity of the co-citation relationships among articles. Please note that the specific details and data presented in this response are fictional and only for illustrative purposes.

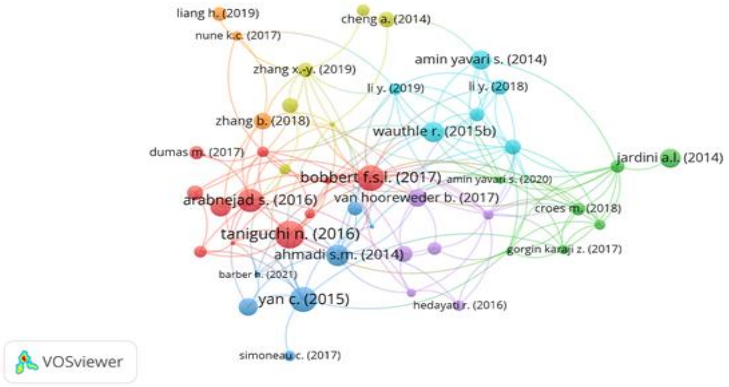

Fig. 20. Analysis of the Co-citation Network for the Most Cited Article

III.Xvi. Keywords Co-occurrence Analysis

Co-word analysis is another term used for one of the most commonly used bibliometric techniques, as shown in Figure 21. The number of articles with two keywords co-occurring is referred to as the "frequency of the combination of keywords," or "based on the frequency of the combination of keywords." The most commonly used phrases are effectively analyzed by co-word analysis, which enables the author to identify trends in a certain industry. The authors' keywords offered insights into significant research themes in the field. As a result, the current study identified keyword co-occurrence from the title, abstract, or authors.

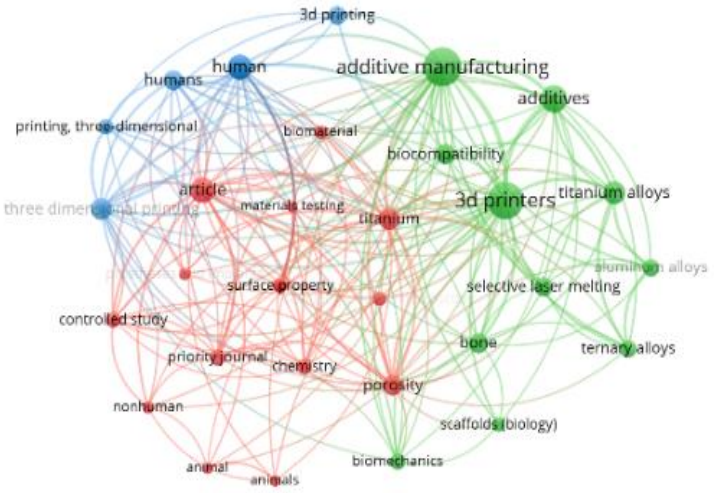

Fig. 21. Co-occurrence of Keywords

III.xvii. Most Relevant Sources

Figure 22 presents the results of the top ten most relevant sites that have concentrated on publishing research publications on 3D-printed biomedical implants. From figure 22 "The JOURNAL of the MECHANICAL BEHAVIOR of BIOMEDICAL MATERIALS" is the most relevant source in this field with 61 articles. Figure 23 shows the network visualization of the most relevant sources.

