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Research Article

The Bibliometric Analysis of 3D Printer Research Development and Opportunities in Indonesia

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Abstract: Indonesia is a large country in the ASEAN region with great potential to apply 3D printing technology. However, due to the archipelagic nature of the territory, the distribution process between islands is time consuming and expensive. The problems were promoted by the government to move the National Capital to other islands to improve efficiency and affordability of distribution channels. With respect to this analysis, 3D printers is a solution to the logistical challenges because it presented an opportunity for technology development in the 4.0 era. The finished products have numerous advantages such as low cost, fast process, creation of complex shapes with simple processes, and enabled the use of various materials. Therefore, this research aimed to determine how the opportunities associated with the use of 3D printers will be determined in the future. The bibliometric analysis method was used to quantitatively overview the research. The results showed that the growth of 3D printers in Indonesia increased annually by 14.6% in various fields of science. Additionally, it explored Indonesia global position, frequently targeted publications, institutions with the highest contribution, collaborating countries, prevalent topics, and future prospects.

Keywords: 3D printer; Bibliometric analysis; Indonesia; Literature review

1. Introduction

Indonesia is the country with the most significant manufacturing value added in ASEAN in 2017 (Innovation, 2019). The country has a massive landmass, which is even larger than the total area of 11 Western European countries. Meanwhile, as an archipelagic country, most economic activities are centered on Java Island. This concentration resulted in lower product prices on this island compared to the others, due to distance constraints and expensive sea or air transportation. The government is currently working towards building a more affordable and faster route to connect the islands, aiming for a more evenly distributed economy. Additionally, the plan of the Indonesian government to move the National Capital to Kalimantan, also served as a catalyst for the development of this distribution channel.

The developmental process was supported by industry 4.0, a revolution used to transformed human life through advanced technologies connected to *cloud services*. The evolution era facilitated the rapid and straight forward integration of various systems, which is widely developed and widely adopted technologies in industrial 4.0 era known as 3D printing. This printing process

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can be carried out in a relatively faster time, used to make products with complex geometries, have easier operations, uses various materials, and lower production costs (Ambrus et al., 2019; Skawiński and Goetzendorf-Grabowski, 2019; Vilardell et al., 2019; Boyard et al., 2018; Tofail et al., 2018; Aremu et al., 2017). These advantages attracted multiple industries, including aerospace, military, food, manufacturing, automotive, electronics, etc (Herianto et al., 2020). Initially, 3D printing technology was used for rapid prototyping, creating product prototypes in a short period and produce finished products. However, due to the nature of adding material sequentially, this technology is also called layered manufacturing (Esslinger and Gadow, 2020; Fountas et al., 2020; Honarvar and Varvani-Farahani, 2020; Khosravani and Reinicke, 2020; Matos and Jacinto, 2019; Ngo et al., 2018; Rinaldi et al., 2018; Song et al., 2018).

The evolution of 3D printing technology helped to address the economic distribution challenges faced by Indonesia, and supports the relocation of the National Capital to another island. The technology prevents the need for expensive sea or air transportation costs.

The literature review method served as a valuable tool for summarizing and synthesizing technological advancements (Donthu et al., 2021). Technology, has been applied in various fields such as logistics (Cano et al., 2021), lean manufacturing (Driouach et al., 2019), Digital employee experience (Moganadas and Goh, 2022), and Labor Force (Mudzar and Chew, 2022). The literature review method was also used to assess the development of additive manufacturing technology. However, complexities were experienced because the number of publications were too large with broad topics. Meanwhile, to address these challenges, bibliometric analysis, offered a solution to effectively present current research development within a specific topic (Donthu et al., 2021).

Bibliometric analysis had been widely applied in several research fields. Ahmed et al. (2021), conducted a bibliometric review focusing on 3D printing research during the Covid-19 pandemic. Similarly, bibliometric analyses had been used to explore 3D printing applications in the health sector (Lin et al., 2023; Yang et al., 2023; Jin et al., 2022), food (Fasogbon and Adebo, 2022), and robotics (Aghimien et al., 2020). Presently, the research on 3D printing technology in Indonesia is lower compared to other nations such as China, America, Germany, Australia, and Japan. The present investigation addresses this disparity by discussing the current and potential future directives of 3D printing research in Indonesia. It serves as a valuable guide for several research conducted globally and offers insights that facilitate the collaboration of other countries, and individual cooperations.

2. Research Question

The research questions and objectives were used to identify, collect and analyze data. The bibliographic review was used to address the following questions and objectives, namely

Q1: What is the comparative position of 3D printing research in Indonesia on a global scale?

O1: The answer to this question aims to determine the position of 3D printing research globally, providing insights into the necessary efforts, and technological readiness required for competitiveness in Industry 4.0.

Q2: How does the development of publication numbers and citations in 3D printing research relate to Indonesia?

O2: The answer to this question aims to explain the history of 3D printing research in Indonesia and the concurrent efforts to advance additive manufacturing technology, through research development.

Q3: How does the characteristic of the published manuscript relate to 3D printing in Indonesia?

O3: The answer to this question aims to analyze the distribution of publications and identify potential target journals for further research. Additionally, it seeks to evaluate the quality of these publications in order to identify areas for improvement.

Q4: Which institution contributes significantly to the number of documents related to the theme of 3D Printing in Indonesia?

O4: The answer to this question aims to map the distribution of institutions that have conducted 3D printing research, providing valuable data for potential collaborations in research, patents, or manufacturing endeavors.

Q5: Which countries collaborate with Indonesia regarding the theme of 3D printing?

O5: The answer to this question aims to identify existing collaborative research relationships related to 3D printing as well as assess the strength. Furthermore, it seeks to explore potential collaborative opportunities that have not yet been established but show promise.

