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Research Proposal

Assessing the Feasibility of Implementing 3D-Printed Prosthetics in Conflict Zones Across the Middle East and North Africa

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Abstract

Conflict zones often lack stable healthcare infrastructure, but harbour disproportionately large amputee populations, creating a dangerous gap in healthcare support for amputees. With low production costs and a limited need for established medical infrastructure, 3D-printed prosthetics may have the capability to address this gap. This study explores the feasibility of implementing 3D-printed prosthetics for amputees living in conflict zones across the Middle East and North Africa (MENA).

While successful uses of 3D-printed prosthetics in conflict zones exist, academic literature lacks a comprehensive analysis of barriers and successful strategies. With a focus on Syria, Gaza and the West Bank, and Yemen, combined with extended research across the general MENA region, this research analyzes government policy documents, case studies, and semi-structured interviews with industry experts in order to understand the barriers that exist within the implementation of 3D-printed prosthetics in conflict zones. Using a qualitative analysis method, I will implement a concept-indicator framework across collected data to analyze the challenges present within government policies, engineering and production, physical practicality, and scaleability.

Introduction

With airstrike conflict heightening across the MENA region, the population of amputees in conflict zones has skyrocketed to unprecedented levels. Amputees living in these conflict zones lack access to stable healthcare infrastructure (hospitals, clinics, etc.) due to airstrikes, scarce medical staff, and medical resource shortages. As a result, the capacity to deliver prosthetic care to amputees in these regions remains constrained.

However, with recent developments in 3D printing, durable prosthetics can be feasibly implemented at lower costs.[1] With proper construction, 3D printed prosthetics may have the capacity to create customized prosthetics tailored to patient needs without requiring healthcare infrastructure or the presence of a medical practitioner.[2] If globalized, 3D printed prosthetics may have the capacity to change the livelihood of amputees in areas of war and conflict across the MENA region.

Despite implementation across the globe, a knowledge gap exists in understanding the challenges that engineers, prosthetists, and humanitarian NGO staff face in developing and implementing 3D-printed prosthetics in conflict zones across the MENA region. These challenges include sourcing low-cost materials, engineering durable and fitted prosthetics for patients, importing prosthetics amidst strict import policies, and medically attaching these prosthetics in areas

[1] Matthew B. Burn, Anderson Ta, and Gloria R. Gogola, "Three-Dimensional Printing of Prosthetic Hands for Children," *The Journal of Hand Surgery* 41, no. 5 (May 2016): e103–9, https://doi.org/10.1016/j.jhsa.2016.02.008.
[2] "Limbkit | Operation Namaste," Operation Namaste, 2021, https://www.operationnamaste.org/collaborative-care.

impacted by routine airstrikes or other forms of military conflict. This research aims to highlight the potential obstacles that may inhibit the adaptability of 3D printed prosthetics into conflict-affected areas. In doing so, this research subsequently prompts the engagement of these obstacles in order to strengthen the feasibility of 3D printed prosthetics as a low-cost, low-maintenance alternative for amputees living in conflict areas that lack stable healthcare systems.

Research Objectives & Questions

What capacity do 3D printed prosthetics have to address rising amputee populations in conflict zones that lack medical infrastructure? What obstacles exist in the contexts of engineering, policy, practicality, and scaleability that prevent the implementation of 3D prosthetics in these high-conflict areas?

Background

Existing literature has began exploring how 3D-printed prosthetics serve amputee populations in developing nations. A paper published by Ishengoma et al. in 2014 concluded that the physical and logistical components of 3D-printed prosthetics make it a low cost, feasible healthcare asset in developing nations.[3] Furthermore, a case study conducted in 2020 by van der Stelt et al. focused on the implementation of 3D-printed medical aids in rural and remote areas of Sierra Leone, concluding that 3D-printing is "useful for healthcare purposes, especially in resource-limited settings" due to its lower costs and easy-to-use technology.[4] The findings of these studies and many others indicate the potential that 3D-printed prosthetics and medical aids have to help amputees in developing contexts.

