Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AF07.20260426
Published: May 13, 2026

Exploring the Utilization of Blended Biodegradable Polymers in Additive Manufacturing Products Using Bibliometric Analysis

Kudzai Mudada
Industrial Engineering
Faculty of Engineering
Stellenbosch University, Stellenbosch, South Africa
30506433@sun.ac.za

Stephen Matope
Professor: Advanced Manufacturing Engineering
Industrial Engineering Department, Faculty of Engineering, South Africa
smatope@sun.ac.za

Abstract

This study explores the applications of biodegradable polymers across multiple fields. A systematic literature review was conducted using the Scopus database, and bibliometric analysis was performed with Biblioshiny to identify research trends, thematic development, and gaps in the field. The findings indicate that biodegradable polymers are predominantly used in biomedical applications (54%), followed by electronics (17%), aerospace and automotive sectors (13%), packaging (8%), and robotics (4%). Thematic analysis indicates that core areas such as 3D printing, biodegradable polymers, and sustainable development are well established but not yet fully developed. Co-occurrence analysis further highlights drug delivery systems as an emerging yet underexplored research theme. Geographically, research is concentrated in Asia and North America, with limited contributions from Africa, underscoring the need for greater regional research engagement. Overall, the study highlights both the growing importance and existing gaps in the field, particularly for biomedical applications.

Keywords
Additive Manufacturing; Blended biodegradable polymers; 3D printing; Drug delivery systems; Biomedical applications; Bibliometric analysis.

1. Introduction
Since biodegradable polymers first gained widespread attention in the early 1970s, they have been extensively studied in both academia and industry, passing through several key stages of development (Ebnesajjad 2012). Recently, factors such as sustainability, environmental concerns, and green chemistry have become central to shaping the future of materials, products, and processes (Abdelwahab et al. 2012). Increasing environmental awareness has prompted a shift from biostable materials to biodegradable alternatives that are environmentally compatible, thereby promoting a safe, eco-friendly environment across various applications. Environmental issues such as climate change and biodiversity loss are approaching critical thresholds or tipping points. Scientists estimate that the world is already surpassing safe limits for carbon dioxide levels and biodiversity loss (Makhijani et al. 2015). These issues are so complex that investing billions of dollars in projects to address them is just a drop in the ocean (Makhijani et al. 2015).

At the same time, additive manufacturing (AM), also called 3D printing, has become a revolutionary technology for producing complex shapes with high accuracy and low material waste(Gokul et al. 2025). Polymers are the most common materials used in AM due to their versatility, ease of use, and compatibility with techniques such as material extrusion, vat photopolymerization, and powder bed fusion(Gokul et al. 2025). Using biodegradable polymers in AM processes presents a promising route to sustainable manufacturing, merging material efficiency with eco-friendly design. Among these materials, polylactic acid (PLA) is widely used in fused deposition modelling (FDM) (as shown in Figure 1) due to its biodegradability, ease of processing, and commercial availability(Sandanamsamy et al. 2023; Joseph et al. 2023)

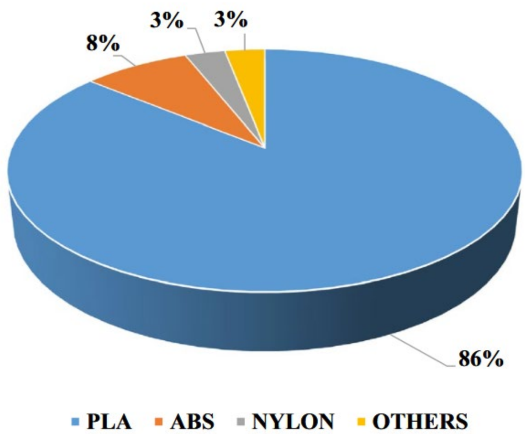


Figure 1. Pie chart representation of the base materials for FDM**.** Adapted from (Sandanamsamy et al. 2023)

Bibliometric analysis plays a crucial role in systematically mapping the development of this interdisciplinary field(Ellegaard 2018). By analyzing publication trends, keyword co-occurrence, citation networks, and collaboration patterns, bibliometric methods reveal research hotspots, influential authors, and emerging themes.

Therefore, examining the application of biodegradable polymers in additive manufacturing through a bibliometric lens is crucial for comprehending the current research landscape and pinpointing future directions. This approach not only uncovers technological advancements and material innovations but also reveals critical challenges and opportunities for achieving sustainable, high-performance AM products.

2. Methodology

A systematic literature search was conducted using the Scopus database. The search was performed within the fields: Article Title, Abstract, and Keywords, to ensure the relevance and precision of the results.

