talenta PUBLISHER

Jurnal Sistem Teknik Industri
Journal homepage: https://talenta.usu.ac.id/jsti

Additive Manufacturing in Prosthetics Field: A Literature Review

Rosnani Ginting*[1], Aulia Ishak[1], Fadylla Ramadhani Putri Nasution[1], Alfin Fauzi Malik[1], Putri Syahmina Atirah Bangun[2]

[1]*Industrial Engineering Study Program, Faculty of Engineering, Universitas Sumatera Utara, Medan, 20155, Indonesia*
[2]*Industrial Engineering Department, Faculty of Engineering, Universitas Andalas, Padang, 25175, Indonesia*
*Corresponding Author: rosnani@usu.ac.id

ARTICLE INFO

Article history:
Received 11 April 2025
Revised 5 May 2025
Accepted 20 July 2025
Available online 31 July 2025

E-ISSN: 2527-9408
P-ISSN: 1411-5247

How to cite:
Ginting, R., Ishak, A., Nasution, F. R. P., Malik, A. F., & Bangun, P. S. A. (2025). Additive Manufacturing in Prosthetics Field: A Literature Review. *Jurnal Sistem Teknik Industri*, 27(3), 221-226.

http://doi.org/10.32734/register.v27i1.idarticle

ABSTRACT

Prosthetic devices play a critical role in restoring mobility and enhancing the quality of life for individuals who have experienced limb loss due to trauma, disease, or congenital conditions. However, the high cost, discomfort, and limited accessibility of conventional prosthetics present ongoing challenges. In response, Additive Manufacturing (AM), particularly 3D printing, has emerged as a transformative solution in the field of prosthetics. This technology enables the creation of patient-specific prosthetic components with complex geometries, improved fit, and reduced weight, all while lowering production costs and minimizing the need for post-processing. Through a comprehensive review of recent studies, this paper explores the advancements and applications of AM in prosthetics, including the integration of machine learning, finite element method (FEM) simulations, and new materials such as PLA, ABS, ASA, and carbon fiber-reinforced composites. Research findings indicate that AM facilitates the development of durable, lightweight, and anatomically accurate devices, such as transfemoral sockets and prosthetic thumbs, which pass international fatigue and safety standards. The studies also highlight the advantages of AM in pediatric prosthetic design, where rapid anatomical changes necessitate frequent adjustments. By streamlining the production process and enabling customization, AM significantly improves comfort, usability, and accessibility for users. This review concludes that additive manufacturing holds immense potential to revolutionize prosthetic development by offering cost-effective, sustainable, and user-centered solutions. The continued advancement and integration of digital manufacturing technologies are poised to address existing limitations in prosthetic care and support the growing global demand for innovative, inclusive, and high-quality assistive devices.

Keyword: Additive Manufacturing, Customization, Material Selection, Prosthetics, 3D Printing

ABSTRAK

Prostesis merupakan perangkat bantu yang penting bagi individu dengan disabilitas untuk menggantikan bagian tubuh yang hilang, baik pada tungkai atas maupun bawah. Namun, akses terhadap prostesis masih menjadi tantangan besar, terutama karena biaya yang tinggi dan proses manufaktur yang kompleks. Teknologi manufaktur aditif (Additive Manufacturing/AM), seperti pencetakan 3D, muncul sebagai solusi potensial untuk mengatasi keterbatasan ini dengan menawarkan pendekatan yang lebih efisien, terjangkau, dan dapat disesuaikan dengan kebutuhan pengguna. Studi ini meninjau pemanfaatan AM dalam bidang prostetik, termasuk pendekatan desain berbasis algoritma, pemodelan multi-body dynamics, dan simulasi metode elemen hingga (FEM). Penelitian menunjukkan bahwa pendekatan ini menghasilkan prostesis yang lebih kompatibel secara anatomis, ringan, dan tahan lama, serta memberikan kenyamanan yang lebih tinggi bagi pengguna. Beberapa penelitian juga menekankan pentingnya bahan seperti ABS, PLA, dan komposit serat karbon (CFRPC) untuk menghasilkan

komponen prostetik yang kokoh dan ringan. Selain itu, aplikasi AM pada prostesis anak-anak juga terbukti efektif dalam menyesuaikan perubahan dimensi tubuh yang cepat selama masa pertumbuhan. Kesimpulannya, manufaktur aditif memberikan terobosan dalam pengembangan prostesis yang bersifat individual, ekonomis, dan berkinerja tinggi. Teknologi ini tidak hanya meningkatkan kualitas hidup penyandang disabilitas melalui peningkatan kenyamanan dan mobilitas, tetapi juga mendorong inklusivitas dalam pelayanan kesehatan global.
Keyword: Kustomisasi, Manufaktur Aditif, Pemilihan Material, Pencetakan 3D, Prostetik

