Design, Fabrication, and Evaluation of a 3D-Printed Hand Amputees within a Kathmandu Innovation Ecosystem

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Received: 14 April 2025; Revised: 9 June 2025; Accepted: 12 July 2025, Published: 17 August 2025

Abstract

In low-resource settings such as Nepal, patients with partial hand amputation face serious difficulties in obtaining prosthetic options both in terms of functionality and social acceptability. This paper presents the design of a customized 3D-printed cosmetic prosthesis through local innovation ecosystems to bridge these gaps. With a participatory, user-led process, the project combined the expertise of occupational therapists (OTs), prosthetists and orthotists (P&Os), and engineers to design, produce, and test by iterative cycles a prosthetic device tailored to the anatomical and psychosocial needs of a partial hand amputee. Occupational therapists played a key role in establishing user requirements, that the prosthesis supported legitimate everyday activities, whereas P&Os contributed clinical input on biomechanical alignment and prosthetic performance. Advanced techniques, including computer-aided design and 3D scanning, directed the evolution of anatomically correct prototypes manufactured from thermoplastic polyurethane (TPU), selected for its blend of flexibility and strength. Multiple iterations emphasized aesthetic realism, ergonomic fit, and task-specific function, based on quantitative biomechanical assessment and qualitative user scores. The resulting prototype demonstrated meaningful improvements in user-reported confidence and performance in daily activities, as well as enhanced social integration. Material sustainability, scalability in production, and the technical limits of 3D printing were critically interrogated, highlighting the imperative for context-matched innovation. The study recognizes the capability of locally situated, inter-disciplinary interventions to democratize access to assistive technology in low-resource settings as a replicable model for inclusive healthcare innovation.

Keywords: *Bespoke product design, co-design, Partial hand prosthesis, Interdisciplinary experts, 3D scanning, CAD, 3D printing*

1. INTRODUCTION

Prosthetics, which are external devices intended to replace a missing part of the body, seek to restore both function and form to individuals who have experienced limb loss. Prosthetics have traditionally evolved from basic wooden and leather devices to highly sophisticated devices with advanced materials and technologies. While modern prosthetics have significantly improved the quality of life for users globally, their applicability and suitability in the situation of low- and middle- income countries (LMICs) like Nepal remain limited (Abbady et al., 2022). In Nepal, the statistics report that 2.2% of the population has some form of disability, yet compared to international averages, this is estimated to be hugely underreported, and may even be over the international average, due to the incidence of injury (M'Vouama Jennifer, n.d.). Both technological advancement and healthcare are only improving, and given the geographical and economic status, the need for the creation of local assistive products is high. In this study, we are specifically interested in the development of prosthetics for partial hand amputees, a subset of hand loss for which an actuating solution like Actuating hands might not always be feasible and required to be mounted on the residual hand of a partial amputee (Oldfrey et al., n.d.).

Partial hand amputations, particularly those resulting from industrial accidents, represent unique difficulties. Partial amputation in which the hand is caught in a machine, resulting in three mid-finger losses and compromised motion in the other two is an example of such a situation. Such a condition has the tendency to inflict functional disabilities such as inability to grasp, significantly impairing one's activities of daily living (ADL) and quality of life. Added to biomechanical problems, social acceptance and user confidence complicate the design and fitting of prosthetic devices.

There are many traditional products and productions available in the market but they do not meet the requirements of a user based on their ADL, which can be achieved by the custom-made product that is created with the help of a user-centered design process (Hall, 2018). This not only produces a better product but also enables the user to feel part of the process and they can be encouraged by the joint effort to overcome the disability and be part of a society where their voice and needs are respected by everyone.

The issue this paper tries to solve is at the intersection of innovation, inclusiveness, and contextually relevant adaptation. More specifically, this paper will endeavor to explore prosthetic solutions for a partial hand amputation by digitally fabricated customized solutions. This solution is developed by using a co-design methodology that directly involves clinical practitioners, engineers, and the ultimate user. This approach ensures the prosthetics are created based on the user's specific needs and environmental conditions, addressing core functional imperatives but overwhelmingly aesthetic aspirations and comfort. By embracing user-centered design principles and leveraging local materials and expertise, our work contributes to the development of accessible, contextually appropriate prosthetic solutions for users in LMICs like Nepal.