Initial exploratory searches were conducted using the keywords sustain and additive manufacturing to identify commonly used terminology in the field. Based on these preliminary results, a refined search string was developed to broaden coverage while maintaining focus, as shown in Table 1.

Table 1. Initial search results from the Scopus database

Search term	**Search field**	**Scopus**
Sustain* AND Additive manufacturing	Article title, Abstract, Keywords	1927
Sustain* OR biodegradable polymer AND additive manufacturing products	Article title, Abstract, keywords	470

"2016 to 2026		439
Sustain* OR biodegradable polymer AND additive manufacturing OR 3D printing products	Article title, Abstract, keywords	220
Sustain* OR blended biodegradable polymer AND additive manufacturing OR 3D printing	Article title, Abstract, keywords	24

2.1 Data Extraction

An intensive review of abstracts, introductions, subsections, and conclusions of publications was conducted to identify applications of biodegradable polymers across different fields in Table 2.

Table 2 . Application of biodegradable polymers in additive manufacturing products

Application of biodegradable polymers	**Field of application**	**Polymers**	**Fillers**
Cosmetic application(Santos et al. 2025)	Packaging	PHBV, PLA, Chitosan	
Manufacturing of tissues and organs, personalization of prostheses, orthopedic transplant, and anatomical replicas (Mandala et al. 2022)	Biomedical Engineering		
Customized way of drug delivery, distribution of drugs, and drug screening(Mandala et al. 2022)	Biomedical	Poly lactic Acid	
Anatomical model, Molar teeth, bone scaffolds with microvascular mimicking channels (Esposito Corcione et al. 2017)	Biomedical Engineering	PLA	nHA
Luminescent scaffolds with improved photo stability and non-photo bleaching characteristics (Dehghani et al. 2018)	Biomedical engineering	PLA	Collagen-derived COD
Antimicrobial scaffolds for tissue engineering with increased mechanical properties and enzymic stability. (Radhakrishnan et al. 2021)	Biomedical Engineering		
Scaffolds that heal bone deformation with a bioactive hybrid system(Hernandez et al. 2017)	Biomedical Engineering	Polycaprolactone	Hydrogel with alginate, gelatin

Meshes for wound dressing with antioxidant properties that enhance wound healing (Domínguez-Robles et al. 2019)	Biomedical Engineering	Polylactic Acid	Lignin
Chair connector (Daša et al. 2023)		Polylactic acid	Wood
Drug delivery systems (Gokul et al. 2025b; Panraksa et al. 2025)	Pharmaceuticals	Polylactic acid, polyethylene glycol	cassava pulp-derived fibers
Radiotherapy devices and Phantoms, Surgical instruments and guides (Gokul et al. 2025b)	Medical	Polylactic acid	
Training models and simulators (Gokul et al. 2025b)			
Food product packaging(Brailson Mansingh et al. 2023)	Packaging	Chitosan/Polylactic acid	
Soft robotics(Ali et al. 2024)	Robotics		
Bumpers for an automobile, internal door structures, and window panels (Soni et al. 2025)	Automobile	Polylactic aid	Banana Peel powder
Aerospace components (non-load bearing components) (Sibille et al. 2025)	Aerospace		
Scaffolds for bone regeneration with enhanced bioactivity (Yu et al. 2017)	Biomedical	1,6 –Hexanediol 1-phenylalanine-based poly (ester urea) (PEU)	Hydroxyapatite
Scaffolds increased hydrophilicity and cell behaviour, polyethylene glycol (Roh et al. 2017)	Biomedical Engineering	PCL	HA +Nano MgO
Strips with increased tensile strength, water resistance, and bacterial properties	Biomedical Engineering	PLA-g-MA	Chitosan
Scaffolds for bone regeneration with improved compressive strength, electrical conductivity, protein adsorption, and cell attachment (Gonçalves et al. 2016)	Biomedical Engineering	Poly Lactic Acid	

2.2 Results

The number of publications revealing the applications of biodegradable polymer products produced by additive manufacturing is shown in Table 3.

Table 3. Field of application of biodegradable polymers

Field of application	Number of publications
Biomedical	13
Electronics	4
Packaging	2
Automobile and Aerospace	3
Robotics	1
Others	1

These are graphically presented in Figure 2.