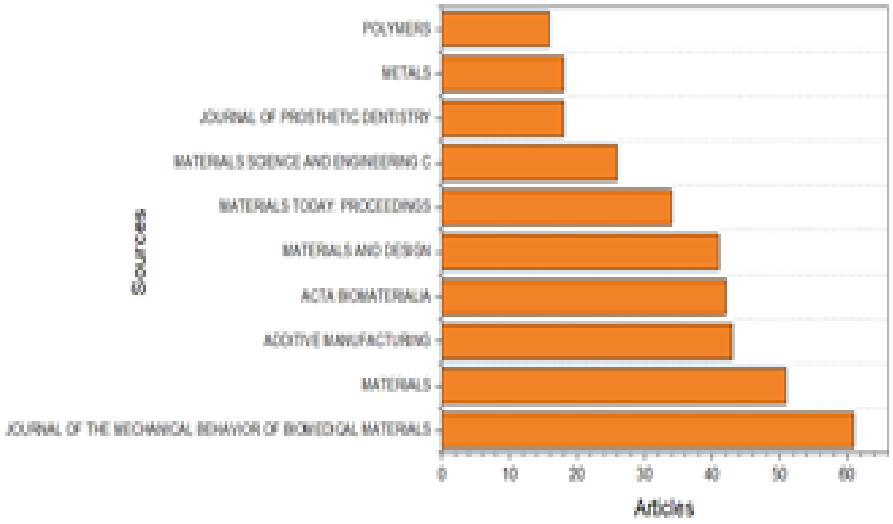

Fig. 22. Most Relevant Sources

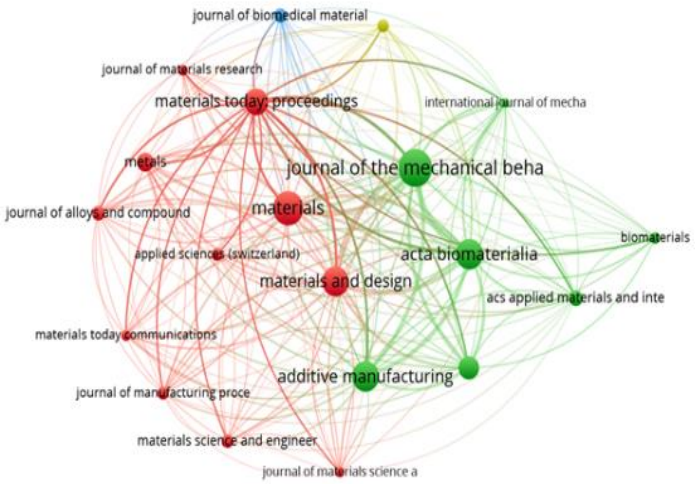

Fig. 23. Network visualization of most relevant sources

IV. Conclusion

The authors used scientometric analysis, which maps publishing trends to evaluate research output, to examine the research output of biofortification. The Scientometric concept is utilized in this study to determine research productivity, the top nations and organizations that excel in the subject, the most prolific authors, the most influential journals, and the most popular keywords, citations, and citation sources. The Scopus database was searched using a restricted search query and the defined inclusion criteria. Examination of scientometric data produced the following findings: Between 2014 country's scientific production 40 nations produced more than 10 research publications in the field of 3D printed biomedical implants. China scored the highest among the 40 nations and India is in 5th place. The number of citations was greatest in 2023. After 2017, there was an increase in publications, which reached a maximum by 2023. The USA is the top-ranking nation with 5372 citations. India was ranked 8th, with no citations of 1021. The author ZADPOOR AA, produced 39 publications. The other three authors (WANG L, LI Y, BANDYOPADYAY A) produced 21,19 and 17 publications, respectively. The USA came in first, with a total of 187 articles published. CHINA comes in second with 163 papers published, and INDIA comes in third with 93 papers published. The most frequent terms were 3D printers, titanium, porosity, and biocompatibility. Despite the fact that several nations have written on the topic, only a small collaborative cluster can be identified. The following nations were included in the cluster: the United States, the United Kingdom, China, India, Canada, Brazil, and Australia. Bradford's Law may be applied from this viewpoint to classify key journals in the field by identifying the most frequently referenced journals for a field or subject. In this top most scientifically productive institute is the Delft University of Technology. Source evaluations and dynamic graphs were provided from 2014 to 2023, and correspondence and cluster analyses were performed. The first ranking, "JOURNAL OF THE MECHANICAL BEHAVIOUR OF BIOMEDICAL MATERIALS", has an H-Index of 27, which indicates that it has 27 studies that have been cited at least 27 times, totaling 2820 citations and 61

publications. The first ranking, "ZADPOOR AA," has an H-Index of 26, which indicates that there are 2990 citations and 39 documents. The highest number of possible article citations per year was 2022. We found that 3D printers are a trending topic. One of the most frequently used techniques in bibliometric analysis is co-citation analysis. The “Journal of the Mechanical Behavior of Biomedical Materials" is the most relevant source in this field, with 61 articles.

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Conflict of Interest:

On behalf of all the authors, the corresponding author states that there are no conflicts of interest.

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