2. METHODOLOGY

The whole co-design process was divided into three phases Pre-design phase, the Product development phase, and the Product evaluation phase as shown in Fig. 1, 2, and 3. Throughout all the processes, either the Occupational Therapist (OT), the Engineering team (ET), or the Prosthetist & Orthotist (P&O) co-led or led each other. It has been proven by utilizing the colour segments i.e. Green: OT led, Orange: ET led, and Yellow: P&O led. The mixed color of the shade indicates two groups co-led the activity. The first step of the co- design as given in Fig. 1, was to collect data about the user, and prospective product. It involved conducting a Canadian Occupational Performance Measure (COPM) interview to define key ADLs of the user, anatomical assessment for extracting biomechanical data, and identification of possible material and production processes of the product.

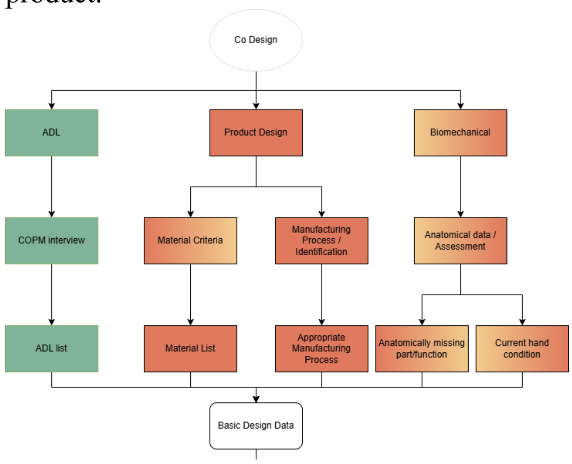

Fig. 1: *Pre-design phase*

During phase 2, with the first design data being received from phase 1, the product was developed from different processes of making a customized cosmetic hand as shown in the Fig. 2. The first trial was done by 3D printing the hand in TPU and color coating to simulate the skin tone and in the second approach trying to use material of the same skin tone as the user.

Finally, in phase 3, the hand is tested and monitored as shown in Fig. 3.

2.1. Pre-Design Phase I

The pre-design phase was accomplished in the presence of a subject expert team and was user-centered. The user took part in a number of discussion sessions to identify their preferences and integrate them in the design process. These discussions were arranged based on inputs provided by experts belonging to different areas. From the process, we can derive the initial design data to decide on the product desired by the user and what to focus on for the experts. The structure divided design requirements into three general criteria:

Activities of Daily Living (ADL) Criteria: The Primary goal was to make the user capable of achieving personal independence in caring for oneself and become confident outdoors with a cosmetic solution.

Biomedical Criteria: The designs attempted to provide sufficient structure to aid in the current
limitations and make use of the available motor capabilities.

Product Design Criteria: Emphasis was placed on selecting appropriate materials that were local and easily maintained to enhance affordability and sustainability. The prosthetic was also designed to be pleasing to the eye, close to realistic in dimensions and form, and simple to use and maintain.

