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Enabling Access Locally: A Systems Approach to Wheelchair Provisioning in Low-Resource Contexts (Nepal)

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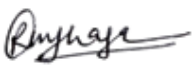
Signature  **Date:** 14 September 2023

Enabling Access Locally: A Systems Approach to Wheelchair Provisioning in Low-Resource Contexts (Nepal)

by

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14 September 2023

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Abstract:

Considering that 2.2% of Nepal's population faces disabilities, improving access to assistive technology is both a moral obligation and a priority for sustainable development. At the governmental level, efforts are underway to integrate essential assistive devices into the healthcare system aligning with WHO guidelines. However, there remain significant challenges in implementing these policies, despite constitutional guarantees of free and equitable access to assistive technology. This thesis proposes a collaborative approach to establish sustainable wheelchair provision in Nepal. This approach involves bringing together global manufacturer, national service providers, and local makers in a synergistic alliance where global partners would contribute expertise in quality control, research and development, and training, while local partners would focus on customization, repair, and context-appropriate design. The research findings, based on qualitative interviews with 14 wheelchair stakeholders, reveal challenges such as product scarcity, reliance on charitable models, maintenance issues, and barriers to rural accessibility. A tangible demonstration of 3D-printed wheelchair spare parts validates the feasibility of localized production but suggests the need for further testing to scale up cross-sector distributed manufacturing, using both digital and conventional local technologies.

In response to these challenges, a globally connected Circular Local Distributed Manufacturing model (CLDM) is proposed. This model combines global quality and scale with local customization, capacity building, and sustainability. It fosters collaboration among users, communities, governments, manufacturers, and makers to create accessible, affordable, and user-centered assistive technology. Favorable policies such as tax incentives for spare parts and raw material imports, free vocational training through national programs, and collaborative public-private partnerships stimulate the ecosystem to fully. While this research offers a roadmap for improving access to assistive technology, it acknowledges that a broader transition of systems requires further exploration.

Keywords: wheelchair provisioning, assistive technology, digital fabrication, distributed manufacturing, circular economy, disability rights, localization, global-local collaboration, Nepal

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- The representatives of wheelchair service providers across Nepal hold my sincere gratitude for their contributions. Their enlightening interviews provided invaluable insights that allowed me to comprehensively map the complex landscape of assistive technology within the country.
- I express my appreciation to Motivation UK for shedding light on the global perspective of wheelchair manufacturing through comprehensive interviews. This provided a crucial comparative context that enhanced the understanding of the Nepali scenario.
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List of Abbreviations

AM - Additive Manufacturing

AP - Assistive Products

AT - Assistive Technology

CBR - Community-Based Rehabilitation

CE - Circular Economy

CLDM - Circular Local Distributed Manufacturing

CNC - Computer Numeric Control

DM - Distributed Manufacturing

FDM - Fused Deposition Modeling

GATE - Global Cooperation on Assistive Technology

GREAT - Global Report on Assistive Technology

LCDMS – Leprosy Control and Disability Management Section

LMICs - Low and Middle Income Countries

NDF - National Disability Fund

PwD - People with Disabilities

SDGs - Sustainable Development Goals

SLA - Stereolithography

SSA - Social Security Allowance

UNCRPD - UN Convention on the Rights of Persons with Disabilities

WC - Wheelchair

WHO - World Health Organization

Definitions of the key terms

Assistive Products: “Products such as hearing aids, wheelchairs and mobility aids, communication aids, spectacles, prostheses, pill organizers, and memory aids that increases well-being of a person by improving individual’s functioning and independence in life.” (World Health Organization, 2023).

Assistive Technology (AT): Assistive Technology (AT) is defined by the WHO as “an umbrella term covering the systems and services related to the delivery of assistive products and services.” (World Health Organization, 2023).

Appropriate Wheelchair: A wheelchair "that meets the user's needs and environmental conditions; provides proper fit, posture, and comfort; is safe and durable; is available in the country; and can be maintained and services sustained in the country at the most economical and affordable price" (WHO, 2008).

Disability: According to the WHO International Classification of Functioning, Disability and Health (ICF), disability is an umbrella term for impairments, activity limitations and participation restrictions of individual at body, person, or society level (World Health Organization, 2001).

Additive Manufacturing: "Additive manufacturing is the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" (ASTM International, 2022).

Distributed Manufacturing: A model where "industries are able to produce components in different places and assemble them to make the final product” (Srai et al., 2016).

Linear Economy: A linear economy is an economic model that follows a "take-make-waste" pattern of production and consumption where raw materials are extracted, products are manufactured, and goods are disposed of at the end of their useful life (Kirchherr, Reike and Hekkert, 2017).

Circular Economy: An economic model that "aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system” (Ellen MacArthur Foundation, 2013).

1. Introduction

1.1 Nepal: Geography and Context

Nepal is a landlocked South Asian country located between China and India, with a population of over 30 million people across 147,000 square kilometers of diverse terrain. It consists of three main geographical regions: Terai (plain land), Hilly (foothill Himalayas), and the Himalayan region (higher Himalayas). The country's rugged, mountainous landscape, extreme elevation changes, pose significant challenges to its development and daily life.

Economically, Nepal is one of the poorest and least developed countries in the world, with a GDP per capita of $1,336.5 (World Bank, 2022) with nearly around 10% of its population living under poverty below $2.15 a day. It has a small GDP of around $40 billion of which around 23% comes from remittances. Nepal has over $12 billion trade deficit mainly with its neighboring India (>60%) and China (>15%), countries with mass production and global supply chain. *Figure 1* shows the geographic location of Nepal in the map of Asia and the lines indicate flow of development aid and logistics. Nepal's development heavily relies on aids from the USA and Europe, and more than 75% of imports from India and China.

