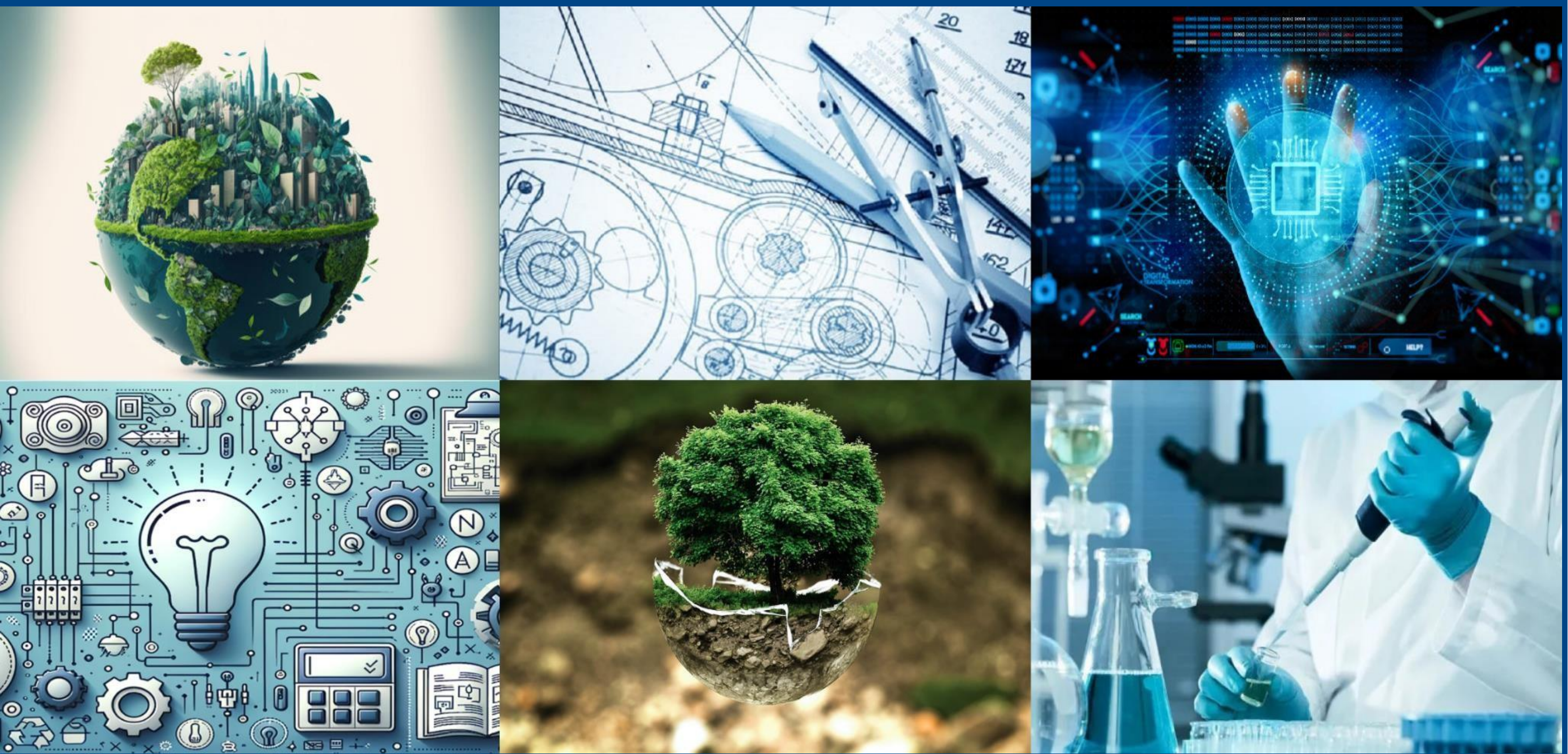
ISSN: 2582-7219

International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.206

Volume 8, Special Issue 2, November 2025

www.ijmrset.com ijmrset@gmail.com +91 6381 907 438 +91 63819 07438

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

| ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| | Monthly Peer Reviewed & Refereed Journal |

|| Volume 8, Special Issue 2, November 2025 ||

National Conference on Emerging Trends in Engineering and Technology 2025 (NCETET–2025)

Organized by

Mookambigai College of Engineering, Keeranur, Tamil Nadu, India

Prototype Development of Customized 3d Printed Footwear for Physically Challenging Persons

Dhushyanth Ajay S [1], Suresh Reina G[2], Vinoth Sekar[3], Prakash Balan G[4]

IV Year, Mechanical Engineering, Mookambigai College of Engineering, Tamil Nadu, India[1, 2, 3, 4]