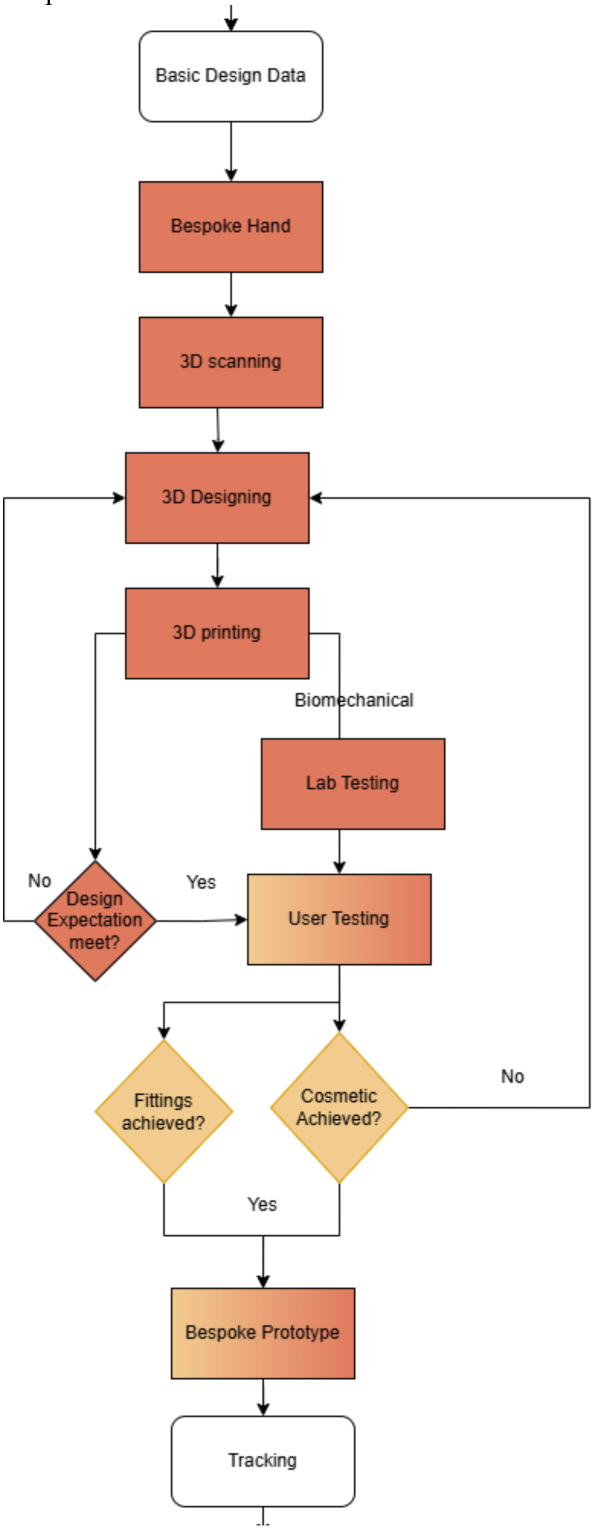

Fig. 2: *Product development phase*

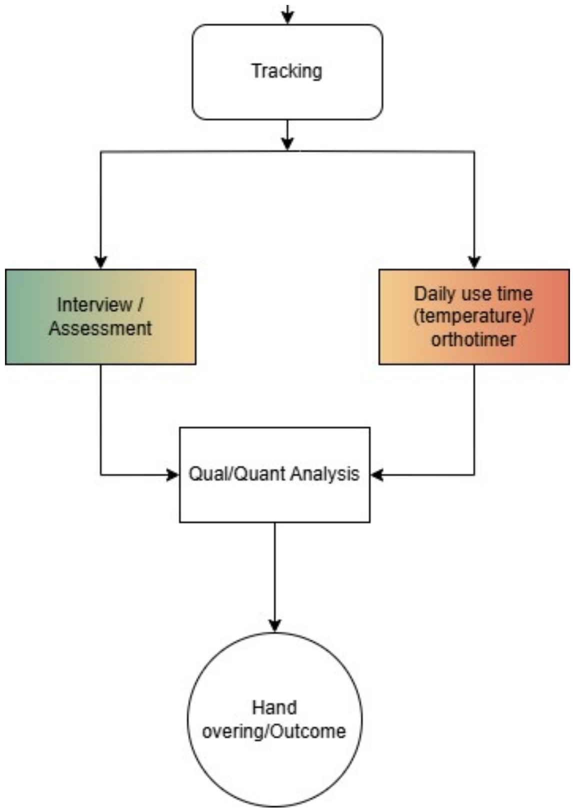

Fig. 3: *Product evaluation phase*

2.2. Product Development Phase

For the prosthetic hand, the first design concept was a device that would be both a fully articulating grip through some means of actuation, and a highly cosmetic device that would make his injury less noticeable. It was recognized fairly quickly that it is very difficult to balance functional and cosmetic attributes at the same time, even in the most high- end full-hand prostheses on the market.

Fig. 4: *Trying simple functional hand with compliant mechanism*

The initial approach prioritized function by searching for existing body-powered prosthetic designs that were available, and some of which were appropriate. Engineers selected one viable design that could be modified for partial amputation, redesigned it as so, and fabricated a 3D-printed prototype. User testing, with the design tailored to the user's personal anatomy as above showed that the solution was undesirable due to its appearance and bulkiness. This input coincided with the functional concerns expressed by prosthetists. This alternative eliminated, work was focused on a cosmetic device. Additional discussion considered the user's residual hand function—if entirely passive, a cosmetic device could further limit their capabilities. Consequently, potential means of introducing actuation into the fingers were explored, leading to the development of preliminary concept designs, as shown in Fig. 5 below.

Fig. 5: *Fully actuating concept designs*

Although these concepts do hold potential for further refinement, they were determined to be unrealistic for use in this project due to concerns about feasibility and longevity. Their need for large-scale manual construction also would increase costs substantially, rendering them a less sustainable service choice.