Q6: What are the frequent topics covered in 3D printing-themed publications in Indonesia?

O6: The answer to this question aims to identify prevalent research themes within 3D printing analyses carried out in Indonesia. The aim is to strengthen existing research areas and uncover unexploited potentials, thereby enhancing the novelty and increasing the number of publications in the country.

3. Method

The bibliometric analysis method was used to address the research questions, as well as analyze the literature to obtain a comprehensive understanding of the topic being studied. In addition, several research have adopted this method with data collected from articles indexed by Scopus (Ahmad et al., 2020; Huang et al., 2020; Martínez-López et al., 2018; Merigó and Yang, 2017; Rey-Martí et al., 2016). The objective of the bibliometric analysis was to examine reports on 3D Printing, discovering the history, development, opportunities, and future directions for research. A search query was used twice to ascertain the global research position on 3D printing, and ascertain the position of ss Indonesia. These searches were conducted on Monday, August 29, 2022, at 4:22 p.m.

First search query: *TITLE-ABS-KEY ("3d print" OR "3d printing" OR "additive manufacturing" OR "additive manufacture" OR "Layered manufacture" OR "Layered manufacturing" OR "3d-print" OR "3D-printing" OR "Selective Laser Sintering" OR "Stereolithography" OR "Digital Light Processing" OR "Electronic Beam Melting" OR "Selective Laser Melting" OR "Fused Deposition Modelling" OR "Laminated object manufacturing" OR "Photopolymer jet" OR "Ployjet" OR "Direct ink writing" OR "Fused filament fabrication").*

Second search query: *TITLE-ABS-KEY ("3d print" OR "3d printing" OR "additive manufacturing" OR "additive manufacture" OR "Layered manufacture" OR "Layered manufacturing" OR "3d-print" OR "3D-printing" OR "Selective Laser Sintering" OR "Stereolithography" OR "Digital Light Processing" OR "Electronic Beam Melting" OR "Selective Laser Melting" OR "Fused Deposition Modelling" OR "Laminated object manufacturing" OR "Photopolymer jet" OR "Ployjet" OR "Direct ink writing" OR "Fused filament fabrication") AND (LIMIT-TO (AFFILCOUNTRY , "Indonesia")).* The first query was used to find publication data worldwide, while the second was for Indonesia, accomplished by adding a limitation query using LIMIT-TO *(AFFILCOUNTRY, "Indonesia")*.

The query was based on both common keywords and specific methods related to 3D printing, intended to capture more relevant articles. This method ensured that even articles using less common terminology were included. In addition, data processing was carried out using vosviewer (Van Eck and Waltman, 2010) and biblioshiny software (Aria and Cuccurullo, 2017).

4. Results and Discussion

4.1. The position of 3D printing research in Indonesia compared to the world

Indonesia lags significantly in 3D printing research, ranking 45th in the number of publications compared to other countries such as America, China, Australia and Russia as shown in Table 1. Additionally, there is an annual increase in the global interest in 3D printing continues with 86 publications already expected in 2023, as shown in Figure 1, which means Indonesia need to intensify the research efforts in this field.

3D printing technology is a major part of the industrial revolution 4.0. As the world continues to advance, the application of sophisticated 3D printing would become more widespread. When Indonesia fails to bridge this gap, it risks falling significantly behind other countries in the future. Furthermore, research can be conducted independently or in collaboration with other countries, and such selection would be based on the number of publications made, as shown in Table 1.

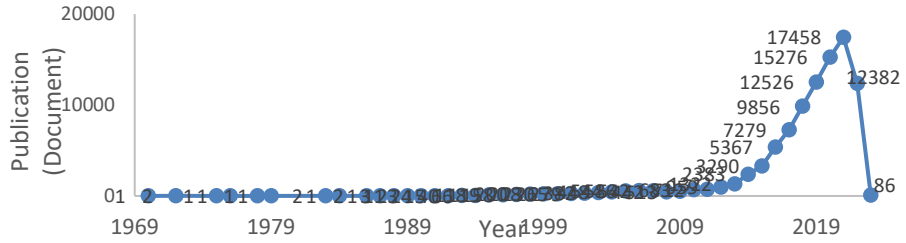


Figure 1 The development of publications (1970-2023)

Table 1 Top 50 countries by number of publications related to 3D print topics

No.	Country/ Territory	Publication (document)	No.	Country/ Territory	Publication (document)	No.	Country /Territory	Publication (document)
1	United States	23106	18	Brazil	1327	35	Danish	528
2	China	19540	19	Taiwan	1313	36	Norway	510
3	Germany	7618	20	Belgium	1189	37	Israel	478
4	United Kingdom	6623	21	Sweden	1129	38	Mexico	455
5	India	4418	22	Turkey	1033	39	New Zealand	414
6	Italy	4377	23	Portugal	999	40	Thailand	377
7	Australia	3224	24	Austria	979	41	Egypt	362
8	South Korea	3129	25	Czech Republic	912	42	United Arab Emirates	353
9	France	3055	26	Malaysia	865	43	Slovak	318
10	Russian Federation	2596	27	Iran	811	44	Pakistan	241
11	Canada	2554	28	Hong Kong	807	45	Indonesian	225
12	Japan	2526	29	Romania	714	46	Hungary	204
13	Spain	2336	30	Finland	693	47	Slovenian	204
14	Singapore	2262	31	South Africa	604	48	Viet Nam	193
15	Netherlands	1508	32	Saudi Arabia	584	49	Chile	192
16	Switzerland	1506	33	Greece	551	50	Ukraine	179
17	Poland	1477	34	Ireland	542			

4.2. The Publications in Indonesia

In Indonesia, 3D printing publications started in 2001, with only two research that have been cited 130 times. After the initial research, there was a gap till 2013, when the number continued to grow until 2021. In mid-2022, the number of manuscripts was greater than 50% of the total in the previous year as shown in Figure 2. The number of citations also increased rapidly, outperforming the growth in publications. The annual growth rate of documents is approximately 14.6%, and the most cited manuscript being Tontowi A. E. in 2001, with a total of 114 citations in the Rapid Prototyping Journal (Tontowi and Childs, 2001) as shown in Table 2.