1. Introduction

Prosthesis is a widely used assistive device designed to support individuals with disabilities in addressing their biomechanical requirements [1]. Prosthetic devices are employed to substitute for absent body parts in both the upper and lower limbs [2]. The loss of one or more body parts because of an etiology is known as amputation, traumatic traumas, certain illnesses, and forced amputation from surgery are the main causes of limb loss (Bekrater-Bodman, Robin, 2021). As a substitute for body parts, prosthetics are essential to facilitate mobility, enable activities of daily living, and foster psychological and social integration [3].

The World Health Organization (WHO) approximates that nearly 0.5% of any population necessitates prosthetic and orthotic services [4]. Nearly one billion people are denied access to assistive technology, despite its potential to improve daily lives and ensure human rights [5]. Access is restricted because of the elevated expenses associatted with new prosthetic technologies, along with the increasing costs within healthcare systems [6]. While a variety of prosthetic products are readily available in the market, they also come with numerous disadvantages. The product's high cost and frequent inaccuracies often resulted in discomfort for the end user [7].

To overcome these problems, many researchers conducted additive manufacturing techniques to fabricate prostheses that put the user at the center of the development process and satisfy all the needs of the user, resulting in more stable gait rehabilitation, improved fits, and comfort [8]. Moreover, this technology has been implemented and evaluated in the development of prosthetic components over time, aiming to create high-quality and cost-efficient prostheses for users [9]. 3D printing, as a form of digital manufacturing, plays a crucial role in this advancement. One of the primary benefits of this technology is the ability to design and visualize three-dimensional objects on a computer, enabling an extensive range of shapes and complexities to be created [10].

Additive Manufacturing (AM) represents a groundbreaking technology with the capacity to transform the healthcare industry and drive social progress [11]. Patient-specific anatomical components, along with tailored prostheses and implants, can be accurately produced using 3D printing techniques. While additive manufacturing (AM) technologies may be slower than traditional methods of medical device fabrication, but they offer the advantage of generating complex designs and multifunctional objects through computer-aided design, including applications in bio-fabrication [12].

Therefore, this review aims to explore the use of additive manufacturing technology in the healthcare field, particularly in the field of prosthetics. This literature review connects cutting-edge technological integration, material innovation, and patient-specific applications in prosthetic development using AM, all while pointing out emerging gaps and new opportunities in the field. To achieve this, the study adopts a literature review methodology by identifying and analyzing peer-reviewed journal articles published between 2023 and 2024 that focus on the integration of AM technologies—including machine learning optimization, finite element method (FEM) simulations, and advanced materials such as PLA, ABS, ASA, and carbon fiber composites. The keywords used for article selection included “additive manufacturing,” “3D printing,” and “custom prosthetic design.” The aim is to synthesize the latest findings on design strategies, material selection, and clinical outcomes, providing a comprehensive overview of current trends and research directions in the use of AM for prosthetic innovation.

2. Literature Review

Additive manufacturing (AM) is propelled by the increasing need for customization and personalization within biomedical applications, facilitating the creation of prosthetics, implants, and medical devices [13]. The integration of AM within the prosthetics sector streamlines the manufacturing process by decreasing the number of production steps involved [14]. Milone, Dario et al., (2023) conducted research by utilizing additive manufacturing with optimization process through machine learning, algorithm, multi-body dynamics, and finite element method (FEM) simulations in hip replacement. Integrating these techniques in the process of design shows significant advantages, which could streamline the flow of iteration to obtain efficient design [15].

Some professionals have agreed that 3D-printing technology produce satisfactory products for upper-limb socket [16]. It is because the design plays crucial factor in this product [17]. Manero, Albert et al. (2023) investigates the integration of various manufacturing techniques to produce both cosmetic and structural components for prosthetic devices. These methods were evaluated to minimize the lengthy post-processing duration. While thumb prosthetic was designed to align with both anatomical accuracy and the specific needs of the user (Ondrejová, Bibiána et al., 2023) [18].

