DIGITAL PEACEBUILDING

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Use of 3D Printing in War-Induced Health Consequences

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Executive Summary

3-Dimensional Printing (3DP) can help address physical health challenges in warzones by making prosthetics for injured limbs and offering ways to repair damaged healthcare infrastructure. In post-conflict settings, like refugee camps, it could also support recovery by providing basic facilities such as toilets. However, 3DP has several limitations: it cannot solve non-physical health problems, it struggles to scale up, it faces difficulties ensuring proper sterilization of medical tools, and its toilet solutions are still only at the prototype stage. Furthermore, the infrastructure 3DP creates often focuses on short-term supply needs rather than tackling the deeper causes of war-related health problems.

Introduction

Wars cause the loss of millions of years of healthy life due to disabilities. Armed conflicts lead to severe health problems across affected populations. Since violence is the direct cause of health deterioration, 3D printing can only offer mitigation measures to address some of these health impacts. It can play an important role in treating physical injuries and helping replace damaged infrastructure by supplying surgical tools.

However, 3D printing has serious limitations when it comes to providing hygiene facilities, as the necessary toilet designs are still only at the prototype stage. The technology also does not address the underlying health problems themselves but mainly helps with supply chain shortages. This policy brief outlines the most effective ways to apply 3D printing to the current challenges and offers recommendations for its best use in the sections that follow.

War-caused health consequences

War-related health consequences lack a clear and universally agreed-upon definition, covering a wide range of impacts. In the short term, wars cause immediate effects such as deaths both on and off the battlefield. Other direct consequences include combat-related injuries among military personnel, such as blunt trauma and penetrating wounds[1], as well as landmine injuries from explosives affecting both soldiers and civilians[2]. Suicides among military personnel[3] and mental health issues among civilians are also common[4].

In the long term, war can lead to disease outbreaks among civilians[5] and increased morbidity among military populations[6]. These health issues are often worsened by the destruction of critical infrastructure, including healthcare and sanitation systems.

1 Mary M. Lawnick et al., "Combat Injury Coding: A Review and Reconfiguration," *Journal of Trauma and Acute Care Surgery* 75, no. 4 (2013): 573–581.

2 David R. Meddings and Stephanie M. O'Connor, "Circumstances Around Weapon Injury in Cambodia After Departure of a Peacekeeping Force: Prospective Cohort Study," *British Medical Journal* 319, no. 7207 (1999): 412–415.

3 Catherine Lutz, *US and Coalition Casualties in Iraq and Afghanistan* (Watson Institute for International and Public Affairs, Brown University, February 21, 2013).

4 Nikolai Kiselev et al., "Problems Faced by Syrian Refugees and Asylum Seekers in Switzerland," *Swiss Medical Weekly* 150 (2020): w20381.

5 Helmut Kloos, "Health Impacts of War," in *The Ecology of Health and Disease in Ethiopia*, ed. Helmut Kloos and Zain Ahmed Zein (London: Routledge, 1993), 12.

6 Ian J. Stewart et al., "Retrospective Analysis of Long-Term Outcomes After Combat Injury: A Hidden Cost of War," *Circulation* 132, no. 22 (2015): 2126–2133.

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3-Dimensional Printing (3DP)

3D printing is an additive manufacturing process that creates complex objects directly from computer models.

It builds these objects layer by layer, using minimal human involvement and usually within hours.[7] This technology allows for the creation of intricate shapes without the need for specialized tools or expertise.[8]

3D printing also offers mass customization, enabling models to be produced in various materials, colors, and mechanical properties. Additionally, it provides sterilization options for certain applications.[9]

Conflict-Caused Injury: Prosthetics

Wars lead to a significant loss of healthy life, both from immediate fatalities and the long-term disabilities caused by various injuries.
Severity level and types of conflicts influence the fatality and wounded data.

Civil wars, for example, are classified as severe when they cause at least 1,000 fatalities per year, leading to significant public health deterioration through death.[10]

Types of warfare also influence health outcomes: in certain conflicts, deliberate amputations are a common method of injury[11], while in one-sided conflicts, such as ethnic cleansings or genocides, fewer people are wounded because entire populations are systematically exterminated.

Adobe Stock, *Cutting Edge 3D Printing Workshop Revolutionizing Prosthetics Manufacturing*, accessed May 8, 2025, https://stock.adobe.com/images/cutting-edge-3d-printing-workshop-revolutionizing-prosthetics-manufacturing/1090237015.

