Bibliometric Analysis of Documents in Scopus, in the Field of Additive Manufacturing

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***Abstract*— The result of a bibliometric analysis of publications in Scopus, including the phrase Additive manufacturing in the abstract, or in the title, or in the keywords, is presented. The data used from Scopus was generated in September 2024. The analysis is specified in the field of engineering sciences, and for Bulgaria. Using the specialized software Vosviewer were created maps, that give an overall picture of the trends in the researched field. Such analyses are suitable for quick information about current trends on a selected topic and for tracking research on it over the years.**

***Keywords*—** *additive manufacturing, additive technologies, 3D printing, 3D modeling, bibliometric analysis, Vosviewer*

I. Introduction

Historically, the terms used to describe the processes of creating three-dimensional objects using 3D printers have undergone various changes [2], [5]. The many factors influencing the quality of printers, materials and products, as well as the methods for creating them, through this type of production, initiated the creation of the "Committee F42 on Additive Manufacturing Technologies" [1]. The F42 Committee, in partnership with "ISO/TC 261, Additive manufacturing", and in collaboration with Committee CEN/TC 438, Additive manufacturing", developed the standard "ISO/ASTM 52900:2015", which adopted the term additive manufacturing (AM) for these processes [7]. In the second revised edition "ISO/ASTM 52900:2021", the known categories and processes have been updated, as well as new ones have been added [8].

Getting to know the diversity of additive processes, the availability of new printing materials, the creation of new 3D printers, the development of their application in a number of industrial sectors, etc., require constant efforts from manufacturers and consumers. We recognize the need for ways to quickly inform about current trends in the field of additive technologies, and to track their development over the years. Modern scientific platforms, with published materials from authors from all over the world, allow such an analysis to be made.

Here we will present a bibliometric analysis of publications in Scopus, including the phrase "Additive manufacturing" globally, in the field of technical sciences, and for Bulgaria. Using the specialized software Vosviewer [19], maps have been created that give an overall picture of the trends in the researched field.

II. Analysis of Documents in Scopusm Containing the Phrase "Additive Manufacturing"

According to data from the entire Scopus database, the phrase "Additive manufacturing" occurs in 85,039 documents, when searching in the "Article title, Abstract, Keywords" mode, "Fig. 1". An increase in the number of published documents is noted after 2013, which will be the starting year of a more in-depth analysis using Vosviewer.

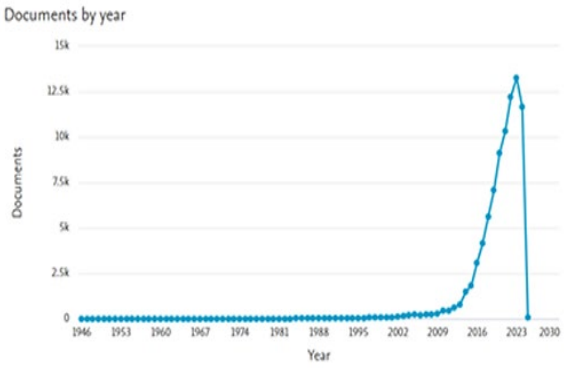

Fig. 1. Example of a figure caption

The distribution of documents according to the subject areas they refer to is given in "Fig. 2". The most published materials are in the fields of "Engineering" (31.8%), "Material science" (24.3%) and "Physics and astronomy" (10.9%). The values by field are between 2% and 6% higher compared to those for "3D printing".

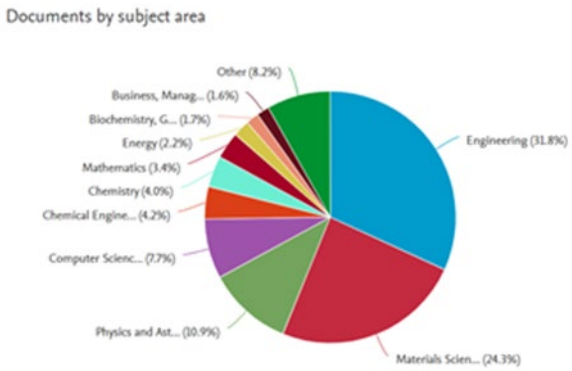

Fig. 2. Distribution of documents containing the phrase "Additive manufacturing" across the Scopus database by subject area (Source: Scopus).