The issue of accessibility to limb prostheses for children is significantly more pronounced than for adults. This disparity arises from the rapid changes in human anatomy, particularly limb dimensions, that occur during adolescence [19]. Sun, Changnin *et al* (2024) conducted research that the application of Additive Manufacturing (AM) using industrial robots holds great promise to produce prosthetic sockets. This innovative approach offers an efficient way to create customized geometries while ensuring high mechanical strength and lightweight characteristics [20]. While Shah, Kamran, and Rehman, Mustafa Ur (2025) found that the compatibility of PLA with 3D printing technologies enables the creation of personalized, anatomically accurate sockets, thereby improving comfort and fit for each user [21]. The journals were identified using keywords “additive manufacturing,” “3D printing,” and “custom prosthetic design,” reflecting current trends in personalized prosthetic innovation. These reputable studies—published between 2023 and 2024 in *IOP Conference Series*, *MDPI Prosthesis*, and *Composites.*

Table 1. Literature Review

No	Authors & Year	Title	Methodology	Key Findings	Conclusion
1	Milone, Dario et al., 2023	Smart Design of Hip Replacement Prostheses Using Additive Manufacturing and Machine Learning Techniques	Optimize the 3D printing product with machine learning algorithms, multi-body dynamics, and finite element method (FEM) simulations.	Subject-specific optimization is particularly significant as it considers the unique anatomy and needs of each individual.	Enhancing the compatibility between the prosthetic device and the human body.
2	Manero, Albert et al., 2023	Evolving 3D-Printing Strategies for Structural and Cosmetic Components in Upper Limb Prosthesis	Using ABS and PLA through FDM machine	The slender layer of ABS plastic exhibited greater durability compared to the 3D-printed version, while also resulting in a decrease in the component's weight.	The integration of various manufacturing techniques could produce both cosmetic and structural components for prosthetic devices.
3	Ondrejová, Bibiána et al., (2023)	Prosthetic Thumb Design and Development by Additive Manufacturing	Fabricated thumb prosthesis by utilizing ASA material through FDM AM techniques	The thumb needed to be rotated more laterally to enhance the gap between the palmar surface of the socket and the prosthetic thumb.	Through the application of 3D printing technology, one can achieve weight reduction and enhance ventilation by incorporating small perforations into the model's surface.

No	Authors & Year	Title	Methodology	Key Findings	Conclusion
4	Changning, Sun et al., 2024	A shape-performance synergistic strategy for design and additive manufacturing of continuous fiber reinforced transfemoral prosthetic socket	Developed transfemoral prosthetic sockets (TPS) with multi degree of freedom 3d printing system	The weight and thickness were both reduced compared to traditional TPS.	The 3D printed CFRPC (TPS) successfully completed the fatigue test in accordance with an international standard, demonstrating that the TPS possesses adequate durability.
5	Shah, Kamran & Rehman, M	Finite Element Analysis of Custom Designed and Additive Manufactured Total Surface Bearing Prosthesis for Trans-Tibial Amputees	Investigate AM for Total Surfae Bearing (TSB) Sockets	Revealed a uniform distribution of pressure throughout the residual limb.	AM could create affordable, long-lasting, and individualized prosthetic solutions for patients.

The first research found that through the evaluation of the prosthetic device under a loading cycle that simulates typical walking patterns, the enhanced prosthesis was engineered for a potentially unlimited lifespan. This design exhibited stress levels that remained consistently beneath the yield strength of the material, even when subjected to the most challenging conditions assessed by the algorithm. The enhanced prosthesis reduces the necessity for regular medical oversight and replacements.

The second study utilized ABS plastic via additive manufacturing, thermoforming, and injection molding techniques, while also integrating metallic elements and LSR polymers into the assemblies. The transition to a thermoformed cosmesis led to a 33% decrease in weight, equating to a savings of 39 grams. This reduction in weight could prove particularly beneficial during a full day of prosthesis usage, potentially alleviating fatigue.

The third research discovered that the ultimate configuration and design of the prosthetic thumb met expectations in terms of both functionality and aesthetics. The application of 3D printing technology allowed for a reduction in weight and improved ventilation through the incorporation of small perforations on the model's surface. The patient reported experiencing comfort and a sense of lightness with the newly produced thumb prosthesis.

The fourth study found that the 3D printed thermoplastic shell (TPS) made from carbon fiber reinforced polymer composite (CFRPC) in this study successfully passed a fatigue test in accordance with international standards. The findings suggest that the CFRPC TPS developed here is expected to remain safe for a minimum of three years, assuming an average of 5,000 steps per day for the amputee. This research produced a TPS that fulfills safety and comfort criteria, as it is both lighter and thinner than commercially available options tailored for the specific patient, thereby enhancing maneuverability.