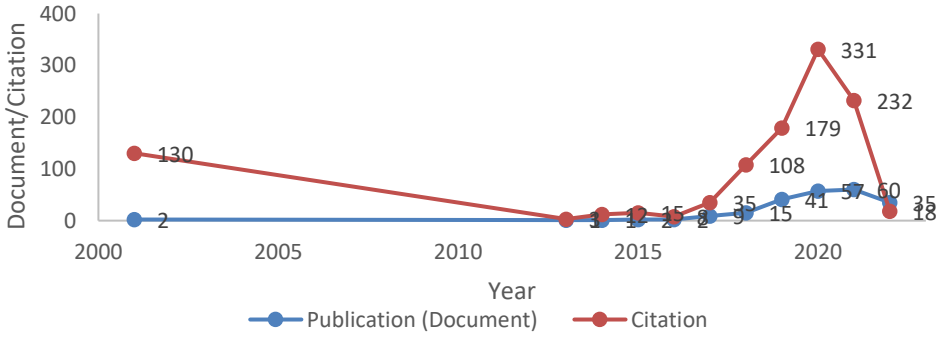


Figure 2 Publications and citations in Indonesia

Table 2 Most cited document in Indonesia

Paper	Total Citations
Tontowi Ae, 2001, Rapid Prototyping J	114
Arif Mf, 2020, Compos Part B: Eng	70
Ilyas Ra, 2021, Polym	67
Shie M-Y, 2019, Polym	54
Wibowo A, 2020, Mater	43
Das Ak, 2020, S Afr J Bot	39
Kristiawan Rb, 2021, Open Eng	37
Rosli Na, 2021, J Mater Res Technol	31
Gojzewski H, 2020, Acs Appl Mater Interfaces	30
Zadi-Maad A, 2018, Iop Conf Ser Mater Sci Eng	23
Gudjónsdóttir M, 2019, Magn Reson Chem	18
Wahyudi Ah, 2018, Ieee Int Workshop Antenna Technol, Iwat - Proc	18
Nasrullah Aih, 2020, Structures	16
Suteja Tj, 2020, J Phys Conf Ser	16
Hsiao Cc, 2001, Adv Space Res	16
Nurhudan Ai, 2021, J Manuf Processes	15
Marbelia L, 2020, J Membr Sci	15
Triyono J, 2020, Open Eng	15
Rismalia M, 2019, J Phys Conf Ser	15
Tanoto Yy, 2017, Aip Conf Proc	15
Dwiyati St, 2019, J Phys Conf Ser	13
Nugroho A, 2018, J Phys Conf Ser	13
Syuhada G, 2018, Aip Conf Proc	12
Arifin M, 2015, Energy Procedia	12
Suwandi D, 2014, Appl Mech Mater	12

The 3D printing technology developed in 2001 was a selective laser sintering method. The expensive cost of tools and materials posed a significant challenge to further research. Regardless of the database and parameters used, the research on 3D printing did not completely stop between 2001 and 2013. Instead, it was not detected in the search queries due to several factors such as unindexed journals, language barriers, or the use of more specific keywords related to material development, machine features, etc. For example, the research on laser sintering had been carried out since 1997, but these investigations were published in Bahasa and were not indexed in the Scopus database.

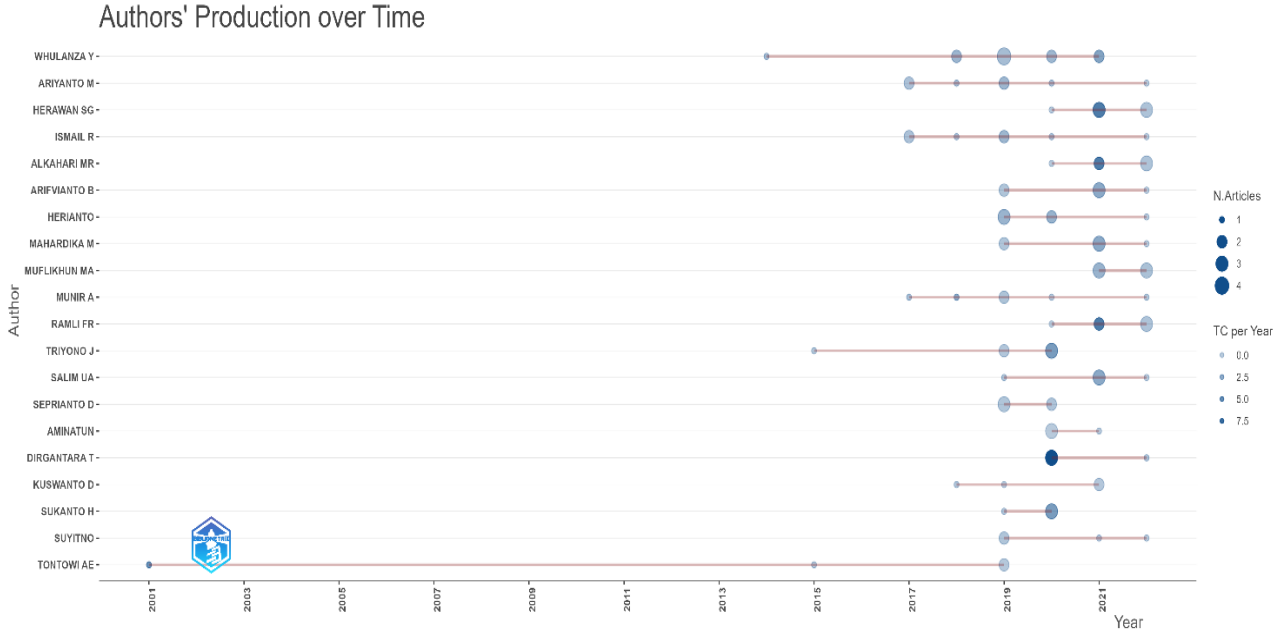
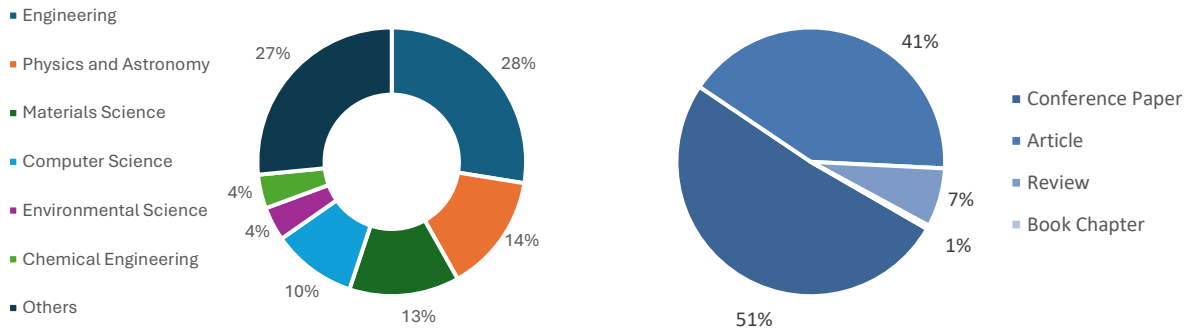


