How 3D Printing Has Changed the Landscape of Prosthetic Devices by Atri Shankar

When I was younger, I was in awe of 3D printers after seeing the first versions of commercial products at family trips to a local makerfaire. But I always questioned what these machines could really mean for the world, thinking. “They’re so expensive now, but in the future could they become something that could help everybody someday?”

Today, I am excited to say that this is the case. This is especially true for those in need of artificial limbs. 3D printing and rapid prototyping technology has not only transformed mechanical prosthetics to be widely manufacturable and accessible, but has also allowed for a significant improvement in the development and testing of prosthetic devices.

Affordability and Cost-Effectiveness

3D printing has allowed for increased accessibility, affordability and cost-effectiveness of prosthetic devices. According to the World Health Organization, an estimated 35–40 million people globally require prosthetics and orthotics services (Chadwell et al. 1). It is clear that prosthetics are in extremely high demand, but that need is not completely fulfilled.

In low-income countries, there are only a few big cities capable of providing reasonable healthcare conditions, and travel to these cities from rural areas is usually complicated, expensive, and long (Cuellar et al. 1). Local prosthetic workshops are limited and hard to manage due largely to the high price of these devices, often costing thousands, if not tens of thousands, of dollars.

But recently, 3D printers have decreased dramatically in price, and more people have access to printers than ever before. In the last few years, quality printers have become available for $200-$300, with some extra-budget options going down to $100. This newly lowered price encourages communities to provide 3D-printed prosthetic limbs to amputees facing financial constraints.

One such community that serves to help people is e-NABLE. Funded by global donations and comprised of a network of over 10,000 people, makers involved in the e-NABLE network manufacture prosthetic arms and hands; due to the cost-effectiveness of 3D printing, a typical prosthetic arm is priced as low as $30-50, and designs for each hand are publicly available for anyone to print. In many e-NABLE chapters across the world, these arms are made with no cost to the patient ("Enabling the Future").

Processes to make affordable 3D printed prosthetics are happening worldwide, such as an automated production line developed by scientists at the Israel Institute of Technology in March 2021 ("Global 3D Printed"). With these types of systems, corporations investing in the development of these prosthetics will contribute to a significant rise in market share and investments. In 2020 for example, the market was valued at $91.163 million and its compound annual growth rate is expected to be 31.50% over the forecast period to reach a total market size of $619.961 million by 2027 ("Global 3D Printed"). As these numbers indicate, the market will likely skyrocket and expand as rapid prototyping and manufacturing evolve. Costs will continue to go down and more prosthetic labs and workstations will open across the world to continue to serve those who need limbs.

Material Flexibility and Patient Centric Design

3D printing has not only changed the accessibility of prosthetics, but has surpassed traditional manufacturing technologies in its ability to print using wide ranges of materials and creating complex shapes otherwise impossible. Before 3D printing technology, prosthetics were being made using techniques such as injection molding and vacuum forming for plastics and complex cutting, rolling, and welding techniques for metals. But these processes all take significant time, resources and people to start, operate and maintain, as each material needs a specific chain of machines to use.

However, 3D printing can bypass these complex systems through multiple methods such as fused deposition modeling (FDM), selective laser sintering (SLS) and stereolithography (SLA) that each can work with ranges of materials. Plastic, a safe and cheap material, is widely used in the form of PLA, polylactic acid. Other materials such as acrylonitrile butadiene styrene (ABS), polyethylene terephthalate glycol (PETG), thermoplastic polyurethane (TPU) and even carbon fiber-infused plastics can also be utilized with FDM technology, which melts the filament (a roll of material in string-like form) into a liquid and puts layer over layer of material that naturally dries to take the desired shape. Resins are used as part of the SLA process, which uses a laser to cure a vat of resin in layers, creating complex yet detailed and smooth geometries. TPU and other soft materials can be used to make prosthetics more soft and pliable for certain uses.

Researchers at Northumbria University studying the design of 3D printed upper limb prosthetic sockets have found that a selection of advanced materials, such as thermoplastics, mixed materials, and resins, is important to determine the best material based on the needed mechanical properties, biocompatibility, and resistance to wear and tear (Xu and Qin 6). The versatility of 3D printing technology enables prototyping and manufacturing with many different materials that best suit the end user.

Additionally, 3D printing creates support structures to hold overhangs in place, allowing for more complex shapes that no other manufacturing method can create as quickly and for models to be easily scaled up or down to fit a certain patient. This customization is integral to the comfort and functionality of a prosthetic.

As a report from the Journal of NeuroEngineering and Rehabilitation highlights, “Allowing for personalization of the outside of the prosthetic will help prevent non-use of the device. Adding customizable options to the aesthetics of prosthetics can be valuable in making the person feel like it is their own” (Chadwell et al. 2). Unlike previous manufacturing technology, 3D printing can create unique geometries and curvatures that can add to the aesthetic of a device and make someone feel more connected with their device.

Recent Advancements in Prosthetics

The advent of 3D printing will push research on prosthetics and biomechanics to a new level, as rapid prototyping technology will allow for smaller lead times in projects and faster testing of prosthetic parts and mechanisms. This may prove particularly helpful for prosthetic arms. There are multiple types of prosthetic arms: passive, myoelectric, hybrid and body powered. Passive prosthetics do not have any motion and serve as a cosmetic to replace a limb. Myoelectric limbs use electroencephalograms (EEGs) to detect electrical signals from the brain and convert these signals into movement in an arm powered by motors. A hybrid arm uses a mix of mechanical movement from the elbow and electric systems to actuate joints and fingers. Body powered prosthetics utilize the motion of a wrist or elbow to actuate joints, typically with cords connected to the controlling joint to create tension. They serve as highly functional replacements that can be lightweight, waterproof, and have natural feedback through resistance in the clamping mechanism (Philipson 3).