USA (20,618 items) and China (13,900 items) have the highest number of published documents in terms of " Additive manufacturing", “Fig. 3”. The next countries with the most materials on the topic are Germany (8,292), India (6,121) and the United Kingdom (5,809).

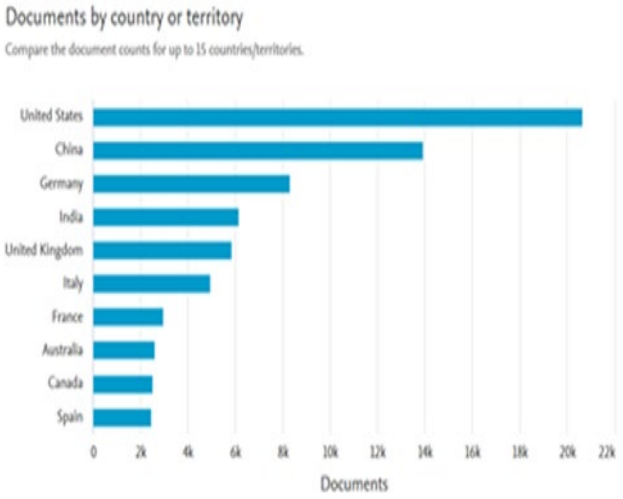

Fig. 3. Distribution of documents containing the phrase “Additive manufacturing” across the entire Scopus database, by country or territory (Source: Scopus).

A more detailed overview of the phrase “Additive manufacturing” was conducted for the period from 2013 to 2023, in the field of “Engineering”. According to Scopus data, as of September 2024, a total of 45,530 documents were published during the selected period, “Fig.4”.

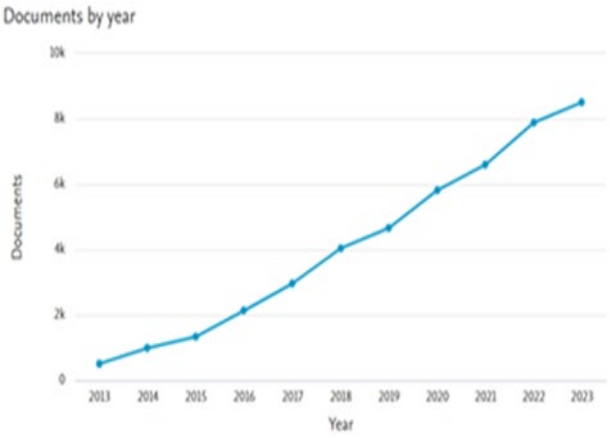

Fig. 4. Number of documents containing the phrase “Additive manufacturing”, in the field of “Engineering”, from Scopus, for the period 2013-2023. (Source: Scopus)

In this case too, the interdisciplinary scope of journals and conferences leads to the distribution of articles in more than one subject area. Therefore, although the condition is set to show documents only for “Engineering”, there are also documents in other areas. According to the ready-made schemes, the largest percentage of published documents, in addition to “Engineering” (44.2%), are also in the fields of Material science” (21.1%), “Computer science” (9%), “Psyics and astronomy” (8.2%), “Fig.5”.

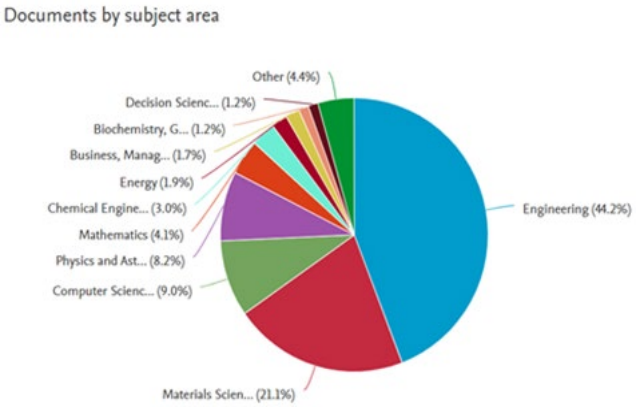

Fig. 5. Distribution of documents by subject areas in which the phrase “Additive manufacturing” occurs, for the field “Engineering” from Scopus, for the period 2013 - 2023. (Source: Scopus).