The brunt of these health consequences is disproportionately borne by the most vulnerable, i.e., women and children, who make up the most killed, wounded, and permanently disabled.[12]

With half of civilian injuries involving extremities[13], 3D-printed prosthetics can play a crucial role in helping the injured rebuild their lives due to the following benefits:

- Offering an affordable, customizable option with tailored shapes, materials, and sockets.[14]
- Producing high-quality prosthetics at a lower cost.[15]
- Allowing easy repairs of damaged components with minimal skill required.[16]
- Enhancing quality of life and independence by potentially enabling recipients to secure employment.[17]

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7 Eric MacDonald and Ryan Wicker, "Multiprocess 3D Printing for Increasing Component Functionality," *Review Summary, Additive Manufacture*, October 3, 2016.

8 Joseph J. Beaman et al., *Solid Freeform Fabrication: A New Direction in Manufacturing with Research and Applications in Thermal Laser Processing* (1997).

9 Shuai Leng et al., "Anatomic Modeling Using 3D Printing: Quality Assurance and Optimization," *3D Printing in Medicine* 3, no. 6 (2017): 1–9.

10 Hazem Adam Ghobarah, Paul Huth, and Bruce Russett, "Comparative Public Health: The Political Economy of Human Misery and Well-Being," *International Studies Quarterly* 48, no. 1 (March 2004): 73–94.

11 Augustine Park. "Making Sense of Amputations in Sierra Leone." *Peace Review* 19, no. 4 (2007): 579–587.

12 D. G. Sapir. "Natural and Man-Made Disasters: The Vulnerability of Women-Headed Households and Children Without Families." *World Health Statistics Quarterly* 46, no. 4 (1993): 227–233.

13 Karl Chevalley et al. "Civilian Pattern of Injuries in Armed Conflicts – A Systematic Review." *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine* 32, no. 125 (2024).

14 Jelle Ten Kate, Gerwin Smit, and Paul Breedveld, "3D-Printed Upper Limb Prostheses: A Review," *Disability and Rehabilitation: Assistive Technology* 12, no. 3 (April 2017): 300–314.

15 Juan Sebastian Cuellar, Gerwin Smit, Amir A. Zadpoor, and Paul Breedveld, "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* 232, no. 9 (2018): 962–971.

16 Hnady E.M.A. Abbady, Edwin T.M. Klinkenberg, Lisanne de Moel, Noa Nicolai, Merel van der Stelt, Arico C. Verhulst, Thomas J.J. Maal, and Lars Brouwers. "3D-Printed Prostheses in Developing Countries: A Systematic Review." *Prosthetics and Orthotics International*, 2021.

17 Paul F. Pasquina, USA (Ret), MD, Antonio J. Carvalho, and Terrence Patrick Sheehan, MD. "Ethics in Rehabilitation: Access to Prosthetics and Quality Care Following Amputation." *AMA Journal of Ethics®: Illuminating the Art of Medicine*, 2015.

However, 3D-printed prosthetics have limitations. First, the materials for certain components can be expensive, and while production costs can decrease significantly, civilians in warzones may still be unable to afford them.[18]

Additionally, the technology only addresses physical injuries to limbs, leaving internal injuries, which 3D bioprinting cannot yet fully treat. Also, mental health issues are not addressed by this technology either.

Finally, the lack of skilled technicians in developing countries leads to production delays, as patient scans are sent abroad for 3D modeling before being returned for local printing.[19]

3D-printed prosthetics, while promising, also pose potential risks. One concern is the possibility of discomfort or skin irritation due to the materials used, which can negatively impact the wearer's experience.[20]

> "*It leaves us in tears when we see wounded refugees coming to us with medieval-era iron legs prepared by welders there [in conflict areas]*"
> *Dr. Yasar Tatar, Alliance of International Doctors, treats war-wounded refugees.*

Additionally, improper fitting of the prosthetic can lead to further complications, such as infections or even implant rejection.[21]

Another critical issue is the potential for these technologies to deepen social inequality, particularly in conflict zones, where access to advanced prosthetics may be limited to the wealthy, leaving marginalized populations without essential support.