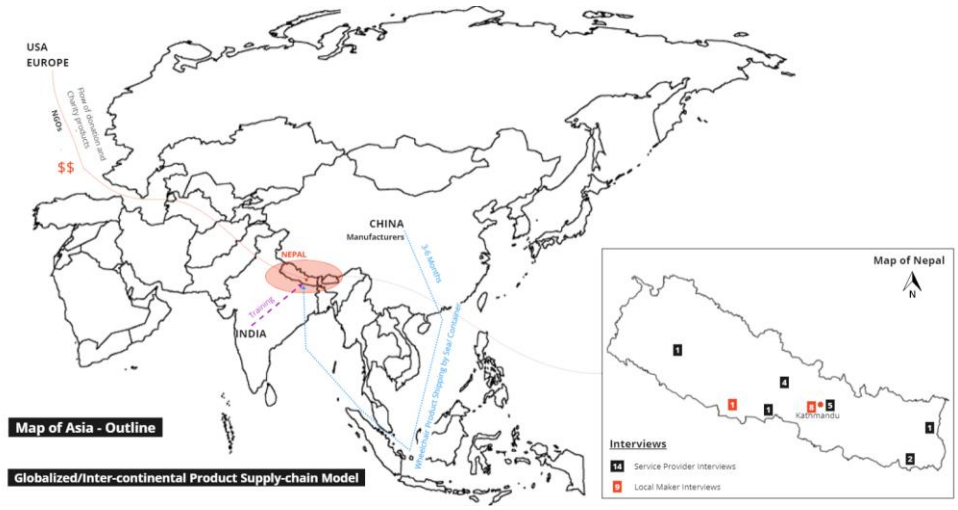

Figure 1 Geographic location of Nepal in the map of Asia and the number and location of interviews conducted for this research. (Source: Author)

Despite surrounded by India and China, it doesn't fully embrace the benefits of two giant producers as it was observed during the Nepal earthquake 2015. In September 2015, India enforced a four-and-a-half-month unofficial blockade on Nepal, halting all supply trucks from crossing the Indian border. This resulted in severe scarcities of cooking and transportation fuel, intensifying Nepal's challenges after the April 2015 earthquake. The study highlights that countries

over-reliant on a single maritime trading partner can experience humanitarian crises and thus requires exploring alternative trade routes (Karki, 2022). Otherwise, over reliance on import driven mass production economy model will further aggravate the effect of already grappling economy. In such hardship, people with disabilities (PwD) are the most affected ones as they have accessibility issues and often rely on family members or care takers for day-to-day activities. As shown by numerous researchers, poverty and disability are closely intertwined in a vicious cycle that exacerbates inequality and negatively affects the individual leading to limited access to education, inability to access work and social opportunities, and reduced health outcomes which are likely to lead to worsening of disability (Biyanwila, 2011; Groce *et al.*, 2011) and finally limiting them of fundamental human rights.

1.2 Disability Rights, Issues and Development Challenges

Access to assistive technology (AT) is mentioned as a human rights enabler in various articles of the UN Convention on the Rights of Persons with Disabilities (UNCRPD). The convention has been ratified by more than 180 participating nations including Nepal, which binds them to the state's obligations of promoting, protecting and ensuring the rights of people with disabilities (PwDs) through undertaking or promoting research and development of, and promoting the availability and use of suitable and affordable assistive products (*Convention on the Rights of Persons with Disabilities*, 2006).

According to the 2021 census, over 2.2% of Nepal's population lives with some form of disability (Nepal Census, 2021). However, disabilities often go unreported due to stigma and cultural reasons. Several researchers have discussed the prevalence of disabilities and challenges related to assistive technology provisioning in developing countries, focusing on Nepal and South Asia (Karki *et al.*, 2021; Shrestha, 2023; Holmes et al., 2018). They point out that while there's a substantial global need for assistive products, access remains low in low and middle-income countries (LMICs), particularly in rural areas. Other researchers have linked UN Sustainable Development Goals (SDGs) with the provision of assistive products, emphasizing the need to ensure that vulnerable groups, including persons with disabilities, are not left behind in the pursuit of equitable development (Holmes et al., 2018; United Nations, 2015).

Achieving the UN SDGs requires universal assistive technology access (Tebbutt *et al.*, 2016), but climate change disproportionately affects vulnerable groups(Otto *et al.*, 2017), further hindering rights realization. Although a wide research has been carried out on the problems and challenges faced by PwDs and AT service providers in the developing countries (Mukherjee and Samanta,

2005; McClure *et al.*, 2009; Karki *et al.*, 2021; Andrews *et al.*, 2023), there have been very few empirical investigations into how those complex and intertwined issues can be solved practically to increase accessibility amongst wider population in the developing contexts. These group of researchers identified lack of assistive product availability, lack of repair facilities, inaccessible infrastructure, lack of local production, charitable distribution of products, lack of skilled personnel and lack of training, etc. as major problems faced by stakeholders. Several assistive technology related issues, its impact on users and recommendations for change has been widely discussed in several WHO reports: *Global Report on Assistive Technology* (2022), *Wheelchair provision guidelines* (2023), (World Report on Disability, 2011) , etc.

World Health Assembly in 2018 adopted a resolution requesting the World Health Organization (WHO) Director-General to prepare a global report on improving effective access to assistive technology (later published as GREAT report in 2022). WHO Global Report on Assistive Technology (GREAT) identified several barriers in AT provisioning and suggests strategies based on Global Cooperation on Assistive Technology (GATE) 5P's framework (Policy, Products, Provision and Personnel with People at the centre) to improve access to safe, effective and affordable AT through a people-centred, rights-based approach, actively engaging users in all aspects of AT (*WHO*, 2022).