III. Bibliometric Analysis Using VOSViewer, in the Field of Engineering

To visualize a general scheme using Vosviewer, data from the first 20 thousand documents out of the 45,530 available on the topic, in the field of engineering sciences, were downloaded and used. “Fig. 6” shows a map of the connections between the countries that the co-authors noted when publishing their materials. An additional condition has been set in the settings to show only countries with at least 5 publications. Of all 181 countries in the analysis, 84 meet the specified condition. According to this network, authors from Bulgaria have common activities with China, Germany, India, Italy and Finland “Fig. 7”.

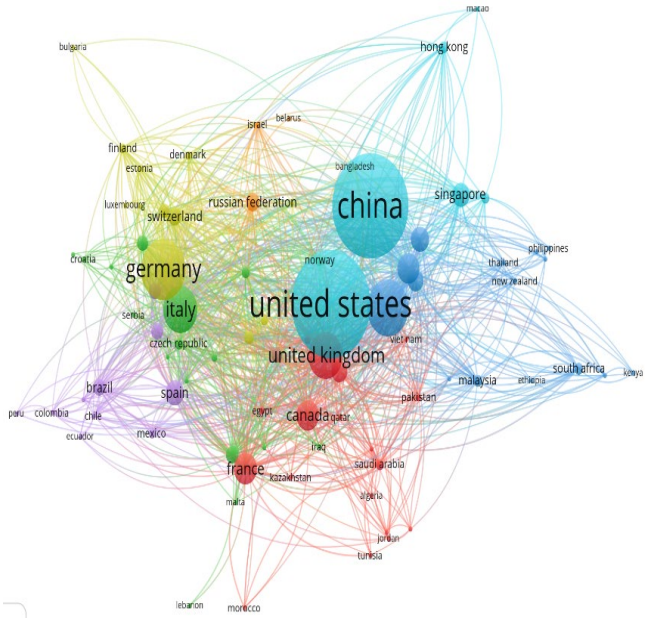

Fig. 6. Author-annotated countries in documents, containing the phrase "Additive manufacturing", in the field of "Engineering", in Scopus.

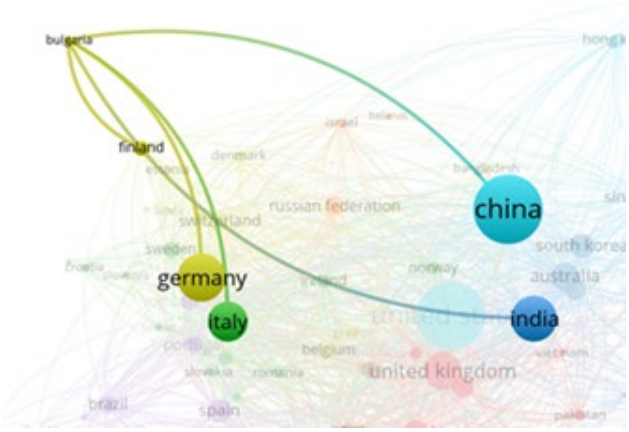

Fig. 7. Countries mentioned by authors with whom Bulgarian scientists have common publications.

"Fig. 8" shows the scheme made up of the 100 most common keywords in documents including the phrase "Additive manufacturing". The top 5 are: additive manufacturing, additives, 3d printers, 3d printing, 3-d printing. The repetition of the phrase 3D printing is due to its presentation in several variants, according to the place of the punctuation marks used. The following most common keywords include the phrases: "powder bed", "microstructure" and "aluminum alloys". The three keywords have independent connections and with each other. They are part of the same cluster and have at least 1 connection with a keyword from all other clusters.