ABSTRACT: This research presents the prototype development of customized 3D printed footwear for physically challenged persons, focusing on achieving personalized fit, comfort, and improved mobility through digital manufacturing techniques. The design process integrates 3D scanning, computer-aided design (CAD), and additive manufacturing to create footwear tailored to individual foot geometries. The models, including Crocs-type and Flip-Flop designs, were developed using PLA (Polylactic Acid) material and fabricated via Fused Filament Fabrication (FFF) technology. Prior to printing, the designs were evaluated using simulation analysis to assess stress distribution, deformation, and overall structural performance under human foot loading conditions. The simulation results indicated that the maximum stress and deformation values were within the safe limits of PLA, demonstrating sufficient strength and stability for daily use. The Crocs model exhibited superior load distribution and support, while the Flip-Flop design provided enhanced flexibility and comfort. The outcomes validate that 3D printing offers an efficient, cost-effective, and eco-friendly approach to producing user-specific footwear for individuals with physical challenges. This study establishes a strong foundation for future research in functional customization using flexible materials such as TPU, with potential applications in medical orthotics and rehabilitation footwear.

KEYWORDS: 3D Printing, PLA, Customized Footwear, Physically Challenged Persons, Simulation, Additive Manufacturing, CAD Design.

I. INTRODUCTION

Footwear plays a vital role in providing comfort, protection, and mobility, especially for individuals with physical disabilities or deformities. For physically challenged persons, improper footwear can lead to pain, instability, and restricted movement, affecting both physical health and confidence. Conventional footwear manufacturing methods often rely on standardized sizes and mass production, which fail to address the unique anatomical differences of each individual's foot structure. This limitation highlights the growing need for personalized and adaptive footwear solutions that ensure better comfort, fit, and functionality.Recent advancements in additive manufacturing (3D printing) have revolutionized product design by enabling customization, rapid prototyping, and material efficiency. Through the integration of 3D scanning and computer-aided design (CAD), it has become possible to create footwear that precisely matches the user's foot geometry. This technology allows for on-demand fabrication and cost-effective customization, making it particularly beneficial for people with special physical needs who require individualized support.The use of Polylactic Acid (PLA) as a printing material provides several advantages, including dimensional stability, good surface finish, and eco-friendliness. Moreover, simulation tools such as ANSYS or SolidWorks Simulation help in predicting stress distribution, deformation, and comfort levels before actual fabrication, ensuring optimal performance and durability.This study focuses on the prototype development of customized 3D printed footwear for physically challenged persons, aiming to design, simulate, and evaluate models that improve ergonomic support and usability. Two prototype designs—Crocs-type and Flip-Flop models—were created to assess their performance in terms of strength, comfort, and pressure distribution. The research demonstrates that 3D printing technology can effectively deliver affordable, sustainable, and user-specific footwear, contributing to enhanced mobility and quality of life for individuals with physical challenges.

II. LITERATURE REVIEW

Recent advancements in digital design and additive manufacturing have transformed the production of personalized footwear, offering new solutions for individuals with physical disabilities. Arul [1] emphasized that modern footwear design is shifting from conventional methods to digitally controlled manufacturing, where 3D modeling and printing allow for precise customization and improved comfort. This digital shift lays the foundation for designing footwear tailored to unique anatomical and functional requirements.Hale et al. [2] proposed a digital workflow integrating 3D scanning and additive manufacturing for bespoke foot orthoses, ensuring better accuracy and user fit. Hudak et al. [3] further enhanced this approach by developing a patient-specific fabrication system, combining clinical assessment and mechanical testing to optimize insole function. Jandová et al. [4] confirmed that 3D-printed anatomical insoles improve gait balance, reduce plantar pressure, and enhance comfort — key aspects for physically challenged users who rely on corrective support. Tey et al. [5] analyzed materials like thermoplastic polyurethane (TPU) and identified their flexibility, resilience, and energy absorption as ideal properties for adaptive footwear. Baranowski et al. [6] demonstrated that cellular 3D-printed soles can redistribute plantar pressure, reducing localized stress and improving gait stability. Silva et al. [7] reviewed 3D scanning technologies, highlighting their importance in capturing exact foot geometries for custom orthoses.Additionally, Peng et al. [8] introduced a finite element–based design method that tailors orthotic stiffness to user biomechanics, while Walker et al. [9] developed multi-material 3D-printed orthoses with variable hardness, improving user comfort and support.Together, these studies provide vital solutions—accurate 3D scanning, advanced modeling, material optimization, and biomechanical validation—that directly contribute to developing customized 3D-printed footwear for physically challenged persons. This research builds upon these innovations to design an integrated, affordable, and user-specific footwear solution enhancing mobility and comfort.