The fifth study highlighted the benefits and extensive possibilities of additive manufacturing in the creation of prosthetic sockets. Within the realm of materials employed in fused deposition modeling (FDM) printers, polylactic acid (PLA) stands out as the most frequently used option. The suitability of PLA for 3D printing technologies enables the fabrication of personalized, anatomically accurate sockets, thereby improving comfort and fit for each user. Additionally, its affordability makes it an attractive choice, particularly in situations where cost is a significant consideration.

To enhance the coherence and robustness of this literature review, the applied methods were systematically integrated within a structured research framework. The process began with defining relevant keywords—such as "additive manufacturing," "3D printing," and "custom prosthetic design"—to guide a focused literature search. Articles published between 2023 and 2024 were selected from reputable sources, including IOP Conference Series, MDPI Prosthesis, and Composites, ensuring the relevance and timeliness of the findings.

Each selected study was analyzed using a consistent framework that includes: (1) the applied additive manufacturing method, (2) materials and tools used (e.g., PLA, ABS, ASA, CFRPC), (3) computational integration (e.g., machine learning, FEM), and (4) outcomes in terms of functionality, fit, and user-centered design. This structured approach enabled a thematic synthesis and comparison across different studies, highlighting methodological strengths, innovations, and practical implications in the development of prosthetic devices using AM.

3. Conclusion

Additive Manufacturing (AM), especially 3D printing, has emerged as a game-changing technology in the development of prosthetic devices. This approach enables the creation of personalized, lightweight, and anatomically accurate prostheses that improve user comfort, fit, and mobility. Compared to traditional fabrication methods, AM allows for complex and customizable designs while reducing production steps, time, and costs. The use of various materials—such as PLA, ABS, ASA, and carbon fiber-reinforced composites—has proven effective in enhancing both the mechanical strength and functionality of prosthetic components. Moreover, the studies reviewed highlight that AM techniques can reduce the weight of prosthetics, increase durability, and accommodate specific patient needs, including pediatric cases and intricate designs like thumb prostheses.

Overall, the application of AM in prosthetics demonstrates significant potential to improve accessibility and performance, especially for underserved populations. Innovations like machine learning integration, fatigue testing, and the use of industrial robotic arms in printing reinforce the reliability and longevity of these devices. By centering design around the user, AM not only enhances comfort and usability but also reduces the frequency of replacements and medical interventions. As this technology continues to evolve, it offers a sustainable and inclusive solution for addressing the growing global demand for affordable, high-quality prosthetic care.

References

[1] D. Kathrotiya, A. Yusuf, R. K. Bhagchandani, and S. Gupta, “A Study for the development of prosthetic foot by additive manufacturing,” *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 45, no. 3, Mar. 2023, doi: 10.1007/s40430-023-04107-y.

[2] Y. Wang, Q. Tan, F. Pu, D. Boone, and M. Zhang, “A Review of the Application of Additive Manufacturing in Prosthetic and Orthotic Clinics from a Biomechanical Perspective,” *Engineering*, vol. 6, no. 11, pp. 1258–1266, 2020, doi: https://doi.org/10.1016/j.eng.2020.07.019.

[3] K. Alluhydan, M. I. H. Siddiqui, and H. Elkanani, “Functionality and Comfort Design of Lower-Limb Prosthetics: A Review,” *Journal of Disability Research*, vol. 2, no. 3, Sep. 2023, doi: 10.57197/jdr-2023-0031.

[4] J. K. Rajah, W. Chernicoff, C. J. Hutchison, P. Gonçalves, and B. Kopainsky, “Enabling Mobility: A Simulation Model of the Health Care System for Major Lower-Limb Amputees to Assess the Impact of Digital Prosthetics Services,” *Systems*, vol. 11, no. 1, Jan. 2023, doi: 10.3390/systems11010022.

[5] J. J. Kim, J. Kim, J. Lee, and J. Shin, “Influence of Lifestyle Pattern on Preference for Prosthetic Hands: Understanding The Development Pathway for 3D-printed Prostheses,” *J Clean Prod*, vol. 379, no. 1, p. 134599, 2022, doi: https://doi.org/10.1016/j.jclepro.2022.134599.

[6] M. F. Baumann, D. Frank, L. C. Kulla, and T. Stieglitz, “Obstacles to prosthetic care—legal and ethical aspects of access to upper and lower limb prosthetics in germany and the improvement of prosthetic care from a social perspective,” *Societies*, vol. 10, no. 1, Mar. 2020, doi: 10.3390/soc10010010.