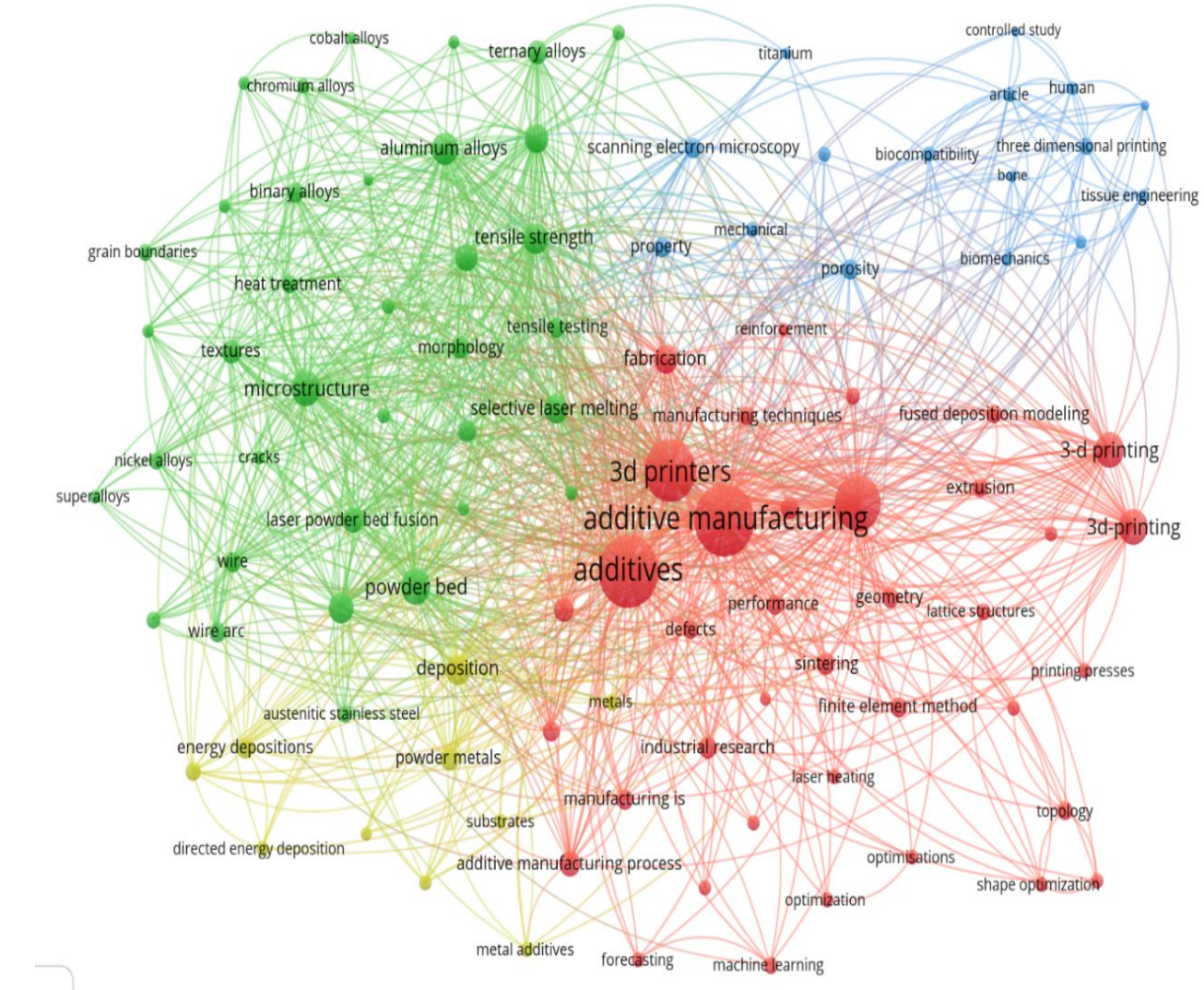

Fig. 8. Keyword in documents for the period 2013-2023, containing the phrase "Additive manufacturing", in the field of "Engineering", in Scopus, from 09.2024.

A complete list of the 100 most common keywords in the analysis on "Additive manufacturing" in the field "Engineering" are presented in Table 1, according to their distribution by cluster.