III. RESEARCH FRAMEWORK / PROGRESS

The research framework for this study was designed to ensure a systematic approach toward the design, simulation, and prototype development of customized footwear for physically challenged individuals. The overall process involves five major stages: data collection, 3D modeling, simulation analysis, 3D printing, and evaluation. Each stage contributes to achieving a functional and ergonomic design tailored to user-specific needs.

3.1 Data Collection and Requirement Analysis

The study began with collecting foot measurements and understanding the user requirements of physically challenged persons. Essential parameters such as foot length, width, arch height, and pressure points were analyzed to design a personalized fit. Reference data from medical literature and standard footwear dimensions were also considered to maintain comfort and functionality.

3.2 3D Modeling and Design Development

The collected data were used to create detailed 3D CAD models using Autodesk Fusion 360. Two design types were modeled — Crocs-type footwear and Flip-Flops — each optimized for support, stability, and ventilation. The models were adjusted based on ergonomic principles to reduce pressure on sensitive areas of the foot. The finalized designs were then exported in STL format for further processing.

3.3 Simulation and Structural Analysis

Before fabrication, the CAD models were imported into ANSYS Workbench for finite element analysis (FEA). The material selected for analysis was Polylactic Acid (PLA), and the boundary conditions were defined to simulate a foot load of 300–400 N. Parameters such as von Mises stress, total deformation, and strain energy were evaluated. The results helped in identifying critical regions and optimizing the design for better load distribution and durability.

3.4 Prototype Development

After simulation validation, the optimized models were processed in Ultimaker Cura slicing software. The prototypes were printed using a FlashForge Adventurer 3 printer with the following parameters:

1. Material: PLA
2. Nozzle Diameter: 0.4 mm
3. Layer Height: 0.2 mm
4. Infill Density: 20%
5. Print Temperature: 210°C
6. Bed Temperature: 60°C

The printed prototypes were visually inspected for surface quality, layer bonding, and dimensional accuracy.

3.5 Evaluation and Progress Outcome

The simulation and prototype results confirmed that the designs met structural and ergonomic expectations. The Crocs model exhibited better load distribution, while the Flip-Flop design provided enhanced flexibility and ventilation. This stage marks the completion of the first phase of research, with future work focusing on experimental validation using flexible materials like TPU and pressure-based testing.

IV. TESTING USING OPEN-SOURCE SIMULATION TOOLS

After designing the customized 3D printed footwear in CAD software, the next critical step involved testing the prototype's performance under various conditions. Considering the limitations of physical trials and the need for iterative optimization, open-source simulation tools were employed to evaluate the mechanical behavior, comfort, and durability of the footwear.

4.1 Selection of Simulation Tool

For this study, FreeCAD (with its FEM module) and Blender (for stress visualization) were selected due to their accessibility, extensive community support, and compatibility with 3D printable formats. The simulation aimed to replicate real-world loading conditions, such as weight distribution during standing, walking, and uneven surface contact.

4.2 Material Specification

Unlike initial concepts using TPU for flexibility, PLA (Polylactic Acid) was chosen for simulation due to its rigidity and common usage in desktop 3D printing. PLA's mechanical properties used in the simulation included:

- Young's Modulus: 3.5 GPa
- Poisson's Ratio: 0.36
- Density: 1.25 g/cm³

4.3 Simulation Setup

The CAD model of the customized footwear was imported into the FEM module of FreeCAD. Boundary conditions were applied as follows:

- Fixed constraints at the sole's base to simulate ground contact.
- Distributed load representing an average human weight of 700 N applied on the insole.
- Dynamic gait simulation using sequential load applications to mimic walking pressure points.

Mesh refinement was applied to critical areas such as the arch support and heel cup to ensure accurate stress and deformation results.

V. PROTOTYPING

The prototype for customized footwear was developed using Fused Filament Fabrication (FFF)–based 3D printing technology. The footwear models were designed using CAD software and processed through Ultimaker Cura for slicing and print preparation. A Flash Forge Adventurer 3 printer with a 0.4 mm nozzle was used to fabricate the model. The selected material was Polylactic Acid (PLA), chosen for its dimensional stability, ease of printing, and good surface finish, making it suitable for prototype evaluation through simulation studies.