However, existing research does not extend into conflict zone contexts. According to the United Nations, Gaza "now has the highest number of child amputees per capita anywhere in the world".[5] Moreover, according to the WHO, 86 000 individuals living in Syria have sustained injuries that have led to amputations.[6] In parallel, academic and institutional literature, including a study published by Harvard University and WHO news release, have outlined the detrimental impacts that military conflicts have upon the stability of healthcare systems and hospitals in

[3] Fredrick Ishengoma and Adam Mtaho, "3D Printing: Developing Countries Perspectives General Terms 3D Printing and Developing Countries Keywords Additive Manufacturing and Rapid Prototyping," *International Journal of Computer Applications* 104, no. 11 (2014): 975–8887, https://arxiv.org/pdf/1410.5349.
[4] Merel van der Stelt et al., "Improving Lives in Three Dimensions: The Feasibility of 3D Printing for Creating Personalized Medical Aids in a Rural Area of Sierra Leone," *The American Journal of Tropical Medicine and Hygiene* 102, no. 4 (April 1, 2020): 905–9, https://doi.org/10.4269/ajtmh.19-0359.
[5] "Driven by Hunger in Gaza, Amputees Are Part of the Collateral Damage," UN News, August 25, 2025, https://news.un.org/en/story/2025/08/1165713.
[6] "Amputation Crisis in Conflict Zones: Report Reveals Urgent Need for Rehabilitation Services in Gaza, Syria and Ukraine," Humanity-inclusion.org.uk, 2025, https://www.humanity-inclusion.org.uk/en/amputation-crisis-in-conflict-zones-report-reveals-urgent-need-for-rehabilitation-services-in-gaza-syria-and-ukraine.

conflict zones.[7] Despite the high correlations between amputee populations and military conflict zones, a clear gap exists in understanding how the dimensions of unstable healthcare, military conflict, government policy, and engineering challenges intersect to shape the potential that 3D-printed prosthetics have to improve the livelihood of amputees living in conflict zones.

Methodology

To conduct this research, I will use a qualitative analysis approach across three primary forms of data collection, using Yemen, Gaza and the West Bank, and Syria as central case studies to guide this research.

1. Conflict-Zone Policy Analysis

I will conduct a qualitative analysis of the legislations and policy frameworks in conflict zones impacting the use of 3D-printed prosthetics, analyzing government and military policies surrounding medical care, imports and equipment use, and military and non-state political actor presences. I will draw on global and national reports and databases, along with think tanks and NGO reports, in order to collect and analyze this data.

2. Case Study Analysis

I will also conduct a comparative qualitative analysis of three to six case studies of attempted implementations of 3D printed prosthetics in conflict zones or remote areas in order to locate key issues in the administration of these prosthetics that remain consistent across multiple contexts. I will then assess how, if at all, these challenges were addressed, and the scaleability of these successful strategies.

3. Semi-Structured Interviews

I will conduct three to six semi-structured interviews with biomedical engineers, prosthetists, doctors and NGO staff in order to triangulate my data collection and understand how these policy, practicality, engineering, and scaleability barriers operate in action through the lived experiences of industry experts. Using thematic analysis, I will code interview data to identify recurring themes and patterns.

4. Concept/Indicator Framework

To analyze the data collected, I have developed a concept-indicator framework outlining the key concepts of policy, practicality, engineering, scaleability and the corresponding indicators I will use to operationalize these constructs. I will reference this framework to guide my analysis.

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[7] Dennis Kunichoff et al., "Are Hospitals Collateral Damage? Assessing Geospatial Proximity of 2000 Lb Bomb Detonations to Hospital Facilities in the Gaza Strip from October 7 to November 17, 2023," *PLOS Global Public Health* 4, no. 10 (October 10, 2024): e0003178–78, https://doi.org/10.1371/journal.pgph.0003178; World Health Organization, "Health System at Breaking Point as Hostilities Further Intensify in Gaza, WHO Warns," Who.int (World Health Organization: WHO, May 22, 2025), https://www.who.int/news/item/22-05-2025-health-system-at-breaking-point-as-hostilities-further-intensify--who-warns.