Figure 3 Publication Timeline based on the top 20 authors with the most publications

The number of research increased rapidly after 2013, coinciding with the development of fused deposition modeling technology (FDM) in Indonesia. This method shown in Figure 3, gained popularity due to the affordability and ease of use compared to selective laser sintering in terms of machinery and materials. In addition, advanced technological development made FDM more accessible, leading to an increase in research on 3D printing across various scientific fields. Engineering accounted for 27 percent of the research, followed by physics and astronomy, materials and computer sciences at 14%, 13%, and 10%, respectively. Other fields, such as environmental, chemistry, mathematics, earth sciences, business, etc also had significant contribution as shown in Figure 4(a).



(a) (b)

Figure 4 (a) Subject of research, and (b) Document types

4.3. Publication characteristics

Based on the data obtained, majority of the 3D printing research in Indonesia was dominated by conference papers (51%), followed by articles (41%). While the review papers constituted only 7% and the book chapter represented only 1% as shown in Figure 4(b). The highest number of publications were found in the AIP Conference, totaling 23 articles, followed by the IOP Conference Series materials, science, engineering and the Journal of physics, each with 17 articles. In accordance with this data, it was observed that the most publications were conference papers centered on these three sources, mainly due to extensive collaboration between international seminars in Indonesia and the publishers. It led to an opportunity for other publishers to cooperate with the organizers of international seminar in Indonesia considering the enormous market potential of the country.

The journals hosting research publications on 3D printing were mainly of high quality, with a prevalence of Q1 and Q2 journals as shown in Table 3. This indicated that the research conducted in Indonesia was of outstanding quality, regardless of the minimal quantity. Based on the data obtained, Polymers was the most cited journal with 140 citations, followed by the rapid prototyping journal with 125.

Table 3 The top sources based on citations per document (excluding proceeding)

Source	Document	Citation	Citation per publication	Citescore	SJR	H Index	Quartile
Materials	1	43	43	4.7	0.604	128	Q2
Rapid Prototyping Journal	3	125	41.66667	6.5	0.852	97	Q1
South African Journal of Botany	1	39	39	4.3	0.479	68	Q2
ACS Applied Materials and Interfaces	1	30	30	14.4	2.413	255	Q1
Open Engineering	2	52	26	2.2	0.209	28	Q3, Q4
Magnetic Resonance in Chemistry	1	18	18	4.3	0.456	76	Q2
Polymers	8	140	17.5	5.7	0.726	89	Q1
Advances In Space Research	1	16	16	4.7	0.613	99	Q2, Q3

Table 3 The top sources based on citations per document (excluding proceeding) (Cont.)

Source	Document	Citation	Citation per publication	Citescore	SJR	H Index	Quartile
Structures	1	16	16	3.1	0.835	29	Q1
Journal of Materials Research and Technology	2	31	15.5	5.9	0.964	59	Q1, Q2
Journal of Manufacturing Processes	1	15	15	7.6	1.315	64	Q1
Journal of Membrane Science	1	15	15	14.8	1.771	267	Q1

4.4. Institutions contributing to 3D printer research in Indonesia

Indonesia has thousands of universities spread across all parts of the archipelago. From the data obtained, research related to 3D printing also collaborated with other universities abroad. Furthermore, Universitas Gadjah Mada leads in the number of publications on this topic, followed by Universitas Indonesia and the Institut Teknologi Bandung as shown in Table 4. These top three ranking institutions are located in different regions, namely Yogyakarta, Jakarta, and Bandung.