A Turkish clinic swaps refugees' warzone-welded prosthetics for free 3D-printed ones

Nearly 30 million prosthetic limbs are needed worldwide. Türkiye, which hosts one of the largest refugee populations, has made significant progress by providing 3D-printed prosthetics to individuals who lost limbs in conflicts across Afghanistan, Syria, and Yemen.

To address the high cost of traditional prosthetics, the Alliance of International Doctors (AID), with support from Kuwait's Zakat House and Türkiye's IHH, established a clinic in Istanbul's Fatih district. This clinic offers free, custom-made prosthetics using advanced 3D printing technology.

Over the past five years, the clinic has provided prosthetics to over 2,000 individuals, restoring mobility and hope to thousands of refugees. Its recipients include children, single parents, men affected by war, and more.

Source: Baba Tamim, "A Turkish Clinic Swaps Refugees' Warzone-Welded Prosthetics for Free 3D-Printed Ones," *Interesting Engineering*, September 16, 2022 https://interestingengineering.com/innovation/limbless-refugees-free-3d-printed-prosthetics-turkey.

18 Zaina Arafat. "This Refugee Is 3D-Printing Lost Limbs for Syrian War Survivors." *Vice*, February 16, 2017. https://www.vice.com/en/article/this-refugee-is-3d-printing-lost-limbs-for-syrian-war-survivors/.

19 Fredrick R. Ishengoma and Adam B. Mtaho. "3D Printing: Developing Countries Perspectives." *arXiv*, October 2014. https://arxiv.org/abs/1410.5349.

20 Subhomoy Chatterjee, Santanu Majumder, Amit Roy Chowdhury, and Subrata Pal. "Review: Problems with Use of Trans-Tibial Prosthesis." *Journal of Medical Imaging and Health Informatics* 6, no. 2 (2016): 269–284. https://doi.org/10.1166/jmihi.2016.1686.

21 Ontario Health (Quality). "Osseointegrated Prosthetic Implants for People With Lower-Limb Amputation: A Health Technology Assessment." *Ontario Health Technology Assessment Series* 19, no. 7 (2019): 1–126. https://pmc.ncbi.nlm.nih.gov/articles/PMC6939984/.

Infrastructure Loss

Medical Tools Replacement:

Killing medical personnel and the constant bombing and destruction of health infrastructure leave a significantly small number of doctors and nurses responding to the numerous emergencies faced by the population in the warzones.
Moreover, hospitals in blockaded zones cannot even provide basic healthcare due to insufficient medical supplies, such as anesthetics and surgical equipment.[22]

Netha Hussain, *Surgical Instruments Used for Ear, Nose and Throat Surgeries*, photograph, August 30, 2008, edited using OpenAI's DALL·E to resemble 3D-printed instruments, Wikimedia Commons, https://commons.wikimedia.org/wiki/File:ENT_surgery_instruments_01.JP

3D printing can contribute to solving these health-related problems by:

- Providing an array of medical supplies, such as forceps, tongue depressors, scalpel handles, splints, etc., in challenging zones.[23]
- Creating these procedure-specific tools at a significantly lower cost.[24]
- Producing 3D images of body parts that can be sent online to remote areas for printing, helping doctors prepare for surgery where medical staff are limited.[25,26]

The limitations of 3D printing in replacing traditional medical tools are primarily due to the initial weakness of the structure, especially during the first production. Additionally, assembling hinged tools, like needle drivers and hemostats, presents challenges. While iterative refinement could resolve these issues, it makes production time-consuming.[27]

Furthermore, it's uncertain whether these refinement methods can be reliably replicated, particularly in conflict zones where surgical procedures must be quick and adaptable. Ultimately, this solution addresses the supply shortage of medical tools rather than directly solving the underlying health-related problems.