As a result, design discussions centered on developing stabilized passive structures that would more effectively enhance the user's existing grip, with an aim towards targeted tasks they identified. Fig. 6 demonstrates some early design studies exploring solutions to gripping a gear stick and buttoning a shirt—tasks requiring a crude spherical grip and pinch grip. By these refinements, previous methods were regularly revisited as inspiration and for further building the direction of the design.

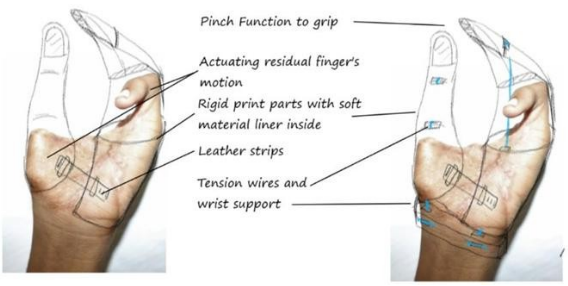

Fig. 6: *Concept design for claw*

2.3. Tools and Techniques

Several tools and techniques were applied in order to achieve precision and functionality while modeling and developing the prosthetic solutions. These technologies included 3D scanning, mesh editing, and Computer-Aided Design (CAD) programs as the prominent technologies utilized within the research.

The body measurements and data collection were where the design journey began. 3D scanning was done in order to get the precise and actual data of the shape, measurements, and hand structure of the residual hand. It took high-resolution information, which could maintain the anatomy of the hand of the user. The 3D scanning process was completed immediately after occupational therapy (OT) and basic checks so the right measurements would be accessed first before continuing on with the design process.

In order to create the prosthetic hand, the healthy hand was used as a reference to achieve cosmetic appearance of the prosthesis. The data from the healthy hand was used as a basis for aesthetic design, while the residual hand was used as a reference for fitting and base of the prosthesis. The stump offset size was used to mask hand asymmetry caused by accidental injury and other fitting changes to offer comfortable and secure fit.

3. RESULTS AND DISCUSSION

3.1. Activities of Daily Living (ADL)

The user worked together with the OT to identify his occupational performance problems, and prioritize their significance, performance, and satisfaction. Three OPPs were identified and graded as shown in the Table.

Table 1: *COPM findings*

Occupationa l Performance Problems(O PP)	**Importan ce**	**Performa nce T1**	**Satisfacti on T1**
Driving vehicles	10	5	5
Buttoning and folding shirt sleeve	10	5	7
Socializatio n with friends	10	3	1
TOTAL SCORE(∑= 1+2+3)		13	13
Average Score(∑/nu mber of OPPs)		4.3	4.3

a. The COPM Process

The Canadian Occupational Performance Measure (COPM) is a client-centered, evidence-based outcome measure designed to capture an individual's self-perception of occupational performance over time. The process consists of four key steps:

b. Problem Definition

The therapist conducts a semi-structured interview with the client to identify issues in occupational performance, focusing on areas of self-care, productivity, and leisure. Problems are identified from the client's own perspective, ensuring a personalized approach to goal setting.

c. Importance Rating

Each identified activity or problem is rated by the client on a scale from 1 to 10, where 1 indicates low importance and 10 indicates extreme importance. This helps prioritize problems that matter most to the client.

d. Scoring: Performance and Satisfaction

The client selects up to five problems deemed most important, for this specific case 3. For each selected problem, the client rates:

Performance: How well they believe they are currently performing the activity

Satisfaction: How satisfied they are with their performance

Both aspects are rated on a 10-point scale (1 = not at all; 10 = extremely well/satisfied).

e. Reassessment

After a defined intervention period (typically several weeks or months), the same problems are re-evaluated using the same rating scales. This allows for measurement of perceived changes in occupational performance and satisfaction over time.

f. Outcome Measurement

The COPM provides quantitative data through the calculation of mean scores:

- The total performance and total satisfaction scores are calculated by summing the ratings for each problem.
- These totals are then averaged by dividing by the number of problems scored, resulting in mean performance and satisfaction scores.
- A change of 2 points or more in either performance or satisfaction is considered clinically significant.

This approach ensures that interventions are both client-centered and measurable, offering valuable insight into the effectiveness of therapeutic strategies.(Hall, 2018; M'Vouama Jennifer, n.d.; Oldfrey et al., n.d.)