Table 4 The number of publications by affiliation

AFFILIATION	Number of documents
Universitas Gadjah Mada	28
Universitas Indonesia	25
Institut Teknologi Bandung	24
Bina Nusantara University	15
Institut Teknologi Sepuluh Nopember	14
Universitas Airlangga	12
Universitas Sebelas Maret	12
Universitas Diponegoro	11
Universitas Kristen Petra	9
Lembaga Ilmu Pengetahuan Indonesia	6

Despite this geographic diversity, the research on 3D printing is mainly centered on the island of Java. Regarding the number of documents published, Whulanza (Nurhudan et al., 2021; Varian and Whulanza, 2021; Charmet et al., 2020; Nunut et al., 2020; Alief et al., 2019a; 2019b; Istiyanto et al., 2019; Syuhada et al., 2018; Whulanza et al.,2018; Damayanti et al., 2017; Suwandi et al., 2014) from the Universitas Indonesia ranked first with 11 papers, followed by Ariyanto et al. (2019, 2018), Taqriban et al., 2019, and Ismail (2022; 2020; 2017) from Universitas Diponegoro, Herawan (Che Mat et al., 2022; Mat et al., 2022; Rosli et al., 2022; 2021; Alkahari et al., 2021; Damanhuri et al., 2021; Ramli et al., 2020) from Universitas Bina Nusantara, and J. Triyono (Sukanto et al., 2020; Triyono et al., 2020a; 2020b; 2019; Achdianto et al., 2019; Solechan et al., 2019; Tontowi et al, 2015) from Universitas Sebelas Maret with seven documents each as shown in Table 5. The collaboration network between institutions on the theme of 3d printing in Figure 5(a), showed that some affiliates even cooperated with the counterparts abroad.

Figure 5(b), illustrated that the keywords for research at Universitas Gadjah Mada focused on FDM technology, measurement of mechanical properties or surface roughness, and the use of PLA as the primary material. However, recent research indicated an interest in the following keywords metal printing, composite, and framework. Figure 5(c) showed that the direction of research conducted by Universitas Indonesia was oriented towards the medical field with keywords such as clinical applications, treatment planning, penetrating cost, biocompatibility, binders, and ankle foot orthosis prominently featured. Meanwhile, Figure 5(d), illustrated the broad application of 3D printing technology. The research conducted at Institut Teknologi Bandung focused on the health sector, particularly bone tissue engineering, anti-infection scaffold, the generation of absorbable, and biodegradable implants. Additionally, there was a reappearance of research on horn antennas

in 2021. The absence of significant representation of medical-related research topics in Figure 4(a) suggested that the direction of development gained prominence only in 2021.

There are numerous opportunities for furthering the application of this technology. Meanwhile, Universitas Gadjah Mada had adopted a slightly different step with the following keywords metal printing and composite. The opportunities for developing these two materials are also huge, considering that weaknesses in FDM technology are often limited to mechanical properties or surface roughness.

Table 5 Top 3D print researchers in Indonesia

AUTHOR NAME	Affiliation	Publication (Documents)	H-index
Whulanza, Y.	Universitas Indonesia	11	11
Ariyanto, M.	Universitas Diponegoro	7	9
Herawan, S.G.	Universitas Bina Nusantara	7	6
Ismail, R.	Universitas Diponegoro	7	10
Triyono, J.	Universitas Sebelas Maret	7	6
Arifvianto, B.	Universitas Gadjah Mada	6	10
Herianto	Universitas Gadjah Mada	6	11
Mahardika, M.	Universitas Gadjah Mada	6	14
Muflikhun, M.A.	Universitas Gadjah Mada	6	8
Munir, A.	Institut Teknologi Bandung	6	15

4.5. Countries Collaborating with Indonesia

In respect to 3D printing research, 37 countries collaborated with Indonesia as shown in Figure 5 (e). Based on the results of the analysis carried out using VOS viewer software, seven clusters were obtained, and divided as follows

Cluster 1: Bangladesh, Brazil, India, Nepal, Sweden, Thailand, Vietnam
Cluster 2: Argentina, Bolivia, Italy, Japan, South Korea, Turkey, United Kingdom
Cluster 3: Bulgaria, Iraq, Malaysia, Pakistan, Slovakia, Tanzania
Cluster 4: Australia, Brunei Darussalam, Netherlands, Poland, Saudi Arabia, Singapore
Cluster 5: Germany, Hungary, New Zealand, Taiwan, United Arab Emirates, United States
Cluster 6: Iceland, Indonesia, Portugal, Russian Federation
Cluster 7: Belgium, Philippines

Examining the visualization results of cooperation between countries as showed in Figure 6, illustrated the extent of the relationship in conducting 3D printing in Indonesia. However, China, a major contributor to research related to this topic, has not collaborated with Indonesia or several African countries.

4.6. Frequently occurring topics

The prevalence of topics are measured by the number of appearances in keywords from the author, which are connected in Figure 5(f). Lighter or yellow color indicates a new topic in 2022, while darker shades denotes a pre-existing issue.

Figure 5(g) showed the most frequently appearing words, namely 3D printing, additive manufacturing, fused filament fabrication, 3d printer, rapid prototyping, mechanical properties, fused deposition modeling, polylactic acid, PLA, etc. The frequently used methods were FDM and FFF, which both require extrusion materials. While these methods offer cost-effectiveness and flexibility, challenges persist in achieving precision and smoothness in the final product. Keywords such as PLA or polylactic acid, were commonly used in FDM, with options including ABS, conductive, and flexible materials. The prominence of mechanical properties in the results indicated that 3D printing research in Indonesia is still in the early stages of testing the strength quality, with fewer explorations into broader applicable themes.