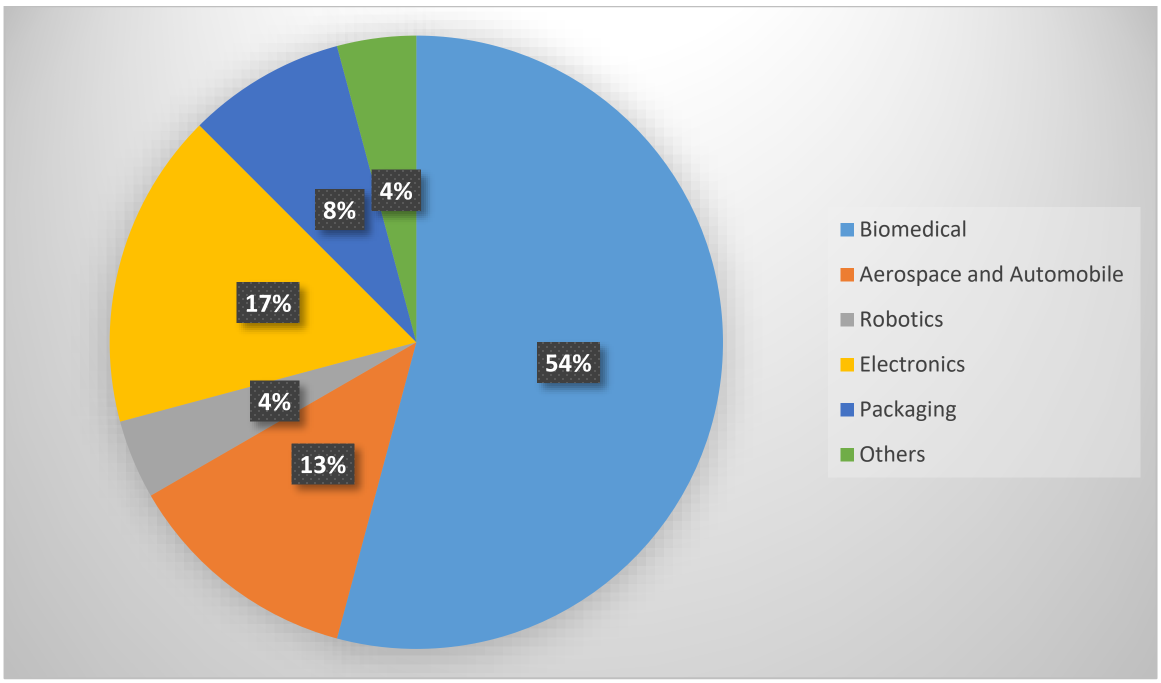


Figure 2. Application of Biodegradable polymers in industry

A pie chart based on 24 publications shows that 54% of studies focus on biomedical engineering, indicating that biodegradable polymers are primarily used in this sector. This supports the study and confirms the importance of biodegradable materials in additive manufacturing for biomedical applications. The trend highlights both the field's relevance and the need for further research into emerging applications.

3.1 Bibliometrix analysis

Bibliometric analysis has become increasingly common in the scientific community (Ellegaard 2018). Production and citation patterns reflect methodologies across disciplines within the specialized field of library and information science, as well as in non-specialist professional fields.

Bibliometrix was used to investigate the structure and patterns of information exchange within the field of distance education research and to interpret the interrelationships among the keywords identified in these articles

(Amoozegar et al. 2018). A total of 24 publications from the Scopus database were analyzed using the bibliometric packages, as shown in Figure 3.