Qualitative measures, such as the Canadian Occupational Performance Measure (COPM) and interviewing, was for determining the difficulty and priority for the user. The outcome from the COPM elicited the user's high priorities, including being able to drive to expand his livelihood and being able to dress up without assistance. His confidence in arriving in social and friend networks was highly important.

Quantitative tests were also utilized during this phase, with a focus on functional clinical tests to determine the existing biomechanical capability of the user. The gathering of anatomical information was also comprehensively carried out to identify the condition of the residual hand. Observations involved taking various sections of the hand to measurement and a study of the remaining fingers' anatomical potential.

The prosthetic hand was designed with a focus on comfort and wear ease by the user, with a lateral cut paired with Velcro to enable ease of on and off. The prosthetic mimics the structure and shape of the user's sound hand for cosmetic appearance and minimal functional compatibility. The 3D-printed part of the prosthesis is for cosmetic appearance to allow him to feel comfortable outdoors with easy assessment in his physical ability.

3.2. Product Design

a. Fitting Process

The fitting and trial of the digitally fabricated prosthetic were conducted at Limb Care Nepal under the supervision of the certified prosthetist in the team. Initially, a 5mm EVA foam was included on the inner surface for a comfortable fit. After testing the hand, the overall functioning of the user was checked and accordingly adjusted to eliminate any misalignment. Further measurements were taken, and potential iterations for future models were considered.
Material Tests on Adhesion Options

For this solution, the material selected was Thermoplastic Polyurethane (TPU), chosen for its flexibility, which provides the realist-like softness of a hand with some rigidity to support items for the residual finger grips.

3.3. Product Development

The first versions were then tested in the laboratory to view the feasibility of design and simulation of the fitting with the 1:1 3D printed model of the stump. Once the process seemed viable, the feedback and alterations were implemented for user trials in a clinical setting and further updates after the user fitting and assessment.

a. V1

The first version involved a scan of the user's rested and healthy hand, which was flipped and merged with the stump's offset. The stump was resized to provide a clearance for the standard padding if needed and was digitally checked for fitting clearance. Fingers were kept whole as the original to act as a substitute for his realistic rested hand position. Some patches were cut on the palm and hand to provide suitable ventilation for the hand so that it does not sweat.

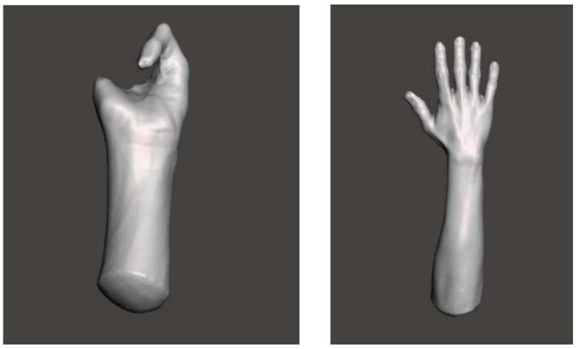

Fig. 7: Initial hand scan

b. V2

Based on OT and specialist feedback, the fingers are now spaced out to show a more relaxed pose and natural look, with added textures on the surface digitally to mimic the skin textures to make it look natural. The cuts were now more organized and printed to match the skin tone and test on the user. The next pink design shows the V2.

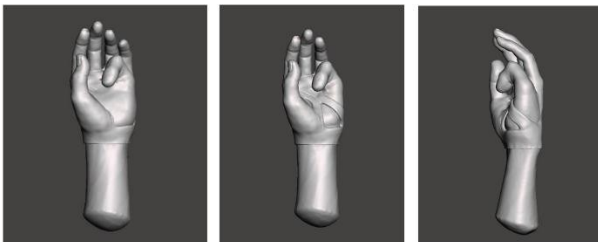

Fig. 8: *Digital Mirror of Right hand*

c. V3

After testing and user feedback, his favorite was the original design but there were issues with fingers alignment which had some functionality issues so fingers were re-arranged as shown by gray model in above Fig. 8. The changes added now had different shapes but it was still realistic and of similar size to his original mirror hand. The holes were also removed as found through testing that ventilation was unnecessary and wasn't aesthetic.

Color for the device was supposed to be skin tone TPU rather than coloring for the future version once shape is fixed because it must be imported and was triple the regular price TPU one could get in the market.