[7] J. Y. Park, H. Y. Kim, J. H. Kim, J. H. Kim, and W. C. Kim, “Comparison of prosthetic models produced by traditional and additive manufacturing methods,” *Journal of Advanced Prosthodontics*, vol. 7, no. 4, pp. 294–302, 2015, doi: 10.4047/jap.2015.7.4.294.

[8] S. Bhatt, J. Deepak, R. Pawan Kumar, and A. K. and Godiyal, “Advances in Additive Aanufacturing Processes and Their Use for The Fabrication of Lower Limb Prosthetic Devices,” *Expert Rev Med Devices*, vol. 20, no. 1, pp. 17–27, 2023, doi: 10.1080/17434440.2023.2169130.

[9] A. N. Amsan, A. K. Nasution, and M. H. Ramlee, “A Short Review on the Cost, Design, Materials and Challenges of the Prosthetics Leg Development and Usage,” 2019.

[10] J. Schweiger, D. Edelhoff, and J. F. Güth, “3d printing in digital prosthetic dentistry: An overview of recent developments in additive manufacturing,” May 01, 2021, *MDPI*. doi: 10.3390/jcm10092010.

[11] B. Tyagi *et al.*, "Fabrication of transfemoral prosthesis utilizing additive manufacturing and reverse engineering: a scoping review," *International Journal on Interactive Design and Manufacturing (IJIDeM)*, vol. 18, no. 6, pp. 3613–3631, 2024, doi: 10.1007/s12008-024-01974-0.

[12] E. Rezvani Ghomi, F. Khosravi, R. E. Neisiany, S. Singh, and S. Ramakrishna, "Future of additive manufacturing in healthcare," *Curr Opin Biomed Eng*, vol. 17, p. 100255, 2021, doi: https://doi.org/10.1016/j.cobme.2020.100255.

[13] P. Onu *et al.*, "Additive Manufacturing (AM) and 3D Bioprinting for Biomedical Application: Understanding the Drivers, Barriers and Technology Trends," *Procedia Comput Sci*, vol. 253, pp. 1276–1282, 2025, doi: https://doi.org/10.1016/j.procs.2025.01.189.

[14] M. R. Aryal and S. Pun, "Additive Manufacturing of Prosthetic Hands: A Brief Overview," *International Journal on Interactive Design and Manufacturing (IJIDeM)*, vol. 16, no. 3, pp. 1099–1112, 2022, doi: 10.1007/s12008-022-00857-6.

[15] D. Milone, D. D'Andrea, and D. Santonocito, "Smart Design of Hip Replacement Prostheses Using Additive Manufacturing and Machine Learning Techniques," *Prosthesis*, vol. 6, no. 1, pp. 24–40, Feb. 2024, doi: 10.3390/prosthesis6010002.

[16] J. Olsen, S. Day, S. Dupan, K. Nazarpour, and M. Dyson, "3D-Printing and Upper-Limb Prosthetic Sockets: Promises and Pitfalls," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 29, pp. 527–535, 2021, doi: 10.1109/TNSRE.2021.3057984.

[17] P. R. Young, J. S. Hebert, P. D. Marasco, J. P. Carey, and J. S. Schofield, "Advances in the measurement of prosthetic socket interface mechanics: a review of technology, techniques, and a 20-year update," 2023, *Taylor and Francis Ltd.* doi: 10.1080/17434440.2023.2244418.

[18] B. Ondrejová *et al.*, "Prosthetic Thumb Design and Development by Additive Manufacturing," *Acta Mechanica Slovaca*, vol. 27, no. 3, pp. 6–11, Sep. 2023, doi: 10.21496/ams.2023.028.

[19] F. Górski, R. Wichniarek, W. Kuczko, and M. Żukowska, "Study on properties of automatically designed 3d-printed customized prosthetic sockets," *Materials*, vol. 14, no. 18, Sep. 2021, doi: 10.3390/ma14185240.

[20] C. Sun *et al.*, "A shape-performance synergistic strategy for design and additive manufacturing of continuous fiber reinforced transfemoral prosthetic socket," *Compos B Eng*, vol. 281, p. 111518, 2024, doi: https://doi.org/10.1016/j.compositesb.2024.111518.

[21] K. Shah and M. U. Rehman, "Finite Element Analysis of Custom Designed and Additive Manufactured Total Surface Bearing Prosthesis for Trans-Tibial Amputees," *Applied Sciences (Switzerland)*, vol. 15, no. 3, Feb. 2025, doi: 10.3390/app15031284.