Organizations and Supervisors

- Professor Victoria Arrandale at the Dalla Lana School of Public Health will be the primary supervisor for this research.
- Additionally, I will utilize resources from University of Toronto Faculty network to source participants for semi-structured interviews. I may also reach out to relevant NGOs, public health organizations, or hospitals, including Sick Kids Hospital, Smile Canada, and Physicians Without Borders to gather professional insights.

Research Ethics Board

Since this research involves human participants as key informants in the semi-structured interviews during Week 4, it will require an ethics protocol that must be approved by the University of Toronto Research Ethics Board.

Timeline

Pre-Research Period: In this section, I will overview the steps I will take in the ten weeks leading up to the research period to prepare for the six-week research period.		
Duration	**Objectives**	**Methodology**
Week 1-2 (April 5)	Understand existing scope of printed prosthetics within war and conflict zones.	In-depth literature review regarding: Nature of conflict in conflict-affected regions (Military presences, scale of citizen casualties, etc.) Engineering process of 3D printed prosthetics ● History and future of technology: How has 3D printed prosthetics developed over the years? ● Various types of prosthetics: Which prosthetics are most feasible for remote and/or conflict-affected areas? ● How does the engineering process differ between 3D printed prosthetics for lower and upper extremities?[8]
Week 3-4 (April 19)	Identify potential interviewees, including biomedical engineers,	Leveraging the U of T Faculty and research networks (prothestists, NGO staff, and biomedical

[8] Haley Yagodinski et al., "E-NABLE: Add Lateral Wrist Movement to an E-NABLE Hand Design," *Disability and Rehabilitation: Assistive Technology* 12, no. 3 (February 2, 2017), https://doi.org/10.1080/17483107.2016.1253117.

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	prosthetists, humanitarian NGO staff, for semi-structured interviews. Draft questions for these interviews depending on their field, experience and expertise.	engineers)[9] ● Ensure interviewees are aware of their role in the research process (signed informed consent forms, REB approval) When drafting questions: ● Identifying obstacles interviewees have firsthand witnessed in the engineering and implementation stages of prosthetics process ● For humanitarian aid staff, focusing on challenges arising in delivery and implementation of prosthetics inside conflict zones ● For engineers, focusing resources, costs of materials, durability of prosthetics, and maintenance for patients
Week 5-6 (May 3)	Gather data and case studies of specific cases of prosthetic implementation in conflict zones	Ensuring diversity in case studies of similar situations with both successes and failures Similarly, drawing on past prosthetic case studies that may not necessarily occur in the MENA region, but occur under similar conditions (e.g., military conflict, remote areas, airstrike zones, unstable medical care systems)[10]
Week 7-8 (May 17)	Identify government legislations, policy frameworks and military presences in the MENA region relevant to healthcare and imports of medical equipment.	Identifying the policies of militaries, governments, and non-state political actors active in MENA region conflict zones (Ex. Dual-Use policy preventing entry of medical aid)[11]
Week 9-10	Continue gathering data and	Reference databases, literary journals, scientific

[9] *Clinical Engineering - University of Toronto Biomedical Engineering*. (n.d.). Institute of Biomedical Engineering (BME). https://bme.utoronto.ca/faculty-research/clinical-engineering/

[10] Merel van der Stelt et al., "Improving Lives in Three Dimensions: The Feasibility of 3D Printing for Creating Personalized Medical Aids in a Rural Area of Sierra Leone," *The American Journal of Tropical Medicine and Hygiene* 102, no. 4 (April 1, 2020): 905–9, https://doi.org/10.4269/ajtmh.19-0359.

[11] "FAQs: Access to Health Care Supplies and 'Dual Use' Items and Restrictions - PHR," PHR, July 9, 2025, https://phr.org/our-work/resources/faqs-access-to-health-care-supplies-and-dual-use-items-and-restrictions/.