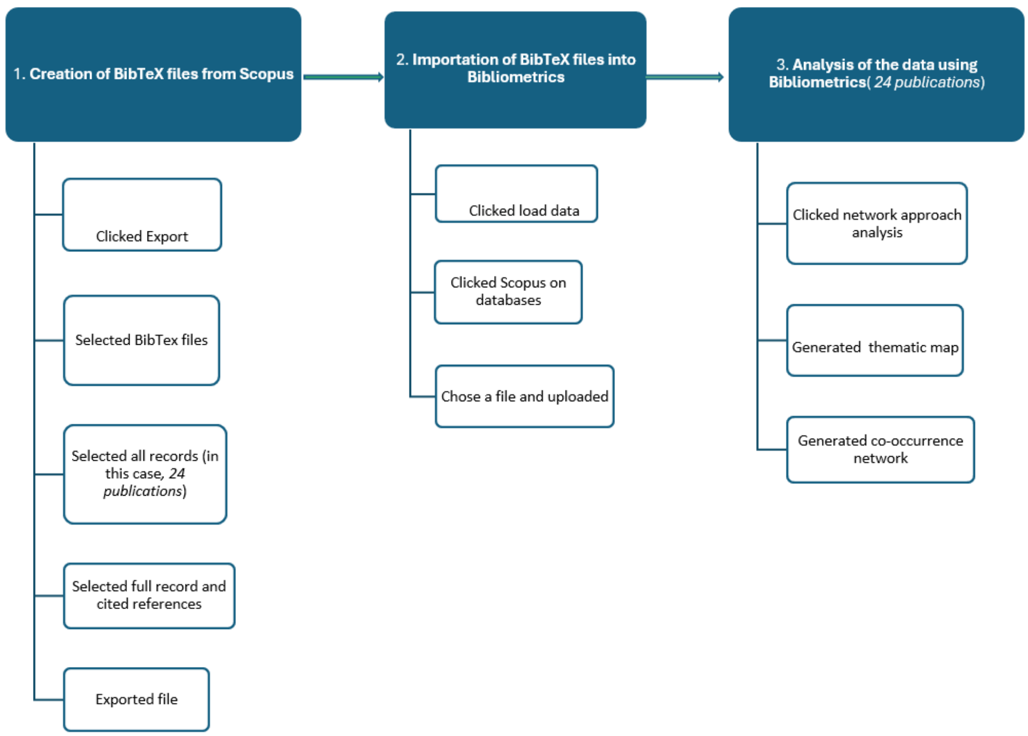


Figure 3 . Steps taken for Bibliometrics analysis

After conducting a bibliometric analysis of the selected body of literature, several analytical outputs were produced, including a thematic map (as shown in Figure 4), a co-occurrence network (as shown in Figure 5), and a geographical collaboration map (as shown in Figure 6)

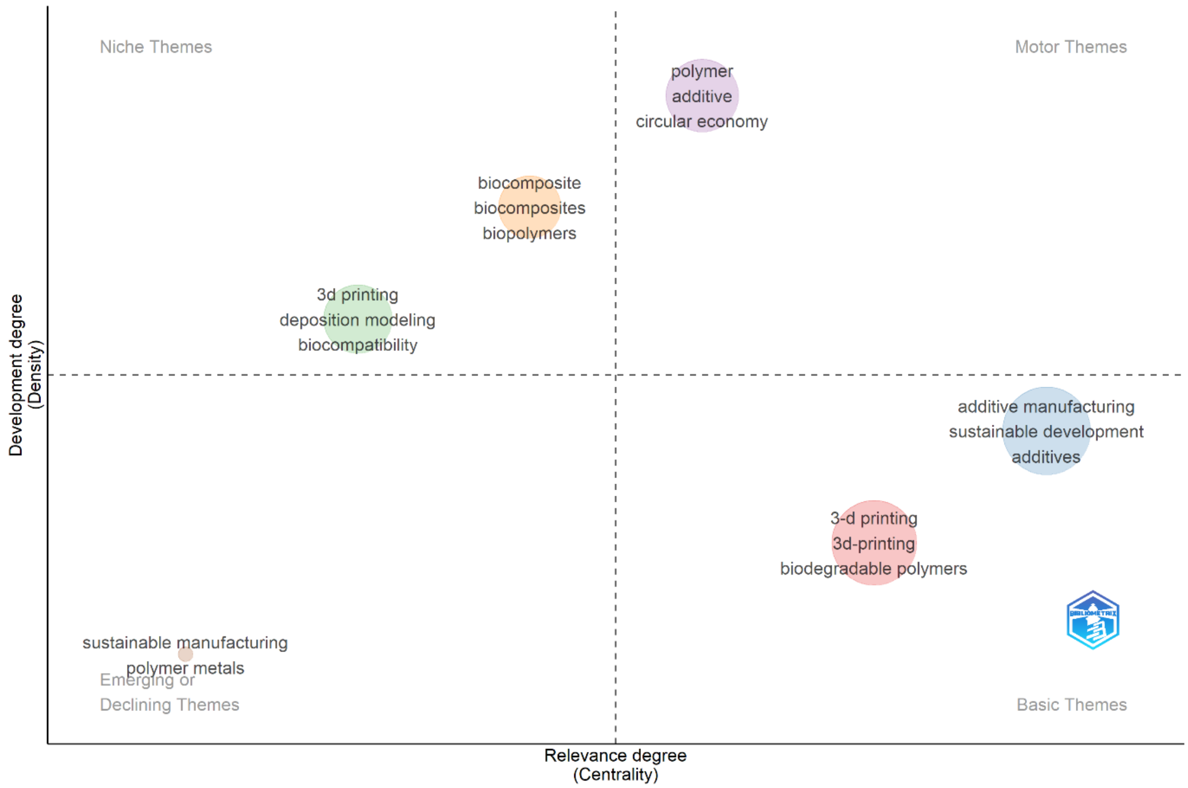


Figure 4. Thematic Map

3.1.1.1 Emerging or Declining themes

Within this thematic map (Figure 4), a theme's classification as emerging or declining reflects its relative developmental stage and degree of integration within its broader research field. Sustainable Manufacturing and polymer-metal systems are shown as emerging or declining themes, with low centrality and density. This positioning suggests that the theme is either in an early phase of scholarly exploration or experiencing a reduction in research attention. Therefore, the topic is neither central nor well-established in the field.