Nepal has made significant progress on disability rights since ratifying the Convention on the Rights of Persons with Disabilities in 2010 (United Nations, 2018), adopting a new Constitution in 2015 that guarantees rights for persons with disabilities, setting out special provisions to ensure their access to education, social justice and proportional representation at local bodies (Constitution of Nepal, 2015), and passing the Disability Rights Act in 2017 to shift from a welfare to rights-based approach (Nepal Law Commissions, 2017). Laying on the foundations of global guidelines and conventions as mentioned above and these recently endorsed national policies, Nepal demonstrated its pioneering interest in steering disability activism by becoming a first few nation to develop first national priority assistive product list following the recommendations outlined by WHO priority assistive product list which aims to improve access to high quality, affordable assistive products (AP) in all countries (WHO, 2016). Report on the first national review and planning workshop on disability in 2017 identified gaps in assistive products in Nepal, outlining AP availability as a significant challenge (MoHP, 2018). These issues are further detailed in Policy, Strategy and 10 years Action Plan on Disability Management 2016-2026 (MoHP/LCDMS, 2018).

The priority AP list document suggests future actions to develop assistive technologies by using local resources. Some of these recommendations has been addressed by formulating National Standard on Assistive Technology (2022) which highlights the importance of system approach in AT service provisioning (MoHP, 2022). For the first time in Nepal's history, this AT standard recognized the use of noble production techniques such as 3D printing and defined protocol for local production and repairs which involves multi-disciplinary participation in problem solving and user satisfaction as key parameters for outputs. Furthermore, Nepal's Policy, Strategy and 10 years Action Plan on Disability Management 2016-2026, which is effective now, is expected to address some of these issues around prevention, treatment and rehabilitation including accessibility in public infrastructures.

The COVID-19 pandemic exposed supply chain vulnerabilities of the well-established, globally functioning mass production system (Wilson), prompting rethinking towards localized, resilient models. A promising alternative technology, distributed manufacturing using 3D printing enables customized assistive device production as discussed by Gallup et al. (2018), though limitations exist (Barbareschi *et al.*, 2020). Transitioning from mass production focused linear to circular economies can enable sustainable growth (Kirchherr, Reike and Hekkert, 2017), but holistic, systems-level change is needed specially in the developing countries. While additive manufacturing offers promises (Huang *et al.*, 2013), synergies with circular principles are required for resilient, efficient and innovative production. Despite Nepal's policy successes in the recent years and admirable efforts in uplifting the lives of PwD's, fulfilling these dreams is a big challenge due to various social, economic, environmental, geographic and economic challenges discussed as above. Above all, investigating sustainable service provisioning and establishing resilient local system is a continuing concern within development sector and research communities.

This thesis examines wheelchair provisioning in Nepal, one of the key assistive products needed for many, as a case study by engaging its key stakeholders such as global manufacturers, national service providers, and local makers. It aims to find collaborative approaches for more sustainable wheelchair access in Nepal which can inform local partners and policy makers about the scope of local manufacturing and repairs of wheelchair components. Finally, the study provides a framework for global-local partnership and building localized capabilities to develop a resilient, sustainable and user-focused wheelchair provision system in Nepal with global scope.

We examine this by doing a thorough literature review to understand current developments in assistive technology provisioning, sustainable production systems, repair and maintenance for sustainable product use and use interview findings and exploratory local production outcomes to

suggest circular and local distributed manufacturing approach for assistive technology provisioning in Nepal.

2. Literature Review

2.1 AT Provisioning in Developing Countries: Nepal and South Asia

Approximately 2.2% of Nepal's population has disabilities, with around 37% of them being physical disabilities (Nepal Census, 2021). Surprisingly, three neighboring nations with similar culture and socio-economic status - Nepal, Bangladesh and India have less than 3% recorded disability population, significantly lower than the global average of 15%. These figures are under-reported due to the association of disabilities with social stigma and taboo in these countries (Karki *et al.*, 2021). Additionally, factors like internal conflicts, insurgencies, natural disasters, road accidents and burns contribute to a higher prevalence of disabilities in these regions (Shrestha, 2023). Karki et al. (2022) found that the AT service delivery process in these countries is complex and non-linear. They highlighted issues such as limited support for personalized services in assessment, fitting, and user training, geographical challenges favoring urban areas, lack of follow-up and AT equipment maintenance, and a shortage of skilled local service providers. The sourcing of AT devices is often ad hoc, with some individuals purchasing devices out of pocket, while others receive them from charities or government-funded centers. The study underscores challenges such as high costs and limited accessibility, particularly for rural residents (Karki *et al.*, 2021).

Nepal's government offers disability allowances through its social security allowance (SSA) programs, aiming to provide financial support and services to PwDs based on their disability identity cards. However, only a fraction of the users hold such cards, and up to 60% of eligible beneficiaries are not receiving the allowance due to barriers in information dissemination, disability assessment, and application processes, particularly affecting children with disabilities, leading to restricted service access and high illiteracy rates among them (Holmes et al., 2018). Obtaining a disability card is a strong means for users to receive public support. The Disability Research Centre at Kathmandu University conducted a study on Nepal's disabled population, revealing widespread negative attitudes and lack of understanding, resulting in discrimination and denial of rights. Fundamental rights such as education and mobility face accessibility issues, leading to economic and social exclusion marked by low education, high unemployment, and poverty among PwDs. Political and public participation is limited, underscoring the need for improved accessibility, affordable assistive devices, and inclusive development policies for dignity, empowerment, and self-reliance (Disability Research Centre KU, 2018). These findings are in parallel with issues identified in several national policy documents mentioned in the introduction section above.