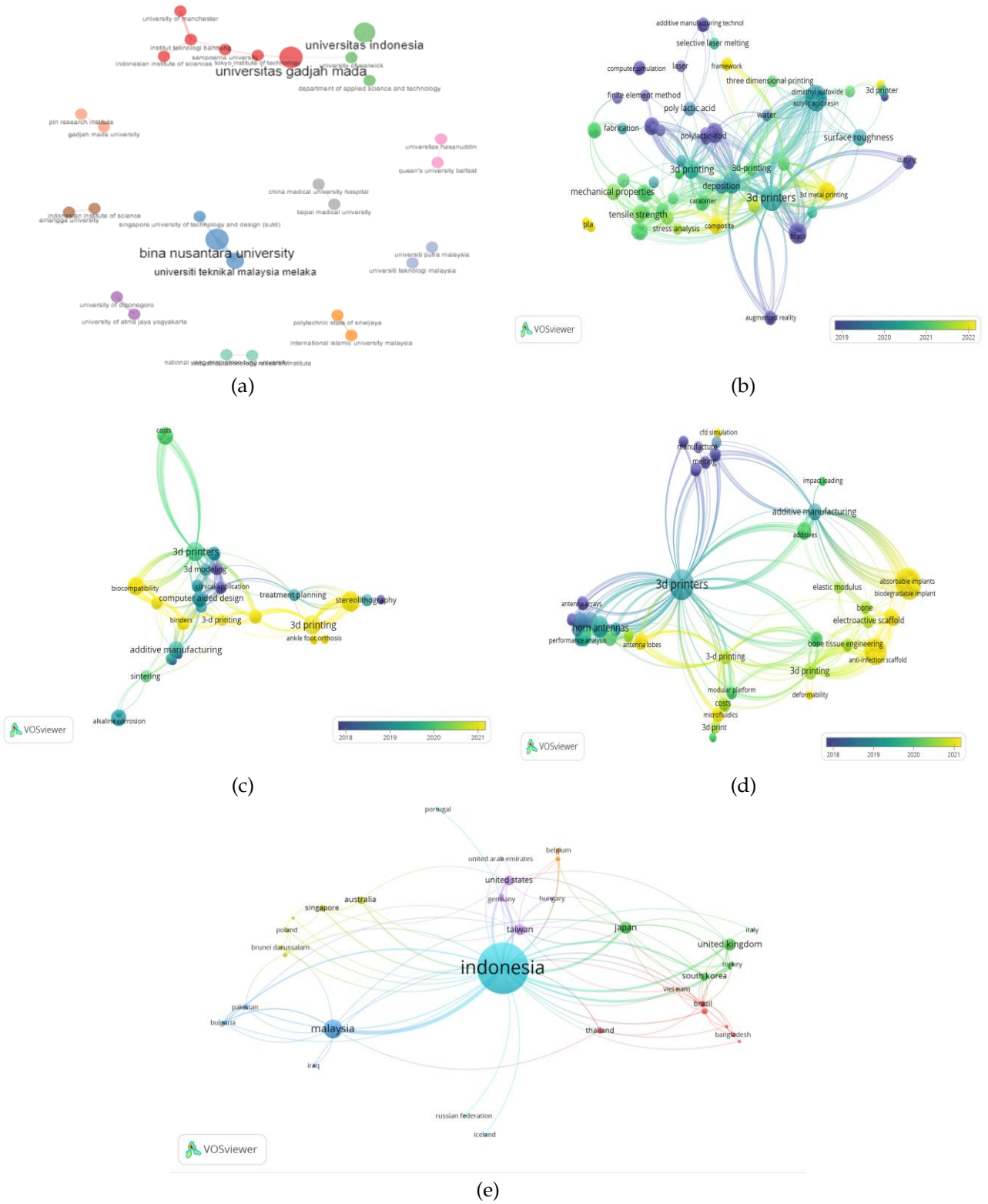
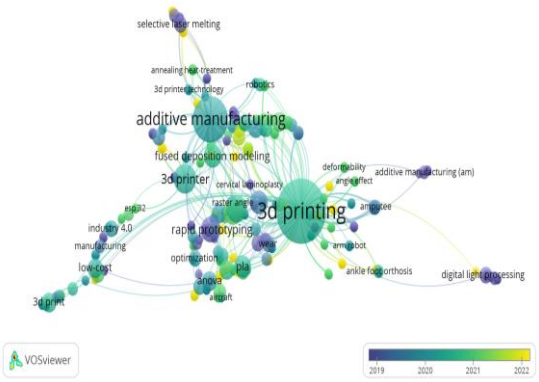
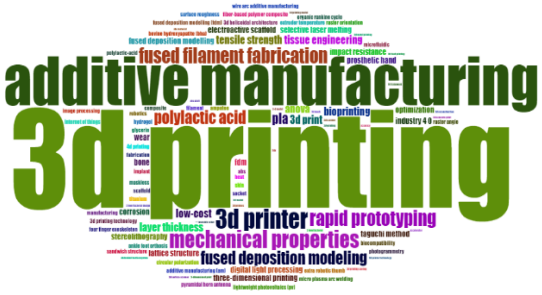


Figure 5 (a) Collaboration between institutions; Research's keyword visualization conducted by (b) Universitas Gadjah Mada; (c) Universitas Indonesia; (d) Institut Teknologi Bandung; (e) Collaboration between countries; (f) VOS viewer visualization for author's keyword; (g) Cloud word for author keywords



(f)



(g)

Figure 5 (a) Collaboration between institutions; Research's keyword visualization conducted by (b) Universitas Gadjah Mada; (c) Universitas Indonesia; (d) Institut Teknologi Bandung; (e) Collaboration between countries; (f) VOS viewer visualization for author's keyword; (g) Cloud word for author keywords (Cont.)