TABLE I. KEYWORDS USED IN THE PERIOD 2013-2023, WHEN SEARCHING IN SCOPUS FOR THE HRASE "ADDITIVE MANUFACTURING", IN THE FIELD "ENGINEERING", ACCORDING TO DATA FROM 09.2024.

Cluster	Keywords
Cluster 1 (38 items)	3-d printing; 3d printers; 3d printing; 3d-printing; additive manufacturing; additive manufacturing (am); additive manufacturing process; additive manufacturing technology; additives; computer aided design; computerized tomography; cost effectiveness; defects; extrusion; fabrication; finite element method; forecasting; fused deposition modeling; geometry; industrial research; laser heating; lattice structures; machine learning; manufacturing is; manufacturing process; manufacturing techniques; optimisations; optimization; performance; printing presses; process parameters; reinforcement; shape optimization; sintering; structural design; surface; roughness; topology; topology optimization.
Cluster 2 (36 items)	aluminum alloys; anisotropy; austenitic stainless steel; binary alloys; chromium alloys; cobalt alloys; corrosion resistance; cracks; electron beams; friction; grain boundaries; hardness; heat treatment; high strength alloys; iron alloys; laser powder bed fusion; laser powders; magnesium alloys; mechanical properties; melting; microstructure; microstructures and mechanical properties; morphology; nickel alloys; powder bed; selective laser melting; superalloys; tensile strength; tensile testing; ternary alloys; textures; titanium alloys; vanadium alloys; wire; wire arc; wire arc additive manufacturing.
Cluster 3 (16 items)	article; biocompatibility; biomechanics; bone; compressive strength; controlled study; human; mechanical; porosity; printing, three-dimensional; property; scaffolds (biology); scanning electron microscopy; three dimensional printing; tissue engineering; titanium.
Cluster 4 (10 items)	deposition; directed energy; directed energy deposition; energy depositions; laser beams; metal additives; metals; powder metals; residual stresses; substrates.

An option to summarize the clusters, according to the elements in them, is as follows:

- Cluster 1 contains keywords used to describe additive manufacturing processes and technical settings in the process itself, depending on the printer used.
- Cluster 2 includes keywords describing the necessary conditions and materials for the use of metals and alloys in additive manufacturing.
- Keywords in Cluster 3 are focused on additive manufacturing in the field of biomedicine.
- Cluster 4 lists keywords related to additive manufacturing technologies through metal processing.

The 10 most cited documents from the search for the phrase "Additive manufacturing" in Scopus, for the period 2013-2023, from the field of "Engineering", are given in Table 2. Self-citations are also included in the final number of citations.Before you begin to format your paper, first write and save the content as a separate text file. Complete all content and organizational editing before formatting. Please note sections A-D below for more information on proofreading, spelling and grammar.

TABLE II. TOP 10 MOST CITED DOCUMENTS IN SCOPUS, WHEN SEARCHING FOR THE PHRASE "ADDITIVE MANUFACTURING", FOR THE PERIOD 2013-2023, ACCORDING TO DATA FROM SEPTEMBER 2024.

№	Title, (Open access – OA)	Author, year	Times cited
1	Additive manufacturing (3D printing): A review of materials, methods, applications and challenges.	Ngo, T. et al. (2018)	5 442
2	3D bioprinting of tissues and organs.	Murphy, S., Atala, A. (2014)	5 153
3	Metal additive manufacturing: A review.	Frazier, W. (2014)	4 573
4	3D printing of polymer matrix composites: A review and prospective.	Wang, X. et al. (2017)	2 543
5	Additive manufacturing technologies: 3D printing, rapid prototyping, and direct digital manufacturing, second edition.	Gibson, I., Rosen, D., Stucker, B. (2015)	2 284
6	A 3D bioprinting system to produce human-scale tissue constructs with structural integrity.	Kang, H.-W. et al. (2016)	2 050
7	The status, challenges, and future of additive manufacturing in engineering.	Gao, W. et al. (2015)	2 042
8	Three-dimensional scaffolds for tissue engineering applications: Role of porosity and pore size.	Loh, Q., Choong, C. (2013)	1 996
9	The metallurgy and processing science of metal additive manufacturing.	Sames, W. et al. (2016)	1 892
10	3D bioprinting of vascularized, heterogeneous cell-laden tissue constructs.	Kolesky, D. et al. (2014)	1 680