3.1.1.2 Niche themes

Within the thematic map, a niche theme is a topic that is well developed internally but has limited connections to the broader research field. As shown in Figure 4, the niche theme has high density and low centrality. This suggests that, although these areas of 3D printing, deposition modeling, and biocompatibility are mature and technically advanced, their application or integration into the wider field remains limited.

3.1.1.3 Motor themes

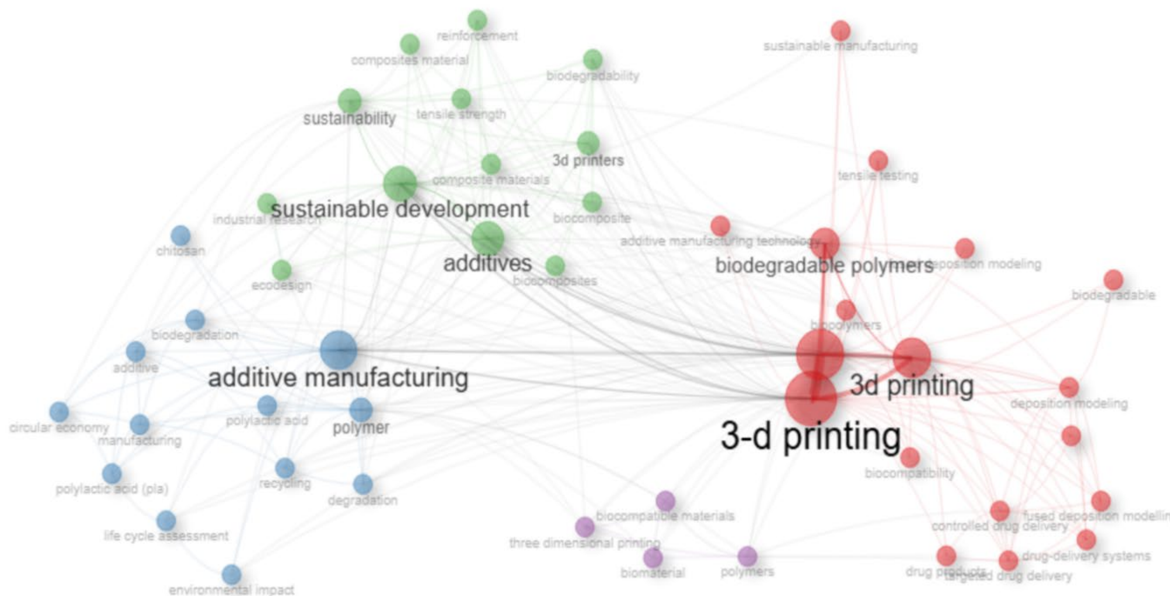
Motor themes are topics that are both highly developed (high density) and strongly connected to the broader research field (high centrality). These themes play a driving role in shaping the domain's direction and evolution. The positions of polymer additives and the circular economy in Figure 4 indicate that they are not only conceptually mature but also integral to ongoing research, actively influencing innovation, material design strategies, and sustainability practices across the field.

3.1.1.4 Basic themes

Basic themes are central to the research field but not yet fully developed. These themes form the foundation of the domain because they are widely connected to other topics, even though their internal development may still be evolving. The position of 3D printing and biodegradable polymers, additive manufacturing, and sustainable development in Figure 4 shows that these themes are essential, widely relevant, and fundamental, and that they are widely used across the research area, while still offering significant opportunities for further development and refinement.

3.1.2 Co-occurrence networking

In a co-occurrence network, visual elements such as dots, colors, and links represent different aspects of relationships among keywords or concepts in the literature, as shown in the key. Together, these elements help visualize the conceptual structure of the research field by highlighting key topics, thematic groupings, and the strength of relationships among them. According to Figure 5, keywords such as drug delivery systems, polylactic acid, circular economy, and biodegradability have small dots, indicating they are still emerging areas of study. In contrast, keywords such as 3D printing have larger dots, indicating they are used more frequently in studies.