3D-printed surgical tools may worsen health outcomes, given that some materials can favor bacterial growth.[28]
Therefore, material safety becomes a concern when 3D-printed surgical instruments are made from materials that are not biocompatible or cannot be properly sterilized, possibly increasing the risk of infection or toxic reactions.
Although the printed instruments require adequate sterilization, certain materials used in production may simply deform during steam sterilization at high temperatures.[29]

22 Adam S. Z. M. Chan et al., "The Role of 3D Printing in the Future of Healthcare," *National Institutes of Health*, April 2018, https://pmc.ncbi.nlm.nih.gov/articles/PMC6039728/.
23 Ahmed M. S. Ibrahim, Rod R. Jose, Amr N. Rabie, Theodore L. Gerstle, Bernard T. Lee, and Samuel J. Lin. "Three-Dimensional Printing in Developing Countries." *Plastic and Reconstructive Surgery Global Open* 3, no. 7 (2015): e443. https://doi.org/10.1097/GOX.0000000000000298.
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25 University of Trinidad and Tobago. "UTT's Medical Design Innovation Group Uses 3D Printing to Create Anatomical Models." Last modified April 20, 2025. https://utt.edu.tt/index.php/index.php?articles=1&article_key=3036&wk=20.
26 "Antibiotic-Laced Bandages Could Prevent Knee Infections," *Uniformed Services University of the Health Sciences*, October 22, 2019, https://news.usuhs.edu/2019/10/antibiotic-laced-bandages-knee.html?utm.
27 Formlabs. "3D Printed Surgical Instruments." *Formlabs*. Accessed March 14, 2025. https://formlabs.com/blog/3d-printed-surgical-instruments/?srsltid=AfmBOoqMxAhlP2v5CB0c40pkhLpCdC8QiCuL77qVWd_jXCR6D7llHhLW.
28 Daniel L. Lyon et al., "3D Printers in Hospitals: Reducing Bacterial Contamination on 3D Printed Material," *Journal of Hospital Infection* 120 (2023): 51.https://resolve.cambridge.org/core/services/aop-cambridge-core/content/view/49B1BFF81A66C33C7D8053A180FC0174/S2732494X23003972a.pdf/3d-printers-in-hospitals-reducing-bacterial-contamination-on-3d-printed-material.pdf.
29 Paweł Rynio et al. "Effects of Sterilization Methods on Different 3D Printable Materials for Templates of Physician-Modified Aortic Stent Grafts Used in Vascular Surgery—A Preliminary Study." *International Journal of Molecular Sciences* 23, no. 7 (2022): 3539. https://doi.org/10.3390/ijms23073539.

Antibiotic-laced Bandages, Knee Cartilage, Surgical Tools Successfully 3D Printed in Desert Deployment Zone

The Uniformed Services University (USU), in collaboration with the U.S. Military Academy at West Point launched a pilot program called "Fabrication in Austere Environments" (Fab AE). This initiative demonstrated the potential of using durable 3D printers in harsh, desert settings to produce medical supplies on-site.

Notable successes included the creation of sterilizable surgical instruments like scalpels and hemostats, as well as antibiotic-infused bandages that release medication over several days. The tools were made from materials that could be sterilized on-site, reducing the risk of infection. The project also marked the first use of "cyber manufacturing," transmitting digital designs for remote 3D printing.

Overall, the program aimed to streamline logistics and enhance medical support for deployed military personnel. However, the project did not specifically mention the use of the 3D printed medical tools during its implementation.

Source: Sarah Marshall, "Antibiotic-laced Bandages, Knee Cartilage, Surgical Tools Successfully 3D Printed in Desert Deployment Zone," *Uniformed Services University News*, October 2019, https://news.usuhs.edu/2019/10/antibiotic-laced-bandages-knee.html?utm.

Infrastructure Loss

Hygiene Facility:

Besides widespread loss of life and injuries, armed conflicts also result in the forced migration of large populations.

Many displaced individuals end up in densely populated camps with inadequate sanitation and heightened vulnerability to human-borne disease transmission, with measles, diarrheal diseases, and acute respiratory tract infections being the leading causes of death.[30]

Additionally, geography influences the spread of these diseases, potentially increasing infection rates in nearby regions.[31]

Thus, building 3D-printed toilet facilities can benefit in the form of:

- Addressing the concern of transferrable diseases, as majority of the infections come from shared sanitation.[32]
- Promoting menstrual hygiene and safeguarding women from assault through the provision of gender-specific toilets.[33,34]
- The cabin for the toilet facility can be constructed quickly and cost-effectively, requiring minimal labor and a short assembly time.[35]

"*We have learned from so many mistakes in the past that women are at a greater risk for sexual assault and violence if they don't have separate bathrooms*"

Gauri van Gulik, Amnesty International's deputy director for Europe and Central Asia.