2.2 Assistive Technology and Local Repair and Maintenance

Assistive mobility devices like wheelchairs have a significant positive impact on people of all ages, particularly children. For children who were previously confined indoors and unable to move, using wheelchairs allows them to sit up, move around their homes, and improve their motor function through physical activity (Andrews *et al.*, 2023). This increased mobility and independence not only benefits the children but also eases the caregiving burden on their caregivers, as they no longer have to carry them constantly. Whereas the lack of access to wheelchairs results in social exclusion and isolation for users. Studies indicate that most wheelchairs require repairs within a year (McClure *et al.*, 2009), and neglecting these repairs leads to reduced mobility, increased injury risk (Emanuel, 2023), and even vulnerability to early death (Fitzgerald *et al.*, 2005; Worobey *et al.*, 2012; Seymour, Geiger and Scheffler, 2019). Delays in follow-up, repair, and maintenance services not only affect users' physical well-being but also impact their education and livelihoods(Worobey *et al.*, 2012; Hogaboom *et al.*, 2018), increasing the risk of poverty and other health issues.

Ensuring the longevity of product use relies on factors like spare parts availability, skilled repair centers, and cost-effective repair options. Karki et al.'s research revealed that follow-up services, including repair and maintenance, were inadequately provided in Nepal, India, and Bangladesh. This deficiency negatively impacts the users' experience with assistive technology devices and reduces the devices' overall lifespan. In low-resource areas, wheelchair models with simpler, locally repairable, or replaceable designs are preferred by users and receive higher ratings compared to other models. This was evident in a study by Rispin, Riseling and Wee (2018), where such models outperformed other wheelchair options in the community. In a South Asian study, Karki et al. (2022) propose enhancing follow-up services by creating assistive technology devices using local materials and training local artisans to repair and maintain these devices.

2.3 Issues and Challenges in wheelchair provisioning in developing countries

In low- and middle-income countries (LMICs) grappling with humanitarian and economic challenges, wheelchairs are often distributed through non-government organizations (NGOs) and voluntary organizations (Mukherjee and Samanta, 2005). Studies by Saha et al. (1998), Mukherjee et al. (2006), and Andrews et al. (2023) reveal that wheelchairs are often abandoned

due to environmental mismatch, discomfort, inaccessibility, and damage issues. The detailed result is shown in *Appendix 5.* It is more common in children, reflecting rapid growth, and aligning with North American research showing over 50% of wheelchairs needing repairs within six months (McClure *et al.*, 2009). These research from various geographies and culture presents wheelchair repair service as a global need and emphasizes the significance of frequent repair and maintenance. Engaging end users in design and assessment is crucial, prioritizing function and quality of life over technical aspects (Mulholland *et al.*, 2000). This is further discussed in the paragraphs below. To complement charitable efforts and local manufacturing, the need for large-scale domestic production and import is highlighted by Pearlman *et al.* (2006) for supply-demand alignment, sustainability, and positive outcomes.

This group of researchers criticize on the charitable wheelchair distribution practice acclaiming its limitations in selection and adjustment (Andrews et al.,2023), proper fit and customization (Mukherjee et al., 2006), leading to frequent breakdowns and discomfort. They identified weight bearing parts such as castors, wheel bearings, axels and tires, and positioning supports such as seats and cushions, arm rest, back rest, and footrest, etc. to be the commonly damaging parts which require frequent repairs in less than a year time. They attribute unavailability of spare parts, repair facilities and skilled labor as the challenges to repairs. Hansen, Tresse and Gunnarsson (2004) claim that the frequent breakdowns result from insufficient maintenance and design flaws, highlighting the importance of accessible spare parts and local design capacity. Charitable distribution, which often involves purchase and mass distribution to a target region (Pearlman *et al.*, 2006) without (skips) proper assessment, fitting, training, or follow-up maintenance with support services (Kim and Mulholland, 1999; Mukherjee and Samanta, 2005; Visagie *et al.*, 2015; Tebbutt *et al.*, 2016) which are against the WHO/ISWP *Wheelchair provision guidelines* (2023), results in dissatisfaction and poor usage (Gowran *et al.*, 2021). The four wheelchair service steps is shown in *figure 2 (right).*

2.4 Wheelchair Provision Guidelines

The Wheelchair Provision Guidelines aim to ensure equitable access to appropriate wheelchairs by offering clear recommendations to Member States and helps governments meet their obligations under the UN Convention on the Rights of Persons with Disabilities (UNCRPD)[1] and

[1] UNCRPD is an international human rights treaty adopted in 2006 to protect and promote the human rights of disabled people.

achieve relevant Sustainable Development Goals (SDGs)[2]. The guideline is developed adopting the WHO GATE 5P framework[3] which serves as a comprehensive strategy, emphasizing **policy, products, provision, and personnel** centered around **people/users** for promoting fair access to assistive technology such as wheelchairs. This approach supports international commitments and the goal of universal health coverage (UHC) while fostering inclusivity and advancing SDGs. The 5P model is shown in *figure 2 (left).*