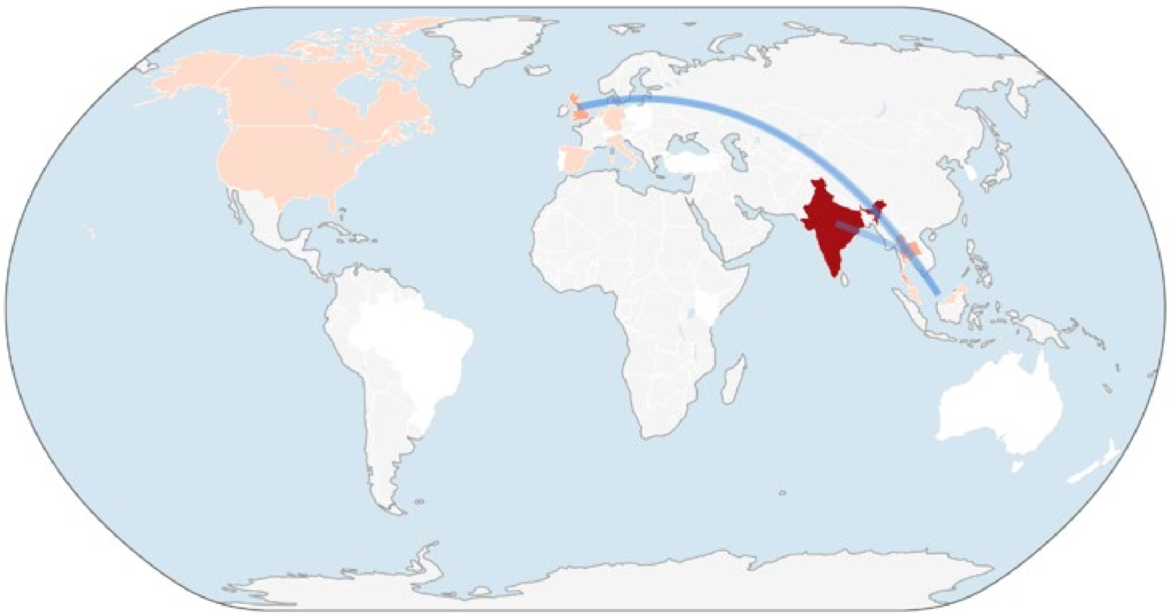


KEY
Dots -keywords
Size -frequency of occurrence
Colour -related keywords
Links(edges)-connections between keywords

Figure 5. Co-occurrence network

3.1.3 Geographical collaboration

Geographical collaboration in bibliometrics examines how researchers from different countries, regions, or institutions work together, as reflected in co-authored publications. The map shown in Figure 6 indicates that publications on these themes were mainly concentrated in Asia and North America. The curved link shows a strong connection between India and the United Kingdom in the research studies. India is the country that most prominently dominates, as shown in the diagram. Light orange countries (like the UK and parts of Southeast Asia) are collaborating countries.



KEY
Colors
Red-Main focus country
Light orange -collaborating countries
White -no collaborations
Curved line -connection or collaboration link

Figure 6. Geographical collaboration on biodegradable polymers

4. Conclusion

In conclusion, this study examined the use of biodegradable polymers in additive manufacturing for biomedical applications through a bibliometric analysis. The findings show that the key thematic areas, namely 3D printing and biodegradable polymers, as well as additive manufacturing and sustainable development, are central and highly relevant within the field. However, their positioning in the thematic map indicates that these topics, while important, remain underdeveloped and warrant further scholarly attention. Additionally, the co-occurrence network highlights drug delivery systems as an emerging research theme, suggesting a promising yet insufficiently explored intersection between biodegradable materials and advanced biomedical applications. This underscores a significant knowledge gap and an opportunity for future research to deepen investigation into targeted and controlled drug delivery enabled by additive manufacturing technologies. From a geographical perspective, the analysis shows that research output is predominantly concentrated in Asia and North America, reflecting established research capacity and collaboration networks in these regions. In contrast, the limited contribution from African countries points to a critical gap in regional research engagement. This imbalance underscores the need to strengthen research initiatives, infrastructure, and international collaboration in the African context to ensure more inclusive and globally representative advances in this field. Overall, the study highlights both the growing importance and the developmental gaps in the application of biodegradable polymers in additive manufacturing for biomedical products, providing a foundation for future research directions and policy considerations.

5. Recommendations

Looking ahead, there is considerable potential for future research to move beyond thematic exploration toward more specialized, application-driven studies. Future work should focus on optimizing the material properties of biodegradable polymers for specific biomedical applications, such as tissue engineering, implantable devices, and drug delivery systems. In addition, more focused studies are recommended to explore clinical translation, regulatory considerations, and the scalability of biodegradable polymer-based products. Long-term in vivo studies, cost-effectiveness analyses, and the development of standardized testing protocols would be particularly valuable in bridging the gap between laboratory and real-world medical applications.

References

Abdelwahab, Mohamed A., Allison Flynn, Bor-Sen Chiou, Syed Imam, William Orts, and Emo Chiellini. "Thermal, Mechanical and Morphological Characterization of Plasticized PLA–PHB Blends." *Polymer Degradation and Stability* 97 (9): 1822–28. 2012. https://doi.org/10.1016/j.polymdegradstab.2012.05.036.