Pre-Research Period: In this section, I will overview the steps I will take in the ten weeks leading up to the research period to prepare for the six-week research period.		
(May 31)	sources in preparation for research period to begin.	journals, and other resources in order to gain a comprehensive and thorough set of materials to reference throughout the research process. Identify humanitarian aid organizations working to implement 3D printed prosthetics in developing areas: ● Humanity & Inclusion[12] ● E-Nable[13] ● Operation Namaste[14]

Research Period		
Duration	**Objectives**	**Methodology**
Week 1	Conduct an analysis of legislations and policy frameworks of governments in conflict-affected regions in the Middle East and North Africa surrounding medical care, healthcare, and the imports of medical equipment.	**Identify Obstacles** ● Military presences in the region that may impact construction or delivery of medical infrastructure or implementation of 3D prosthetics ● Regulations on medical equipment imports ● Overall uses of medical technologies and equipment in these zones
Week 2	Conduct in-depth case study research of attempted implementations of 3D printed prosthetics in conflict zones	**Performance Metrics** ● Durability and longevity of prosthetics ● Ease/difficulty of delivering aid in the conflict region, given military presence and government policy ● Difficulty of implementation (Did these prosthetics require medical practitioners and/or medical facilities in order to be fitted to the patient?

[12] "3D Printing for Artificial Limbs," The 3D printing revolution for artificial limbs, 2016, https://www.hi-us.org/en/projects/3d-printing-revolution-for-prosthetics.
[13] e-Nable, "Enabling the Future," Enabling The Future, 2023, https://enablingthefuture.org/.
[14] "Limbkit | Operation Namaste," Operation Namaste, 2021, https://www.operationnamaste.org/collaborative-care.

Research Period		
		• Costs of manufacturing **Locate Challenges** • What specific challenges arose in each case study? (E.g., policy obstacles, military intervention, engineering faults resulting in damaging or breakdown of prosthetics) • If addressed, how were these challenges addressed? (What attempts did staff make to solve these issues? What worked and did not work?)
Week 3	Conduct a comparative analysis of the challenges, successes, and overall outcomes of the case studies, using the concept/indicator framework.	**Analytical Goals:** • Identify structural issues that remain consisent across multiple contexts • Identify possible processes, design choices, or implementation strategies that contributed to success in certain cases • Assess the scalability of successful strategies and anticipate their impact if scaled across MENA
Week 4	Conduct three to six semi-structured interviews with interviewees, including biomedical engineers, prosthetists, and humanitarian NGO staff.	Asking specific questions surrounding: **Policy**: What barriers did organizations face in these conflict zones? How do these barriers in reality compare to corresponding policy barriers? What strategies have been adapted by organizations and engineers to address policy barriers? **Physicality**: Identifying the physical, environmental and infrastructural conditions impacting the production, delivery, and use of prosthetics **Engineering**: Identifying the production challenges in manufacturing low-cost prosthetics designed for conflict zones **Scaleability**: Capacity for small-scale 3D printed prosthetic implementation initiatives to scale across the MENA conflict region
Week 5	Analyze interview data. Using thematic coding, integrate findings with case study and	Identifying the key themes that arose across case studies, policy analysis, and interviews. **Policy in action**

Research Period		
	policy analysis.	• Identifying potential discrepancies between government policy and actual enforcement **Successful strategies** • What strategies worked across case studies, manufacturing processes, and delivery processes? What potential scalability do these strategies have?
Week 6	Synthesize and condense data, key findings, and key themes.	Identify **key obstacles** and **intervention points** for: • Humanitarian staff regarding policy barriers • Engineers and prosthetists regarding manufacturing Identify **scaleable successes** in areas regarding • Delivery of prosthetics and medical imports into conflict regions • Production of durable prosthetics at a low costs

Post-Research Period:	
Objectives	**Methodology**
Interpret findings in a written analysis	Translate findings into a written analysis, comparing case study findings, coded interview findings, and policy analysis to communicate key challenges and successes.
Final Report	Accumulate and synthesize findings into a comprehensive and detailed research report.

Potential Impact

By identifying potential challenges that consistently arise from the implementation of 3D printed prosthetics in conflict zones, this study may serve as the basis for an analytical framework of reference for biomedical protesthists and engineers, policymakers, and humanitarian NGO staff to trouble-shoot and strengthen their approaches. Thus, this research fills a detrimental gap within existing academic literature, contributing to a wider understanding of the strengths and weaknesses of 3D-printed prosthetics and their implementation process within conflict zones.

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