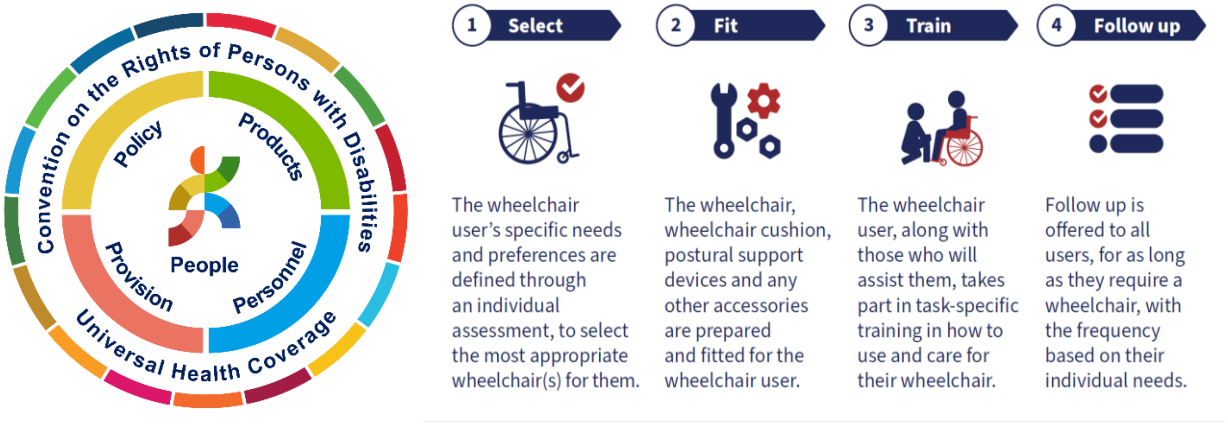

Figure 2 5P framework of AT service provision guidelines (Left); 4 major steps for wheelchair services (Right) (Source: WHO/ISWP wheelchair service provision guidelines – 2023)

2.5 Disability and Global Development (UN SDG)

According to the WHO/UNICEF Global Report, there is a substantial global need for assistive products(*Global Report on Assistive Technology*, 2022). Currently, over 2.5 billion people need one or more assistive devices, and this is projected to rise to over 3.5 billion needs by 2050 due to ageing global population and a rise in noncommunicable diseases such as diabetes and stroke leading to disabilities at any stage of life – yet 90% will not have access. Currently, the access to assistive technologies in low and middle-income countries (LMICs) is as low as 3% of the demand (World Health Organization, 2023).

The UN Sustainable Development Goals (SDGs), which now acts as a framework for international development, is adopted as a "universal call to action to end poverty, protect the planet, and

[2] SDGs, also known as global goals, were adopted by the UN in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity. It consists of 17 integrated goals.

[3] Global Cooperation on Assistive Technology (GATE) is a WHO initiative envisioning a world where AT is universally accessible to everyone, everywhere. More information:

ensure peace and prosperity for all by 2030" (United Nations Development Programme, 2015). The balance amongst social, economic, and environmental sustainability is at the heart of 17 integrated goals and the countries pledge that no one will be left behind and will be ensured by providing equal opportunities to all in the journey to meet inclusive and equitable development (United Nations, 2015). Between one and two billion persons with disabilities and elderly people, especially women, are at the risk of exclusion as they are most likely to remain left behind (World Health Organization, 2022) and they live in low and middle income countries (United Nations, n.d.). Tebbutt et al. explore how each of the 17 SDGs can be achieved through the provision of assistive products (Tebbutt *et al.*, 2016) as they are integrated and the actions in one area will impact the outcomes in others (United Nations Development Programme, 2015). Furthermore, the effect of climate change due to global warming is the biggest threat to humanity today (United Nations, 2021). It disproportionately affect socially vulnerable people because of their gender, socio-economic status and disability (Otto *et al.*, 2017).

2.6 The shifting landscape: Globalization to Localization

Manufacturing and transportation/logistics account to over 35% of the global greenhouse gas emissions and more than 70% of the total emissions are linked to the major goods producing nations including US, China, EU, India, Russian Federation and Japan (Environmental Protection Agency, 2023). The carbon footprint linked to the highly centralized manufacturing and global supply chain is immense. This not only affects the health of our planet but impacts directly on human health as well, as it was evident from the global supply chain disruptions caused during the COVID-19 pandemic which created shortages of essential medical equipment, PPEs and even basic supplies all across the globe. Not only the global scale pandemic but even the slightest disruption in the global logistics such as the Suez Canal blockade in March, 2021, when a 18,300 container carrying Taiwanese ship was wedged due to gust of wind, threw global logistics into chaos for several days (BBC News, 2021).

Geopolitical shifts, a pandemic and recent event such as Russia's invasion of Ukraine have prompted a reconsideration of global supply chains. Neglecting supply chain resilience could lead to major economic impacts in an unstable environment. Focus now shifts from cost savings to reliability and resilience due to uncertainties (Shivakumar, Arcuri and Wessner, 2022). In an increasingly tumultuous global landscape, where disruptions could impact the well-being of

billions, the potential drawbacks of not enhancing the robustness of supply chains through restructuring are substantial.

2.7 Shift from a global supply chain to a more localized supply chain:

An analysis of several research articles by influential institutions and authors revealed that 'Resilient' and 'Sustainability' were the primary supply chain topics discussed in numerous innovative SC disruption management strategies (Moosavi, Fathollahi-Fard and Dulebenets, 2022). Supply chain resilience (SCR) manifests when the network is capable of withstanding, adapting, and recovering from disruptions to meet customer demand and ensure performance. The term 'resilience' can be defined as the systems performance to withstand, adapt, and recover from disruptions to meet customer demand (Hosseini, Ivanov and Dolgui, 2019). In a globalized economy, supply chain and transportation networks form the backbone of the economy and directly influence sustainability of a system. Hosseini et al. suggests that the objective should be towards minimizing total supply chain cost and maximizing the resilience of the supply chain or minimizing the recovery time of a disrupted component of the supply chain through integration of digital technologies. Similarly, Naghshineh et al. add that the adoption of additive manufacturing, also called 3D printing, a disruptive digital technology can improve supply chain resiliency but it can also lead to certain supply chain vulnerabilities due to certain adoption barriers they have identified in their study (Naghshineh and Carvalho, 2022). Iyengar et al. suggests that the innovative applications of 3D printing can ensure parts availability for the manufacture of critical medical devices such as ventilators (Iyengar et al., 2020).