Ali, Shafahat, Ibrahim Mostafa Deiab, and Salman Pervaiz. "State-of-the-Art Review on Fused Deposition Modeling (FDM) for 3D Printing of Polymer Blends and Composites: Innovations, Challenges, and Applications." In *International Journal of Advanced Manufacturing Technology*. Springer Science and Business Media Deutschland GmbH. 2024.https://doi.org/10.1007/s00170-024-14820-0.

Amoozegar, Azadeh, Rouhollah Khodabandelou, and Nader Ale Ebrahim. "Major Trends in Distance Education Research: A Combination of Bibliometric and Thematic Analyze." SSRN Scholarly Paper No. 3173980. Social Science Research Network, April 25. https://papers.ssrn.com/abstract=3173980. 2018.

Brailson Mansingh, Bright, Binoj Selvi Joseph Selvi, Zequan Tan, et al. "Characterization and Performance of Additive Manufactured Novel Bio-Waste Polylactic Acid Eco-Friendly Composites." In *Journal of Polymers and the Environment*, vol. 31. no. 6. 2023. Springer. https://doi.org/10.1007/s10924-023-02758-5.

Daša, Krapež Tomec, Oblak Leon, Kariž Mirko, and Kitek Kuzman Manja. "A Study on the Environmental Assessment of 3D Printing with Wood-PLA Composites." In *ICWST 2023 - 32nd International Conference on Wood Science and Technology: Unleashing the Potential of Wood-Based Materials, Proceedings*, edited by M. Klaric, R. B. Lucic, J. Jovanovic, N. Spanic, and K. Klaric. Faculty of Forestry and Wood Technology, University of Zagreb. 2023.

Dehghani, Alireza, Sara Madadi Ardekani, Mahbub Hassan, and Vincent G. Gomes. "Collagen Derived Carbon Quantum Dots for Cell Imaging in 3D Scaffolds via Two-Photon Spectroscopy." *Carbon* 131 (May): 238–45. https://doi.org/10.1016/j.carbon.2018.02.006. 2018.

Domínguez-Robles, Juan, Niamh K. Martin, Mun Leon Fong, et al. "Antioxidant PLA Composites Containing Lignin for 3D Printing Applications: A Potential Material for Healthcare Applications." *Pharmaceutics* 11 (4). 2019.https://doi.org/10.3390/pharmaceutics11040165.

Ebnesajjad, Sina. *Handbook of Biopolymers and Biodegradable Plastics: Properties, Processing and Applications*. William Andrew. 2012.

Ellegaard, Ole. "The Application of Bibliometric Analysis: Disciplinary and User Aspects." *Scientometrics* 116 (1): 181–202. 2018.https://doi.org/10.1007/s11192-018-2765-z.

Esposito Corcione, Carola, Francesca Gervaso, Francesca Scalera, Francesco Montagna, Alessandro Sannino, and Alfonso Maffezzoli. "The Feasibility of Printing Polylactic Acid–Nanohydroxyapatite Composites Using a Low-Cost Fused Deposition Modeling 3D Printer." *Journal of Applied Polymer Science* 134 (13). 2017.https://doi.org/10.1002/app.44656.

Gokul, K., Rittin Abraham Kurien, Kamonchanok Khoklang, Pornsak Sriamornsak, and Supakij Suttiruengwong. "Biodegradable Polymers and Biocomposites in Sustainable Additive Manufacturing: A Review." In *International Journal of Biological Macromolecules*, vol. 333. 2025a. Elsevier B.V. https://doi.org/10.1016/j.ijbiomac.2025.148611.

Gokul, K., Rittin Abraham Kurien, Kamonchanok Khoklang, Pornsak Sriamornsak, and Supakij Suttiruengwong. "Biodegradable Polymers and Biocomposites in Sustainable Additive Manufacturing: A Review." In *International Journal of Biological Macromolecules*, vol. 333. 2025b.Elsevier B.V. https://doi.org/10.1016/j.ijbiomac.2025.148611.

Gonçalves, Elsa M., Filipe J. Oliveira, Rui F. Silva, et al. "Three-Dimensional Printed PCL-Hydroxyapatite Scaffolds Filled with CNTs for Bone Cell Growth Stimulation." *Journal of Biomedical Materials Research Part B: Applied Biomaterials* 104 (6): 1210–19. 2016. https://doi.org/10.1002/jbm.b.33432.

Hernandez, Ivan, Alok Kumar, and Binata Joddar. "A Bioactive Hydrogel and 3D Printed Polycaprolactone System for Bone Tissue Engineering." *Gels* 3 (3). 2017.https://doi.org/10.3390/gels3030026.

Joseph, Tomy Muringayil, Anoop Kallingal, Akshay Maniyeri Suresh, et al. "3D Printing of Polylactic Acid: Recent Advances and Opportunities." *The International Journal of Advanced Manufacturing Technology* 125 (3): 1015–35. 2023.https://doi.org/10.1007/s00170-022-10795-y.