Four of the most cited papers provide a detailed literature review of the existing materials, applications and technologies for additive manufacturing at the time of the study [6], [13], [17], [21]. All of them are open access. Four other papers consider additive manufacturing when using metals [14], [20], [22], with [25] being the only one in the table with closed read access. Liu and Shin investigated "the microstructures and properties of DED, SLM and EBMbuilt Ti6Al4V components, taking into account manufacturing constraints" [14]. Additive manufacturing in the field od biomedicine was investigated by Murphy and team who focused on the need for an interdisciplinary approach, since the creation of such tissues involves "selection of materials, cell types, growth factors, technical challenges related to the sensitivity of living cells and tissue construction" [15]; and by Wand and team, who considered the potential of using porous metals for "orthopedic regenerative medicine and the design of bone scaffolds and implants that replicate the biomechanical properties of host bones" [24].

IV. Scopus Literature Review in the Field of Engineering Sciences, for Bulgaria

The additional review in Scopus, when searching for the phrase "Additive manufacturing" for the field "Engineering", is limited only to the country/territory of at least 1 co-author from Bulgaria. "Fig. 9" shows the publication activity with this restriction. During the period 2013-2023, a total of 33 documents fall within the specified parameters.

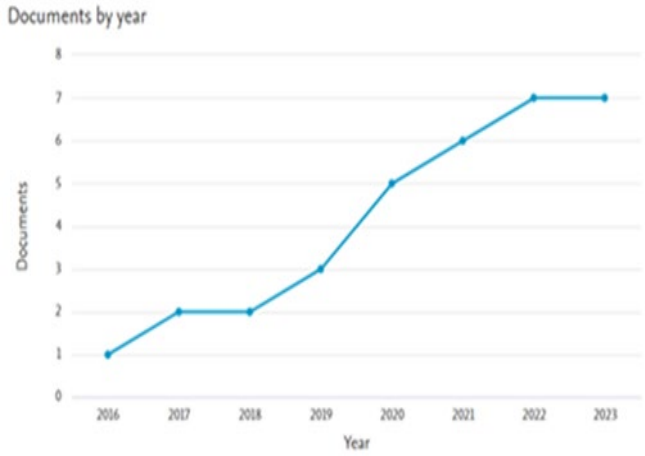

Fig. 9. Number of documents for Bulgaria containing the phrase "Additive manufacturing", in the field of "Engineering" from Scopus, for the period 2013 - 2023 (Source: Scopus)

Their interdisciplinary focus includes the areas shown in "Fig. 10". The most documents are in "Engineering" (38.3%), Material science (14.1%), Computer science (11.8%), Energy (10.6%) and Physics and astronomy (7.1%)

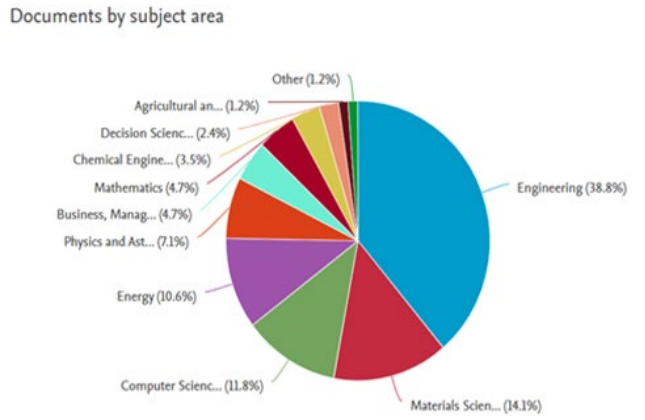

Fig. 10. Distribution of documents by subject areas, in which the phrase "Additive manufacturing" occurs, for Bulgaria, from the "Engineering" field, for the period 2013-2023 (Source: Scopus)

The type of documents is in the following distribution: conference publications (44.5%), journal articles (19.4%), book chapters (9.1%) and analysis (3.0%).