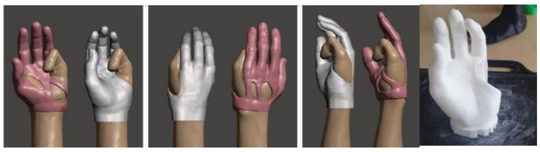

Fig. 9*: Updated design comparison between V2 and V3*

Fig. 10*: 3D printed V3*

3.4. Feedback: Trials

During physical testing, the user experienced greater confidence when using the prosthetic hand since it fit well and was comfortable to use as a it holds firmly distributing the load across the skin contact surface. Functionality was lost, however, due to spaces between the fingers. To try and rectify this, finger positioning and spacing were modified, and the color and skin tone were adjusted to more closely match the user's biological right hand. These were implemented in Version 2, which is evident in Fig. 11.

Fig. 11: *Trial of V2*

3.5. Outcomes

The study yielded transformative outcomes with broad implications for clinical practice, rehabilitation engineering, and global health policy:

Psychosocial Empowerment: Users experienced a profound improvement in self-confidence during social interactions and public engagements, attributed to the prosthetic's lookalike appearance and personalized design with his reference hand.

Functional Gains: Task-specific modifications, such as reinforced palm structures for driving and pinch-grip enhancements for buttoning shirts, led to marked improvements in the performance of prioritized daily activities.

Interdisciplinary Collaboration: The co-design framework fostered synergy between occupational therapists, engineers, and prosthetists, resulting in a holistic solution that achieved substantially lower production costs compared to imported alternatives.

Local Capacity Building: The integration of 3D- printed thermoplastic polyurethane (TPU) and open-source CAD tools established a replicable model for sustainable, community-driven prosthetic fabrication in Nepal

Challenges Encountered

The project identified critical barriers to scaling equitable prosthetic access in LMICs:

Material Constraints: Sourcing skin-tone TPU incurred significant cost premiums, while balancing flexibility and durability demanded extensive prototyping.

Design Trade-offs: Early prototypes prioritizing functionality (e.g., actuated grips) faced rejection due to bulkiness, while cosmetic-focused iterations encountered limitations in enhancing grip strength.

Technical Hurdles: Ventilation gaps intended to reduce sweating compromised aesthetics, and finger misalignments necessitated multiple design iterations.

Scalability Limitations: Manual adjustments and fragmented supply chains underscored systemic challenges in scaling production across Nepal's diverse geographic and economic landscape.

Co-Design in LMICs: A pioneering framework in Nepal that actively engaged end users in prototyping, ensuring solutions align with individual, cultural and socioeconomic contexts.

Aesthetic-Functional Synergy: A shift from purely utilitarian prosthetics, prioritizing aesthetic realism to combat social stigma a critical yet underexplored factor in LMIC settings.

Ecosystem-Driven Innovation: Demonstrated how low-cost digital tools and local expertise can replace dependency on high-cost imported devices, drastically reducing prosthetic costs while enhancing accessibility.

Recommendations for Future Work.

To amplify the study's impact, the following strategies are proposed:

Material Partnerships: Collaborate with regional polymer manufacturers to develop affordable skin- tone TPU variants or explore post-print dyeing techniques.

Modular Design Libraries: Create open-source CAD templates for common partial hand amputation patterns to accelerate prototyping.

Longitudinal Impact Studies: Track user adaptation, durability, and psychosocial outcomes over extended periods to inform iterative refinements.

Policy Integration: Advocate for national subsidies to establish 3D-printing hubs in rural clinics, coupled with training programs for local prosthetists.

Hybrid Prosthetics: Explore passive mechanisms (e.g., silicone flexors) to enhance grip without compromising aesthetics, bridging the gap between cosmetic and functional designs.

4. CONCLUSION

This study showcases the transformative potential of interdisciplinary, user-centric design in addressing the unmet needs of partial hand amputees in low-resource settings. By integrating clinical expertise, engineering innovation, and end- user feedback within Nepal's local innovation ecosystem, the project was able to fruitfully evolve a 3D-printed cosmetic prosthesis that meets aesthetic realism and task-specific performance. The iterative co-design process not only augmented the user's biomechanical performance but also restored psychosocial confidence, underscoring the critical role of contextual adaptation in assistive technology. The findings visualize the potential by illustrating that resource-poor environments can tap into digital fabrication technologies such as 3D scanning, CAD, and locally sourced material to democratize access to low-cost, culturally relevant prosthetic solutions. This report works towards global health equity by offering a scalable model for LMICs to address disability-related inequities through community-driven innovation.

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