In the countries like Canada, Spain, UK and US, designers, scientists, engineers, and manufacturers were collaborating to create a ventilator that is simple, accessible, and manufacturable, utilizing both 3D printing or more conventional techniques (V, 2020). The biggest manufacturing companies in the US and UK such as Tesla, GM, Ford, Dyson and Rolls-Royce were preparing themselves to pivot to COVID related product manufacturing to ensure critical product availability during shortages (Yurkevich, 2020). Bespoke production address the need of PPEs during shortages but it is imperative to follow manufacturers instruction and regulatory advice on material composition and design features to reprocess and customize for use (Rowan and Laffey, 2020).

A UK FCDO-funded program, COVIDaction Local Production Local Solutions (LPLS), demonstrated that local production, distributed manufacturing, and circular economy approaches were quickly adopted by innovators and companies in Africa and South Asia to produce PPPs and other COVID related response items locally (Oldfrey, 2023). Oldfrey claims that the local production and solution approach can enhance emergency resilience, responsiveness, waste reduction, and environmental impact mitigation in the LMICs. These studies and reports show the interconnected nature of our modern globalized economy, and the vulnerability lies not only in low-middle income countries (LMICs), but also in the highly industrialized nations. However, the hope of transformation too lies in the ingenuity of resource rich nations as well as in the struggles of resource constrained communities.

Ibn-Mohammed et al. suggests re-evaluating the current global economic growth model, which relies on linear manufacturing processes of ‘extract-produce-use-dump’ and profit-driven systems, in favor of a sustainable approach based on the circular economy framework. Drawing on evidence that the circular economy can achieve profitability while minimizing environmental impact, the paper provides sector-specific suggestions for adopting circular economy solutions as a means to stimulate global economic growth and development in a resilient post-COVID-19 world (Ibn-Mohammed et al., 2021).

2.8 Shift from Linear economy to circular economy:

For an extended period since industrial revolution began, the fundamental concept of the industrial economy has been based on the conventional linear economic framework, involving the process of extracting resources, manufacturing goods, and discarding products when their lifespan ends. This has often been described by specialists as the "extract-produce-use-dump," "take-make-waste," or "take-make-dispose" energy flow model within industrial operations (Geissdoerfer *et al.*, 2017; Kirchherr, Reike and Hekkert, 2017). Although it could have been the need of industrial revolution, this model is not sustainable forever due to our planetary resource limitations. The means of mass production, although sounds cost effective and faster in the short run, there is a loss of huge amount of raw material and energy during the production stages. One study suggest that there are more waste generation than the actual resource utilization in a linear economy model (Hoornweg and Bhada-Tata, 2012) and this is believed to get even worse in the future as the global demand for resources is expected to double by 2050 (UNEP, 2017). Because of all these limitations and challenges, ‘Circular Economy (CE)’ has never been more relevant

than in today's context. The basic principle of CE is the shift of focus from a linear material transformation to a holistic product value chain where a regenerative nature of product lifecycle is considered through repair/re-use and waste management (Lieder and Rashid, 2016).

Figure 3 illustrates the differences between linear and circular economy model.

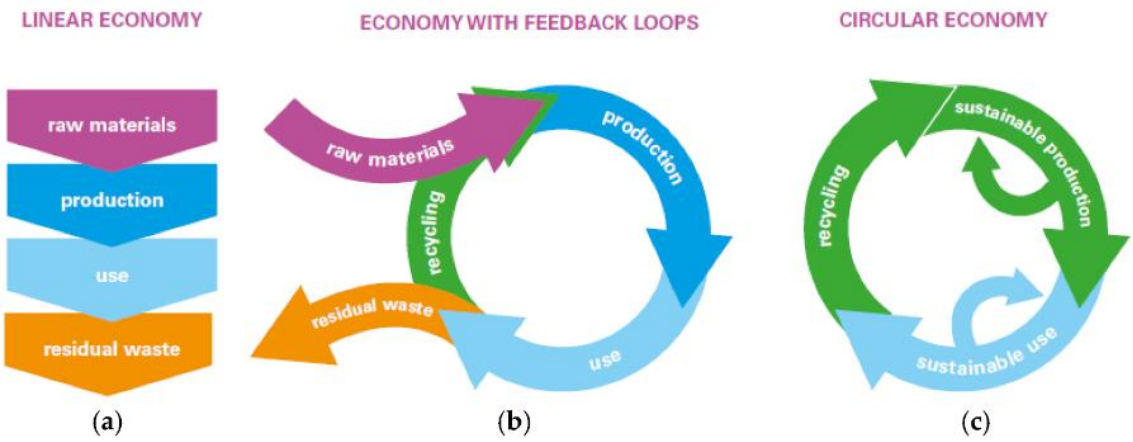

Figure 3 Distinction between (a) Linear economy, (b) recycling economy and (c) circular economy (Source: Van Buren et al., 2016)

Figure 4 explains key 10 R terms which are the key elements of circular economy.