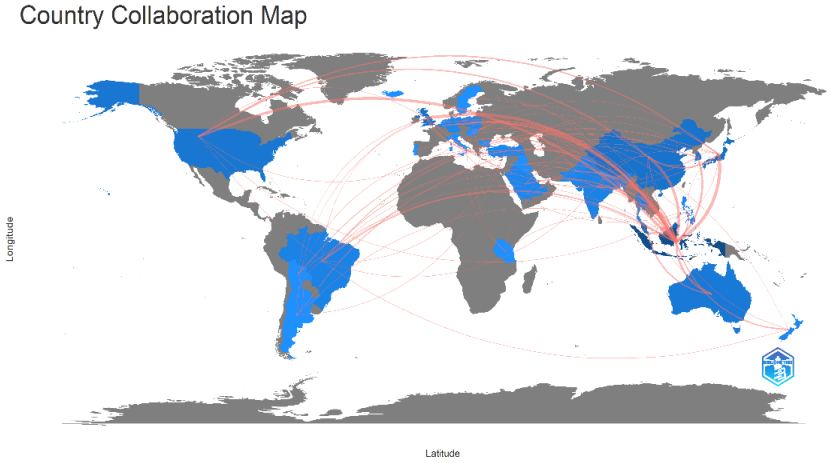


Figure 6 Collaboration map between countries

3D printing technology is increasingly considered as a substitute for manufacturing products or components made of various materials, including metals. However, challenges persist, particularly related to the mechanical properties. Several factors such as speed, nozzle, bed temperatures, nozzle size, printing direction and patternsignificantly influence these properties during the manufacturing process. Therefore, the continuous development of mechanical properties is critical for the advancement of this technology.

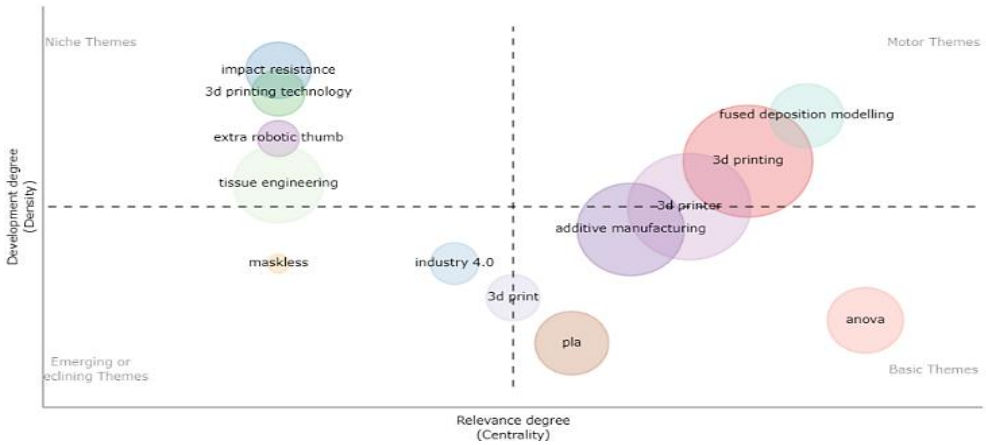


Figure 7 Thematic Map

The research on 3D printing focused on both technological advancements and the development of suitable materials. Although not directly connected to the keywords used, the research on materials is essential for advancing this technology in the country. Furthermore, the exploration of various application of 3D printing technology in the medical, culinary, and electronic sectors is in progress. The support from the government, companies, society, and all parties is crucial for fostering the development of this technology.