In addition to Bulgaria, some of the 33 documents have co-authors from 14 other countries, such as China, Germany, Belgium, India, Italy and others , "Fig. 11".

Table 2. shows the 10 most cited documents by authors from country/territory Bulgaria, when searching for the phrase "Additive manufacturing" in Scopus, for the period 2013-2023, in the field "Engineering". The number of citations in Scopus automatically takes into account and includes self-citations.

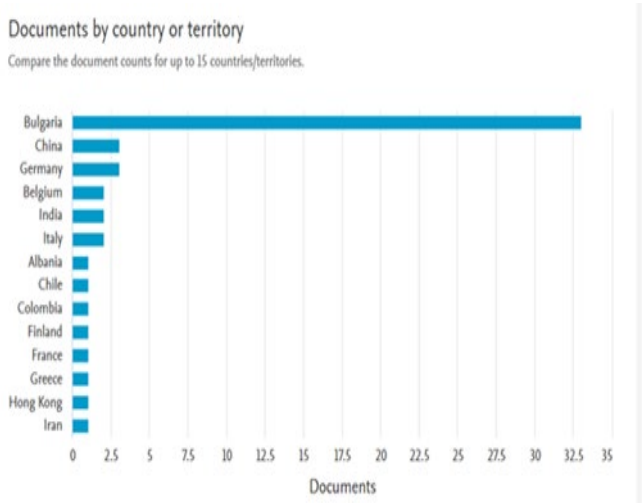

Fig. 11. Distribution of documents with phrase "Additive manufacturing", in Scopus, from the field "Engineering", for the period 2013-2023, with authors from the country/ territory – Bulgaria (Source: Scopus)

The authors, from the country/ territory Bulgaria, with the most published documents in which the phrase "Additive manufacturing" occurs in the title and/or abstract and/or keywords, are shown in "Fig. 12". According to the data from the ready-made analysis in Scopus, Marinova, I., Mateev, V., and Ralchev, M. have the most published materials - 9 issues, in which all three are co-authors. The remaining authors of documents, from the country/territory Bulgaria, have up to 2 published materials on the topic.

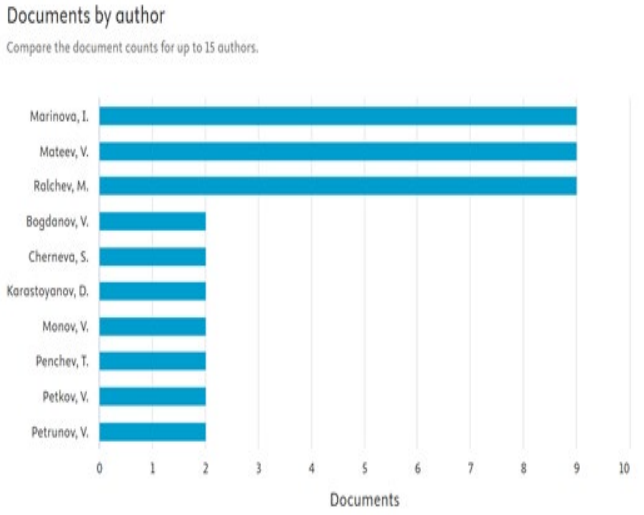

Fig. 12. Authors from country/ territory – Bulgaria, with the most published documents containing the phrase "Additive manufacturing", in Scopus, in the field of "Engineering", for the period 2013-2023. (Source: Scopus)

There is a diversity in the research areas of authors from the country/ territory of Bulgaria. Two of the documents in the table are closed access. From their publicly available

abstracts it is clear that they consider: "a method for magnetic material production suitable for 3D printing by Fused Filament Fabrication (FFF) technology… suitable for fabrication of complex shaped magnetic cores" [10]; and the "orientation of the manufactured products in 3D printing, using the technology of deposition of molten material, on the need to add supporting material" [16]. New methods in the production and use of materials for additive manufacturing are also considered in other documents. For example, Spinelli and team focused "on the basis of Polylactic acid (PLA) filled with two types of highly conductive nano-carbon materials, i.e. multi-walled carbon nanotubes (MWCNTs), graphene nanoplates (GNPs) and a combination of both fillers (MWCNT/GNP)" [4].