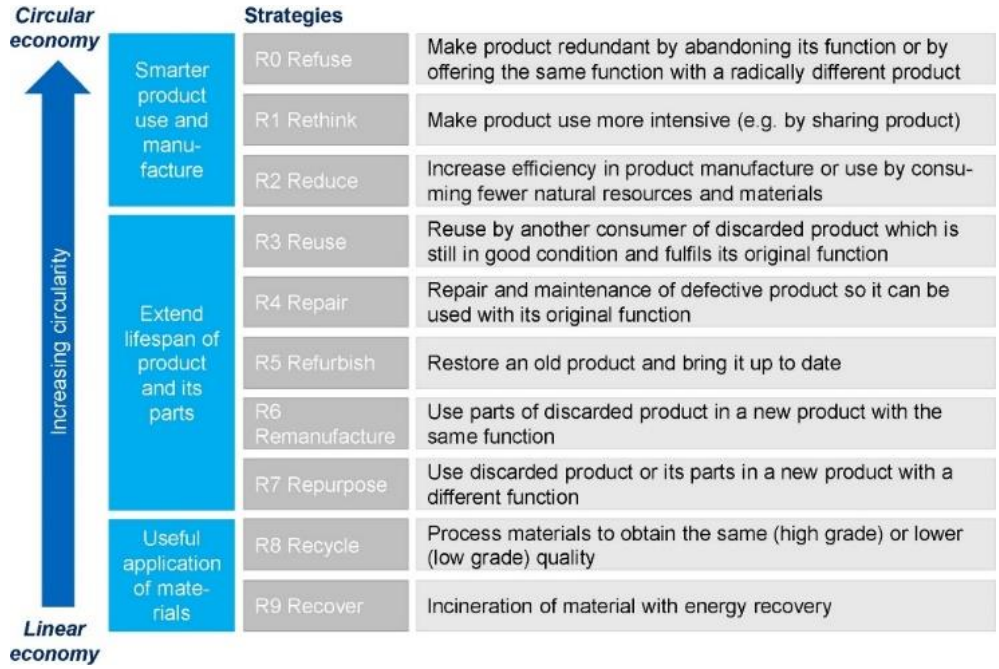

Figure 4 Strategies (R0 to R9) for transitioning from linear economy (bottom) to circular economy (top) (Source: Potting et al., 2017)

2.9 Centralized to Distributed Manufacturing:

The landscape of manufacturing is undergoing a transformative shift with the emergence of Distributed Manufacturing (DM) and Additive Manufacturing (AM). DM's transformative potential lies in its ability to reshape manufacturing economics, enabling diverse strategies that accommodate location and scale dynamics (Durach, Kurpjuweit and Wagner, 2017). DM allows industries to produce components in different places and assemble them for the final product (Srai *et al.*, 2016). A shift from centralized to distributed manufacturing will have implications for local manufacturing, medical equipment remanufacturing, and the built environment.

3D printing, also known as AM process, is a revolutionary process of constructing intricate objects by layer by layer addition of materials as opposed to traditional machining process (subtractive) (ASTM International, 2022) , offers unprecedented design freedom and complexity, yet it complements existing methods rather than replacing them (Jimo *et al.*, 2019). Gallup, Bow and Pearce (2018) found that distributed manufacturing of open-source adaptive devices on average resulted in financial savings greater than 94% compared to commercially-available products in the United States. Barbareschi *et al.* (2020) says that the wheelchair users and service providers both recognized the value of 3D printing innovation approach to making bespoke components, but they identified functional limitations in both the wheelchairs and the service model. Corsini, Aranda-Jan and Moultrie (2022) believe that in order to generate value throughout the supply chain in the humanitarian sector, there is a requirement for both the on-site creation of 3D printers and filament (raw material), along with local design and production efforts.

While hurdles such as costs and technical limitations exist, the potential benefits of AM in reducing costs and production time are undeniable (Naghshineh and Carvalho, 2022). As we navigate this transformative terrain, the concept of a circular economy emerges as a guiding principle, emphasizing sustainable practices by reducing manufacturing’s environmental impact, personalization through localized production, and the repurposing of materials for improved efficiency (Huang *et al.*, 2013). The synergy between these advancements and conventional manufacturing practices will likely define the future of production, fostering efficiency, innovation, and sustainability in an increasingly interconnected global marketplace (Holmström and Partanen, 2014).

Currently, there is significant optimism surrounding Additive Manufacturing (AM) due to its potential to simultaneously lower costs, production time, and tooling requirements, facilitating product customization (Durach et. al., 2017). Research by Huang *et al.* (2013) suggests that

among seven AM processes examined, five are likely to dominate the manufacturing industry: powder bed fusion, directed energy deposition, material jetting, material extrusion, and vat photopolymerization. Notably, powder bed fusion and material jetting are anticipated to outperform material extrusion. However, these high end technologies are often unavailable in LMICs and are costly, which could be compensated by exploring the fusion of widely available FDM 3D printing and conventional mass production processes as evident in this casting 3D printing to metal casting of cook-stove burners case study in Nepal (Britton, 2018). While implementing the alternative approach to scaling production, it is important to minimize waste and environmental impacts, otherwise we are reinventing the wheel of mass production era, which can have negative impacts on our planet. Thus, we explore a new model of production approach in the next section considering economy of scale, adoptability, recyclability and sustainability at the core of it.

Sustainability through the fusion of Circular Local Distributed Manufacturing

Geissdoerfer *et al.* (2017) has tried to synthesize the meaning and use of the term 'Sustainability' and link its modern connection to its uses in ecological context in the past as a principle of respecting the ability of nature to regenerate itself. Sustainability is used widely across economic, social and environmental contexts. One of the widely adopted definitions is by the Brundtland Commission which defines sustainability as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Keeble, 1988). Through the studies of several literature, Geissdoerfer et al. found that the circular economy is a condition for sustainability, or a trade-off adopted in studies. Ibn-Mohammed *et al.* (2021) indicated that the shutdown of fossil fuel powered industries and transportation resulted in the decreased CO2 emissions, improved air quality and the nature thrived amidst pandemic, but this pattern was short-lived as most of the countries around the world entered into economic recession due to the consequences of pandemic. Hence, we can come to a consensus that sustainability cannot be justified by the advancement in one domain alone but through the balance of social, economic and environmental achievements.

How can sustainability be achieved while justifying socio, economic and environmental balance?