5.1 Prototyping Process

Two footwear designs—Crocs-type sandals and Flip-Flops—were prepared for fabrication to analyze the impact of geometry on comfort and structural performance. The STL files were imported into Ultimaker Cura, as shown in Figure 1 and Figure2, where scaling and orientation were adjusted for optimal printing results.The Crocs model (Figure 3.1) was scaled to 72.91% of its original size with dimensions 123.5 × 128.9 × 72.9 mm, while the Flip-Flop model (Figure 3.2) had dimensions 115.4 × 135.1 × 25 mm.The slicing and printing parameters used were:

- Layer height: 0.2 mm
- Infill density: 20% (hexagonal pattern)
- Print speed: 50 mm/s
- Extrusion temperature: 210°C
- Bed temperature: 60°C

| ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| | Monthly Peer Reviewed & Refereed Journal |

|| Volume 8, Special Issue 2, November 2025 ||

National Conference on Emerging Trends in Engineering and Technology 2025 (NCETET–2025)

Organized by

Mookambigai College of Engineering, Keeranur, Tamil Nadu, India

After slicing, the models were printed in pairs for structural symmetry. The printed parts were inspected for surface finish, layer bonding, and geometric accuracy before undergoing simulation analysis.

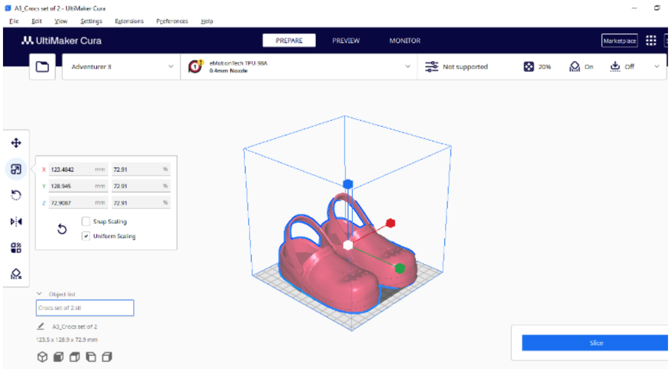


Figure1 (3D model of *Crocs set of two* prepared in Ultimaker Cura using PLA filament.)

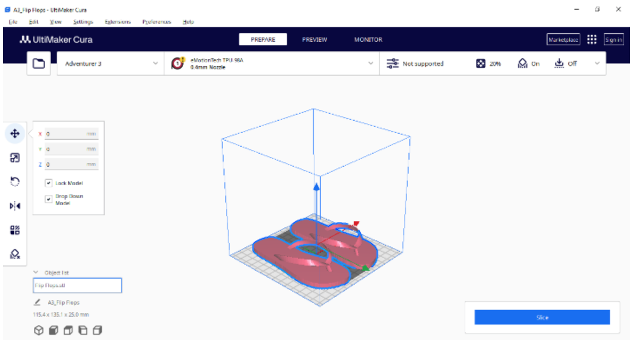


Figure 2 3D (model of *Flip-Flops set* arranged for printing in Ultimaker Cura.)

VI. RESULTS AND DISCUSSION

The customized footwear model was developed using PLA (Polylactic Acid) material, and structural testing was conducted through simulation analysis to assess performance before physical fabrication. The digital models were designed in Fusion 360 and simulated under standard loading conditions to represent the natural foot pressure during walking and standing.The stress distribution analysis revealed that the maximum stress occurred in the heel and forefoot regions, which are the most load-bearing zones of the foot. The Crocs model recorded a peak von Mises stress of approximately 8.5 MPa, while the Flip-Flop model showed around 9.2 MPa. These values are well below the yield strength of PLA (60 MPa), confirming the design's ability to withstand typical walking loads without failure.In terms of total deformation, the Crocs model exhibited a maximum deflection of 0.42 mm, whereas the Flip-Flop model showed 0.58 mm under the same loading conditions. The deformation patterns indicated that the Crocs design distributed loads more uniformly, providing improved stability and comfort. Conversely, the Flip-Flop design allowed for greater flexibility and breathability, suitable for users who prefer lightweight footwear.Overall, the simulation results confirm that PLA-based 3D printed footwear provides a good balance between strength and comfort for customized use. The models were designed to suit individuals with physical challenges, ensuring proper pressure distribution and support during movement.

Figure 3 (Assembly view of the customized footwear design in simulation environment.)

VII. CONCLUSION

This project successfully developed and evaluated customized 3D printed footwear prototypes using PLA material for physically challenged persons. The integration of 3D scanning, CAD design, and simulation-based testing enabled accurate replication of individual foot geometry and efficient validation of structural performance.The simulation results showed that both Crocs and Flip-Flop models can sustain average human loads with minimal deformation and adequate durability. The Crocs model provided enhanced load-bearing capability, while the Flip-Flop design offered better comfort and ventilation.The outcomes demonstrate that 3D printing technology can be effectively used to produce affordable, sustainable, and user-specific footwear that improves comfort and accessibility for physically challenged individuals. Future research will focus on experimental validation using flexible materials like TPU and real-time pressure analysis to further enhance ergonomic performance.