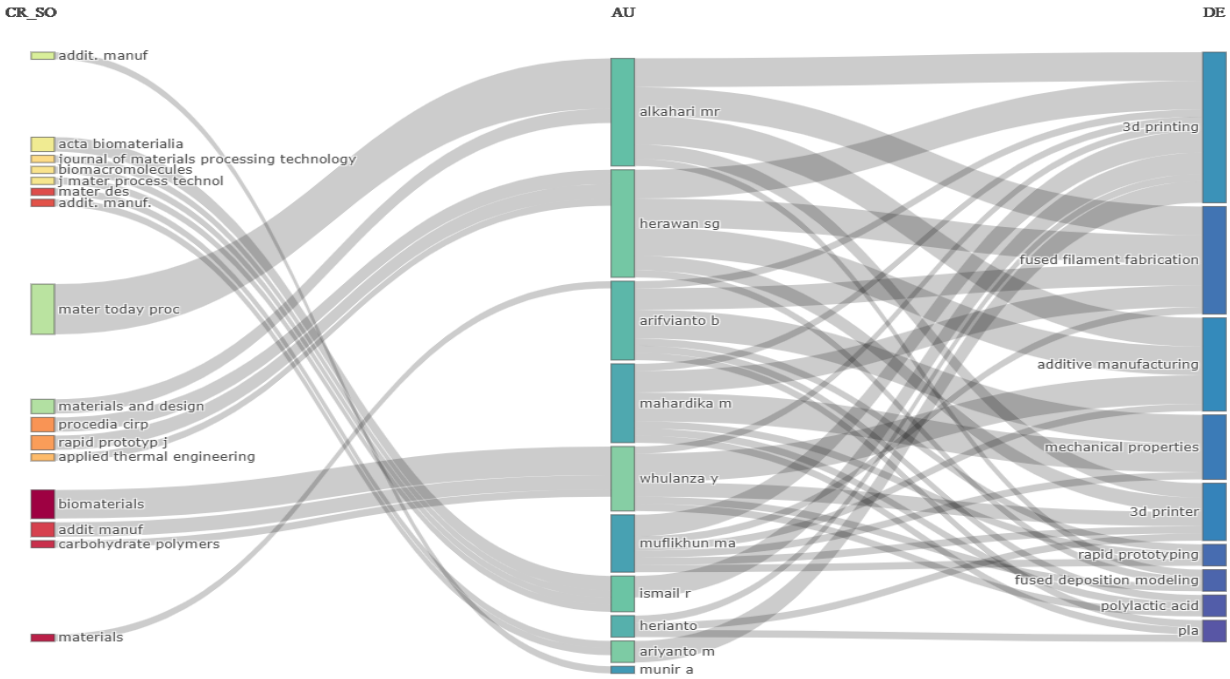


Figure 8 Relationship between cited source, author, and keyword author

The thematic map based on the author keywords describes four quadrants representing the positioning of 3d printing research in Figure 7. The niche themes comprised impact resistance, 3d printing technology, extra robotic thumb, and tissue engineering. Motor themes, consisted of the following keywords fused deposition modeling, 3d printing, and printer. The evolving or disappearing themes include maskless and industry 4.0, while the basic themes were PLA and ANOVA. Figure 8 shows the relationship between the cited sources on the left, authors in the middle, and author keywords on the right. In addition, the relationship illustrated how cited sources inspired authors in producing various keywords.

4.7. Discussion

The results of the bibliometric analysis showed that research on 3D printing in Indonesia mainly focused on mechanical properties. Meanwhile, several research opportunities can be carried out, such as 3D printing research in food (Enfield et al., 2022; Tejada-Ortigoza and Cuan-Urquizo, 2022; Zhang et al., 2022), health (Paradowska-Stolarz et al., 2022; Punia et al., 2022; Asriyanti et al., 2022), jewelry (Abisuga et al., 2022; Gaber Al-Khulaqi et al., 2022; Soares, 2022), robotics (Crowley et al., 2022; Shorthose et al., 2022; Zhou et al., 2022), etc.

Based on in-depth observations, it was discovered that the main research focus of the three most influential universities in 3D printing included metals, composites, antennas, and medical applications. In the future, these areas would undoubtedly become the axis of research in Indonesia, considering the enormous opportunities. Effective collaboration among the institutions led to the formation of particular research clusters, synergizing without redundancy. However, this division must be carefully analyzed to ensure consistency. The proactive participation of the government and relevant associations was crucial to realize research development in the desired direction.

Publicization was widely carried out in proceedings, indicating ongoing advancements in 3D printing technology. The proceedings served as markers, signifying pioneering research in the field. It provided the fastest media for disseminating research when compared to journals. Moreover, future research opportunities in 3D printing would be significantly developed. Publications in the form of articles, turned out to be able to penetrate high-quality journals. Meanwhile, Universitas Gadjah Mada, Universitas Indonesia, and the Institut Teknologi Bandung significantly contributed to the number of documents related to research in this field.

There were at least 37 countries that collaborated with Indonesia in the development of this technology. However, this number could still be increased further to promote more publications in the country. Certain countries, such as China and several African nations were yet to engage in collaboration efforts.

Indonesia mainly focused on FDM and FFF methods in 3D printing, overlooking other available options that could address the needs of the nation. Despite the cost-effectiveness, and accessibility of these methods, its usage posed challenges related to mechanical properties influenced by various factors. Therefore, investigating the influence of factors on mechanical properties and quality dimensions was essential. The research in this field was extensive, which led to the need for further exploration.

The material used also focused on PLA with the theme of mechanical properties, due to the widespread availability, affordability, and versatility in terms of texture and color. Indonesia had barely explored the potential of other materials and the industrial applications. Despite the growing demand for specific materials, such as those used for edible products, biomaterials for prosthetic limbs, conductive materials for electronics, as well as magnetic materials for various industrial purposes, further research and development were needed. As the application of 3D printing continued to expand, the need for specialized materials increased, driving a surge in research activities in this field. PLA is also the keyword that appeared most often in 3D printing research in Indonesia. This affordable and easy to obtain filament is commonly used in melt deposition modeling methods. However, various materials with unique characteristics are available and being sold freely to provide new research potential. These include conductive (Pejak Simunec and Sola, 2022; Stefano et al., 2022), magnetic (Amirov et al., 2022), and flexible materials (Herianto et al., 2019).

Preliminary research conducted in Indonesia showed promising quality and potentials for collaboration with counterparts from other affiliates and countries. Additionally, these research though in the early stages had the potential for further development, particularly in obtaining the final product and societal applications. Various themes such as perceptions, consumer needs, business implications, reciprocity, etc were open for exploration. The versatility of 3D printing technology enabled the generation of complex and artistic shapes, offering opportunities across diverse industrial sectors such as food, medicine, military weapons, sensors, electronics, automotive, medical devices, prosthetics, etc. Indonesia presented a substantial market for both research endeavors and practical applications of 3D print technology outcomes.

5. Conclusions

In conclusion, 3D printing research in Indonesia was still minimal compared to global standards. The research on this topic increased at an annual rate of 14.6 percent and continued. Despite the relatively few numbers of publications, the quality was commendable. The research on 3D printing was centered on Java Island, which made the development on other islands a significant challenge. Assuming this technology could be acquired later, distributing manufacturing products between islands, which required a lot of cost and time, would be resolved. Indonesia had already collaborated with 37 other countries and was expected to increase it even further. The bibliometric analysis provided a complete overview of the 3D printing research map as well as identified future research opportunities. However, it failed to focus deeply on the specific development of this

technology in the country. Therefore, the results obtained were supplemented with a literature review focused on a particular research theme in the field of 3D printing. This method contributed to the advancement of additive manufacturing technology in Indonesia.

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Author Contributions

H. Mastrisiswadi: conceptualization, data collection, analysis, writing-review & editing; M.K. Herliansyah: conceptualization, analysis, and supervision; W.P. Sari: conceptualization, review & editing, and supervision; A.E. Tontowi: supervision; and Herianto: conceptualization and supervision.

Conflict of Interest

The authors declare no conflict of interest.

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