3D printing allows for the development of all of these arms, especially body-powered limbs. Even with no engineering experience or communication with prosthetics corporations or other external groups, anyone can print and assemble these cost-effective devices. But more importantly, large organizations, research groups, and companies can utilize 3D printing as a rapid prototyping technology (RPT). RPT offers many advantages when fabricating and manufacturing custom prosthetic devices, allowing for more design possibilities/freedom, more functional mechanisms, greater cost efficiency, shorter lead times, and an overall better end product. This is especially important for areas of the arms and legs that have more complex curvature and would require significant time to fabricate with traditional manufacturing methods (Barrios-Muriel et al. 2).

Rapid prototyping can create parts and assemblies extremely quickly, both dramatically reducing lead time on devices and improving testing capabilities of certain mechanisms or parts. A design can go through many more iterations and feedback, especially when no third party manufacturer/printer is involved; prototyping can become completely independent and domestic.

Additionally, joint function is vital to the function of an entire prosthetic device, and the fitting of sockets and joints can be expedited and controlled more effectively through the use of 3D printing. Rapid prototyping, FDM, SLA and SLS technology facilitate the creation of non-assembly linkages and sockets, which can fabricate a mechanism in one piece without any extra assembly or construction necessary. Precise detailing and a multitude of manufacturing methods were previously used to achieve this same feat, but with 3D printing, all of these small tasks can be completed in one fell swoop (Xu and Qin 6).

Conclusions

3D printing has changed every facet of prosthetic technology, providing endless customization solutions, and making rapid advancements in functionality, all while addressing the cost barriers that keep many from living more fulfilling lives. As technology continues to evolve, the integration of 3D printing into prosthetic devices holds promise for further innovations and improvements in the lives of individuals with limb differences. While challenges persist, ongoing research and collaborative efforts hold the key to unlocking the full potential of 3D printing in the field of prosthetics.

Works Cited

"3D printing." *Britannica School*, Encyclopædia Britannica, 1 Feb. 2021. school-eb-com.lwhs.idm.oclc.org/levels/high/article/3D-printing/571533. Accessed 29 Jan. 2024.

Barrios-Muriel, Jorge, et al. "Advances in Orthotic and Prosthetic Manufacturing: A Technology Review." *Materials*, vol. 13, no. 2, 9 Jan. 2020, p. 295, https://doi.org/10.3390/ma13020295.

Chadwell, Alix, et al. "Technology for Monitoring Everyday Prosthesis Use: A Systematic Review." *Journal of NeuroEngineering and Rehabilitation*, vol. 17, no. 1, 14 July 2020, https://doi.org/10.1186/s12984-020-00711-4.

Cuellar, Juan Sebastian, et al. "Ten Guidelines for the Design of Non-assembly Mechanisms: The Case of 3D-printed Prosthetic Hands." *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, vol. 232, no. 9, 16 Aug. 2018, pp. 962-71, https://doi.org/10.1177/0954411918794734.

Domínguez-Ruiz, Adan, et al. "Low Limb Prostheses and Complex Human Prosthetic Interaction: A Systematic Literature Review." *Frontiers in Robotics and AI*, vol. 10, 13 Feb. 2023, https://doi.org/10.3389/frobt.2023.1032748.

"Enabling the Future." *e-NABLE*, enablingthefuture.org. Accessed 24 Jan. 2024.

Fossati, Maria R., et al. "From Robotics to Prosthetics: What Design and Engineering Can Do Better Together." *ACM Transactions on Human-Robot Interaction*, vol. 12, no. 2, 19 June 2023, pp. 1-24, https://doi.org/10.1145/3588323.

"Global 3D Printed Prosthetics Market Report 2022: Lower Costs, Turnaround Time & the Capacity for Customisation Driving Adoption." *GlobeNewswire*, 27 Oct. 2022, www.globenewswire.com/en/news-release/2022/10/27/2542529/28124/en/Global-3D-Printed-Prosthetics-Market-Report-2022-Lower-Costs-Turnaround-Time-the-Capacity-for-Customisation-Driving-Adoption.html#:~:text=Traditional%20prosthetics%20costs%20in%20the,as%20low%20as%20just%20%2450.

Lan, Ning, et al. "Next-Generation Prosthetic Hand: From Biomimetic to Biorealistic." *Research*, vol. 2021, Jan. 2021, https://doi.org/10.34133/2021/4675326.

Paterson, Abby Megan, et al. "Comparing Additive Manufacturing Technologies for Customised Wrist Splints." *Rapid Prototyping Journal*, vol. 21, no. 3, 20 Apr. 2015, pp. 230-43, https://doi.org/10.1108/rpj-10-2013-0099.

Philipson, Thomas. "Upper Limb Prosthetic Literature Review." *Neural Engineering Student Projects*, George Mason University, 8 May 2022, mars.gmu.edu/items/f1b81f56-3c1d-435b-a936-95d55010fab6/full.

Xu, Kai, and Shengfeng Qin. "An Interdisciplinary Approach and Advanced Techniques for Enhanced 3D-Printed Upper Limb Prosthetic Socket Design: A Literature Review." *Actuators*, vol. 12, no. 6, 27 May 2023, p. 223, https://doi.org/10.3390/act12060223.

Zuniga, Jorge, et al. "Cyborg Beast: A Low-cost 3d-printed Prosthetic Hand for Children with Upper-limb Differences." *BMC Research Notes*, vol. 8, no. 1, 2015, p. 10, https://doi.org/10.1186/s13104-015-0971-9.