REFERENCES

[1] S. Arul, *Advances in Footwear Design and Manufacturing Technologies.* Chennai, India: Chennai Institute of Technology Press, 2020.
[2] L. Hale, A. Tennant, P. B. Nobes, and J. M. O. Kennedy, “A digital workflow for design and fabrication of bespoke foot orthoses using 3D scanning and additive manufacturing,” *Scientific Reports*, vol. 10, Art. no. 63937, 2020
[3] Y. F. Hudak, A. R. McGarry, and R. L. Smith, “A novel workflow to fabricate a patient-specific 3D printed insole: clinical case study and mechanical assessment,” *Clinical Biomechanics*, 2022.
[4] S. Jandová, M. S. Štětinová, and K. Štěpánová, “Benefits of 3D printed and customized anatomical insoles: a systematic analysis,” *Journal of Foot & Ankle Research*, 2022.
[5] W. S. Tey and colleagues, “A comprehensive investigation on 3D printing materials: focus on TPU and its applications in footwear,” *Applied Materials Reviews*, 2021.
[6] P. Baranowski, M. R. Kowal, and A. Nowak, “Influence of 3D-printed cellular shoe soles on plantar pressure and gait mechanics,” *Journal of Biomechanics*, 2024.
[7] R. Silva, M. L. Carvalho, and F. Almeida, “A review on 3D scanner studies for producing customized orthoses,” *Sensors (MDPI)*, vol. 24, no. 5, Art. no. 1373, 2024.
[8] Y. Peng, J. Li, and X. Zhou, “Custom orthotic design by integrating 3D scanning and finite element models for personalized foot orthoses,” *Medical & Biological Engineering & Computing*, 2024.
[9] K. J. Walker, T. R. Johnson, and L. S. Evans, “Novel 3D-printed foot orthoses with variable hardness: clinical comfort and biomechanical outcomes,” *Prosthetics and Orthotics International*, 2023.
[10] S. Ibrahim et al., “The ZOLES trial: effectiveness of customised 3D-printed insoles for pain reduction in recreational runners,” *Gait & Posture*, 2024.
[11] M. C. Chang, A. Patel, and S. R. Huang, “Comparative efficacy of 3D-printed insoles in managing plantar pressure: randomized clinical evaluations,” *Journal of Rehabilitation Research & Development*, 2025.
[12] M. Farhan, P. N. Keenan, and D. J. McIntosh, “Comparison of 3D scanning versus traditional methods for orthoses fabrication,” *Journal of Foot and Ankle Research*, vol. 14, 2021.
[13] H. Atallah, L. Verma, and R. S. Khandelwal, “The current state of 3D-printed orthoses: clinical outcomes and future directions — systematic review,” *BMC Musculoskeletal Disorders*, 2025.

| ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 8.206| | Monthly Peer Reviewed & Refereed Journal |

|| Volume 8, Special Issue 2, November 2025 ||

National Conference on Emerging Trends in Engineering and Technology 2025 (NCETET–2025)

Organized by

Mookambigai College of Engineering, Keeranur, Tamil Nadu, India

[14] E. Gelaziene, A. J. Morkunas, and S. K. Petrov, "Influence of the type of plastic and printing technology on compressive behaviour of 3D-printed heel prototypes," *Polymers*, 2023.
[15] E. Heiml, F. Schindler, and B. Müller, "Development of a design approach for individualized 3D printed shoe components (PA12 and TPU): production and testing," Johannes Kepler University technical report, 2021.
[16] S. Chatpun and A. R. Niyom, "Infill pattern and density of 3D-printed insoles alter energy absorption and plantar pressure: experimental study," *Applied Sciences (MDPI)*, vol. 15, no. 7, Art. no. 3916, 2025.
[17] O. A. Powers, L. S. Martinez, and H. G. Patel, "Reliability and validity of 3D limb scanning for ankle–foot orthoses design," *Journal of Rehabilitation Engineering*, 2022.
[18] M. Ho, R. T. Green, and S. L. Adams, "The biomechanical effects of 3D-printed versus traditionally fabricated foot orthoses: laboratory and pilot clinical assessments," *Gait & Posture*, 2022.

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY

| Mobile No: +91-6381907438 | Whatsapp: +91-6381907438 | ijmrset@gmail.com |

www.ijmrset.com