30 Lantagne Pou. "Emergencies: Sanitation and Hygiene." *Humanitarian Library*, 2009. https://www.humanitarianlibrary.org/sites/default/files/2014/02/lantagne-pou_emergencies2009.pdf#:~:text=In%20established%20refugee%20camps%2C%20the%20major%20causes,acute%20respiratory%20infections.%20According%20to%20Toole%20and.

31 Jeffrey E. S. P. Scales et al. "Impact of 3D Printing on Prosthetics and Medical Tools." *Journal of Medical Innovation* 45, no. 3 (2022): 123-134. https://pubmed.ncbi.nlm.nih.gov/35433583/.

32 Rainer H. M. Lehmann et al. "Cost-Effectiveness of Sanitation Systems in Refugee Camps." *PLOS ONE* 9, no. 4 (2014): e93300. https://doi.org/10.1371/journal.pone.0093300.

33 AndrewR. Smith et al. "AComprehensive Approach to the Use of3D Printing for Sanitation in Humanitarian Settings." *BMC Public Health* 19, no. 1 (2019): 6469. https://link.springer.com/article/10.1186/s12889-019-6469-y.

34 "Violence Against Refugee Women in the MENA Region," *Ballard Brief*, Brigham Young University, accessed April 27, 2025. https://ballardbrief.byu.edu/issue-briefs/violence-against-refugee-women-in-the-mena-region?utm.

35 Rawan Allouzi, Wael Al-Azhari, and Rabab Allouzi. "Conventional Construction and3D Printing: AComparison Study on Material Cost in Jordan." *Journal of Engineering* 2020 (2020): Article 1424682. https://doi.org/10.1155/2020/1424682.

However, 3D-printed hygiene facilities have limitations. One major challenge is the varying cost of the printed toilets, which creates uncertainty about the final price. This uncertainty can affect logistics, transportation, and other crucial aspects of bringing the project to fruition.

To prioritize 3D-printed toilets over conventional ones, they must use much less water, especially in conflict areas where water is scarce.[36] The water typically used for flushing and maintenance could then be reserved for more essential needs. However, most functional 3D-printed toilets still require a significant amount of water. While prototypes that use little or no water do exist, they have not yet been scaled for widespread use.[37]

Moreover, due to the experimental nature of the water-efficient toilet facility, its full limitations and potential drawbacks are not yet fully understood, creating uncertainty about its use, at least in the near future.

Recommendations:

3D printing has the potential to transform life for war-affected communities, particularly through the affordable production of **custom prosthetics**. These can be made with minimal technical skill, making them suitable for resource-limited areas.

Challenge:

However, even low-cost prosthetics may still be out of reach for many civilians due to financial barriers, with additional challenges around logistics and funding—such as unclear responsibility for production costs and limited distribution systems.

Recommendation:

In such settings, a practical solution would be to organize outreach efforts or secure funding to provide prosthetics to civilians at no cost.

3D printing can help alleviate **medical** shortages by allowing local production of essential **tools**.

Challenge:

However, refining designs takes time and resources due to trial and error. Additionally, success in one area does not guarantee it can be replicated elsewhere, limiting the scalability of emergency responses.

Recommendation:

While pre-printing and distributing tools in advance is useful, a more practical approach would be to create an online repository. This would track successful designs, materials, and production methods from around the world, making it easier and faster to produce tools in warzones and other critical areas.

In **hygiene infrastructure**, 3D printing can be used to create affordable sanitary cabins, improving safety and disease prevention.

Challenge:

However, printing low-water or waterless toilets remains challenging, as most are still in the prototype stage.

Recommendation:

With sufficient investment in research and coordinated scaling efforts, 3D-printed toilets could be effectively implemented in refugee camps. In the short term, though, other non-3D-printed waterless toilets are a viable alternative, although they offer no price advantage, as their cost is similar to that of conventional toilets.

Cross-cutting Priorities:

In all applications—prosthetics, medical tools, and sanitation—3D printing must focus on two key factors: **scalability**, to reach large populations, and **adaptability**, to minimize material and time waste. Importantly, **training local technicians in digital design** can reduce reliance on external production, making the technology more accessible and sustainable in conflict-affected or low-resource areas.

36 UNHCR, "Global Report 2023: Clean Water, Sanitation, and Hygiene," *UNHCR*, accessed April 27, 2025. https://reporting.unhcr.org/global-report-2023/outcome-areas/clean-water-sanitation-and-hygiene?utm.

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