Makhijani, Komal, Ramkesto Kumar, and Sanjay K. Sharma. "Biodegradability of Blended Polymers: A Comparison of Various Properties." *Critical Reviews in Environmental Science and Technology* 45 (16): 1801–25. 2015.https://doi.org/10.1080/10643389.2014.970682.

Mandala, Radhika, Anjaneya Prasad Bannoth, Suresh Akella, Vijay Kumar Rangari, and Deepa Kodali. "A Short Review on Fused Deposition Modeling 3D Printing of Bio-Based Polymer Nanocomposites." In *Journal of Applied Polymer Science*, vol. 139. no. 14. 2022.John Wiley and Sons Inc. https://doi.org/10.1002/app.51904.

Panraksa, Pattaraporn, Pensak Jantrawut, Xin Yi Teoh, et al. 2025. "Formulation and Structural Optimisation of PVA-Fibre Biopolymer Composites for 3D Printing in Drug Delivery Applications." In *Polymers*, vol. 17. no. 18. Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/polym17182502.

Radhakrishnan, Socrates, Sakthivel Nagarajan, Habib Belaid, et al. 2021. "Fabrication of 3D Printed Antimicrobial Polycaprolactone Scaffolds for Tissue Engineering Applications." *Materials Science and Engineering: C* 118 (January): 111525. https://doi.org/10.1016/j.msec.2020.111525.

Roh, Hee-Sang, Chang-Min Lee, Young-Hyoun Hwang, et al. 2017. "Addition of MgO Nanoparticles and Plasma Surface Treatment of Three-Dimensional Printed Polycaprolactone/Hydroxyapatite Scaffolds for Improving Bone Regeneration." *Materials Science and Engineering: C* 74 (May): 525–35. https://doi.org/10.1016/j.msec.2016.12.054.

Sandanamsamy, L., W. S. W. Harun, I. Ishak, et al. 2023. "A Comprehensive Review on Fused Deposition Modelling of Polylactic Acid." *Progress in Additive Manufacturing* 8 (5): 775–99. https://doi.org/10.1007/s40964-022-00356-w.

Santos, Fátima, P. V. Rodrigues, Patricio Vargas, et al. 2025. "A Novel Fully Biobased Material Composite for Cosmetic Packaging Applications." In *Scientific Reports*, vol. 15. no. 1. Nature Research. https://doi.org/10.1038/s41598-025-10426-y.

Sibille, Alice, Maryam Ashkbous, Laurie Hélène Christine Doublet, et al. 2025. "The Sustainability of Recycled Polylactic Acid via Fused Filament Fabrication: Environmental Impacts across Cycles." In *International Journal of Advanced Manufacturing Technology*, vol. 137. no. 3. Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s00170-025-15281-9.

Soni, Ashish, Murugan Vellaisamy, and Dhinakaran Veeman. 2025. "Synergic Effect of Biofillers Reinforcements and Polylactic Acid on the Mechanical Performance of Biocomposites for Structural Applications." In *Clean Technologies and Environmental Policy*, vol. 27. no. 11. Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s10098-025-03270-1.

Yu, Jiayi, Yanyi Xu, Shan Li, Gabrielle V. Seifert, and Matthew L. Becker. 2017. "Three-Dimensional Printing of Nano Hydroxyapatite/Poly(Ester Urea) Composite Scaffolds with Enhanced Bioactivity." *Biomacromolecules* 18 (12): 4171–83. https://doi.org/10.1021/acs.biomac.7b01222.

Biographies

Kudzai Mudada is a master's student in Industrial Engineering at Stellenbosch University. He holds a B. Tech Honors degree in Polymer Technology and Engineering, providing a solid foundation for his advanced studies in materials and manufacturing systems**.** His academic and research interests focus on polymer science and engineering, with expertise in polymer processing, material characterization, and the evaluation of structure–property relationships in polymeric materials. He has developed strong analytical and experimental skills to understand how processing conditions affect material performance. Kudzai is particularly interested in developing advanced materials, including polymer blends, composites, and hybrid structures, for applications in sustainable manufacturing and high-performance engineering systems. His work integrates principles from materials science and industrial engineering to optimize processes and enhance product functionality. He is committed to advancing innovative, efficient material solutions that address real-world engineering challenges, with a focus on sustainability, performance, and industrial applicability.

Stephen Matope is a Full Professor in the Department of Industrial Engineering, Stellenbosch University, with over 16 years of lecturing on industrial engineering-related subjects at the university level. His research interests include advanced manufacturing, with a focus on additive manufacturing, manufacturing processes, and manufacturing systems.