TABLE III. 10 MOST CITED DOCUMENTS BY AUTHORS FROM COUNTRY/TERRITORY BULGARIA, CONTAINING THE PHRASE "ADDITIVE MANUFACTURING" IN SCOPUS, FOR THE PERIOD 2013-2023, IN THE FIELD OF "ENGINEERING"

№	Title, (open access – OA)	Author, year	Times cited
1	Rheological and electrical behaviour of nanocarbon/poly(lactic) acid for 3D printing applications (OA).	Spinelli, G. et al. (2019).	62
2	Application of additive manufacturing for mass customisation: understanding the interaction of critical barriers (OA).	Shukla, M., Todorov, I., Kapletia, D. (2018)	59
3	Cicada-inspired fluoridated hydroxyapatite nanostructured surfaces synthesized by electrochemical additive manufacturing (OA).	Ge, X. et al. (2020)	39
4	Localised electrochemical processes on laser powder bed fused 316 stainless steel with various heat treatments in high-temperature water (OA).	Que, Z. et al. (2022)	16
5	Industry 4.0 for fashion products - Case studies using 3D technology (OA).	Spahiu, T. et al. (2021)	12
6	3D Printing of Magnetic Materials by FFF Technology.	Ralchev, M., Mateev, V., Marinova, I. (2020)	12
7	Food biotechnology: Innovations and challenges (OA).	Cabrera-Barjas, G. et al. (2021)	6
8	Development of a Fused Deposition Modeling System to Build Form-Fit Joints Using an Industrial Robot(OA).	Schwicker, M., Nikolov, N. (2022)	5
9	Using of 3D Printing Technologies in the Manufacture of Mechatronic Products.	Nikolov, S., Dimitrova, R., Dimitrov, S. (2022)	5
10	Innovative processing routes in manufacturing of metal matrix composite materials (OA).	Ružić, J. et al. (2021)	5

In [26] a "comparison of microstructure and high-temperature electrochemical behaviours between LPBF 316 and wrought 316 in simulated pressurized water reactor environment" was made, which is "critical for expanding their applications in nuclear and other high-temperature water environments". Ružić and team identified mechanical alloying as a suitable approach for the preparation of metal matrix composites (MMCs), showing "that by using adequate process parameters to obtain starting materials (reaching the specific size, shape, and reactivity) the control of volume fraction and distribution of reinforcements within the matrix can be achieved" [9]. In [11] the results of testing a robotic system (ARMS) to expand the scope of freedom in the application of the additive process FDM are presented. Cabrera-Barjas and team examined "food technology innovations and advances which will include agri-food technology, food packaging, 3D-food printing technology and biotechnology approaches" [3]. Ge and team designed an "antibacterial surface by combining the cicada wing-like nanopillar structure and the FHA together to potentially exert the advantages of physical and chemical antibacterial strategies simultaneously for battling the antibiotic-resistant pathogenic bacteria more effectively" [23]. Spahiu and team presented options for making differenct kinds of fashion items, noting the benefits of virtual environments for for detection and correction before printing [18]. Shukla and team are analyzing the reasons for the existing barriers for using additive technologies for mass customization, applying Interpretative Structural Modelling (ISM). Their literature review was supported by the opinions of experts in the field [12].

V. CONCLUSION

The analysis of the search results for the phrase "Additive manufacturing", in the field of "Engineering", globally and for Bulgaria, and most cited documents reviewed in Scopus, emphasize research related to: biomedicine and the use of metals in additive manufacturing; current reviews of generally existing technologies, materials and processes for additive manufacturing.

The Vosviewer software allows the analysis to be focused on leading authors, keywords, countries, as well as on the interrelationships between the elements included in the maps. Cluster distribution helps identify current scientific problems, insufficiently studied ones, citation patterns in scientific circles, as well as distinguishing the areas of their application.

Similar bibliometric analysis help to: coordinate trends in scientific and market phrases; discover interested organizations and co-authors for future joint activities; select appropriate scientific journals for sharing results, and others. Visual maps help to highlight key discoveries and track their impacts over time.

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