A study by Westerweel, Song and Basten (2019) supports the economic viability of distributed manufacturing platform suggesting that if "Designers/manufacturers" sell spare part designs rather than physical parts and enable local 3D printing, it becomes advantageous for buyers compared to centralized production. The study also indicates that manufacturers also benefit

through straightforward Intellectual Licensing contracts. González-Varona *et al.* (2020) suggests that such platform significantly benefits SMEs in global markets by enhancing after-sales support for customers. This is achieved through quicker response times and simplified logistics due to local 3D printing of parts, reducing costs and improving sustainability. This approach eliminates unnecessary resource consumption and CO2 emissions associated with producing and shipping unused or replacement parts from distant warehouses.

Pearlman *et al.* (2006) develops a comprehensive framework for transferring wheelchair technology to developing countries by evaluating various models for this transfer, including charitable distribution, workshop, manufacturing, globalization, and a multi-modal approach. The workshop model, offering appropriately designed wheelchairs and moderate sustainability, is considered the most beneficial but would often face issues of quality control and steady market demand. Charitable distribution provides quick wheelchair supply and can be useful during disaster response to fulfill emergency needs but lacks sustainability in other times. Pearlman et al. also discusses joint venture manufacturing example of a consulting model but it can be expensive and the user needs are compromised due to imported designs, while globalization targets market expansion and are challenged with cost and supply chain issues. They ultimately suggest a multi-modal approach which balances the involvement between large-scale and small-scale suppliers after understanding the regional service providers. The research underscores the importance of tailoring models to local needs and addressing challenges related to cost, quality, and sustainability in transferring wheelchair technology.

As indicated by the literature above, production and distribution solely does not solve the issues around accessibility of products as most researchers raised concerns on repairability and timely maintenance to benefit from the product throughout its use. In the section below, we explore how policies on repairs are going to change production and consumption around the world.

2.10 Repair issues and international laws:

Repair plays a vital role in circular economy (CE) strategies, aiming to prolong product and material lifespans and create employment opportunities during CE transitions. However, repair technicians often face challenges like obtaining affordable spare parts, encountering disassembly difficulties and perceived high costs compared to new items and concerns about cleanliness

(Bovea et al., 2017). The study by Türkeli et al. (2019) found that global manufacturers' circular decisions greatly impact repairability.

There are several laws and initiatives in the UK and EU which collectively combat climate change by promoting efficiency, waste reduction, and sustainable design. The "Right to Repair" movement focuses on consumer access to repair tools and resources, aiming to extend product lifespans, reduce electronic waste, and promote sustainability (Right to Repair, 2023). The EU's Circular Economy Action Plan strives to enhance resource efficiency, minimize waste, and promote circular practices in production and consumption (European Union, 2023). The European Green Deal aims for climate neutrality by 2050, emphasizing emissions reduction, clean energy, and environmental protection (European Union, 2023). The UK's Ecodesign Law establishes efficiency standards for energy related products to minimize environmental impact (The Ecodesign Law, 2021).

Lisa I. Iezzoni, a Harvard Medical School professor, highlights uncertainties regarding the impact of right-to-repair laws on power wheelchair repair times due to the intricate nature of the industry. She notes that such laws don't cover manual wheelchairs or scooters. The need for timely wheelchair repairs is crucial as the demand for wheelchairs rises, especially among baby boomers with mobility disabilities seeking community engagement. Resolving the wheelchair repair crisis is becoming more pressing (Iezzoni, 2022).

2.11 Conclusion of the Literature review:

It can be concluded from the literature that wheelchair provisioning and its repair and maintenance is a global challenge which requires collaborative global-local model balancing centralized and distributed approaches, leveraging the quality and efficiencies of centralized networks along with the localization benefits of distributed production. Strategic partnerships between global manufacturers and local makers/technicians can build localized capacity through training programs and quality systems. Local production and service capacity offers freedom from the charitable model of WC distribution, although effective in emergencies, but criticized in most studies. Localized circular manufacturing of spare parts promotes availability, affordability, customization and recyclability. Awareness campaigns, vocational training, policy implementation, and platforms connecting users and inventory can catalyze this ecosystem approach. Overall, global collaboration and localized capacity building through human-centered design provides a

pathway for resilient, sustainable and user-focused assistive technology systems, upholding the rights and inclusion of people with disabilities. We explore more in the following sections through interviews and case studies focused within Nepal. Therefore, based on these existing literature, these are the objectives:

Objective 1: *Understand the situation of wheelchair provision in Nepal and identify opportunities and challenges.*

Objective 2: *Study global-local collaboration model for sustainable wheelchair provisioning in Nepal.*

Objective 3: *Study the feasibility of localized spare parts production for sustainable wheelchair repair and maintenance.*

3. Methodology

This study employs a mixed methods approach, combining a desk review of relevant published and grey literatures, and primary research from qualitative methodology by interviewing stakeholders.

Semi-structured interviews were conducted with ***14 wheelchair service providers (n=14)*** across Nepal *(refer figure 1 in the introduction section)*. Participants were identified through purposive and snowball sampling, with diversity sought across geographical location, type of institution and professional role. The interviews gathered service provider's experiences, strengths and challenges faced in wheelchair provisioning, following the WHO 5P's wheelchair service provision guidelines *(refer figure 2)*. To understand the perspective of ***global wheelchair manufacturers (n=1)*** on balancing centralized and localized approaches, an in-depth interview is carried out with a representative from Motivation UK. As a prominent manufacturer aiming to improve wheelchair access in low-resource settings, their insights offer a useful comparator to the Nepali context. Questionnaire-based interviews with ***9 local makers (n=9)*** in Nepal helped characterize local production capabilities in diverse materials and production processes. Participants across small, medium and large facilities were identified through outreach on email and social media platforms. Following the interview findings, a framework for local production was supported with an exploratory design and local production experiment to understand the practicalities of sustainable production and repair of wheelchairs in Nepal.

Figure 5 is the research flow diagram adopted in this study.

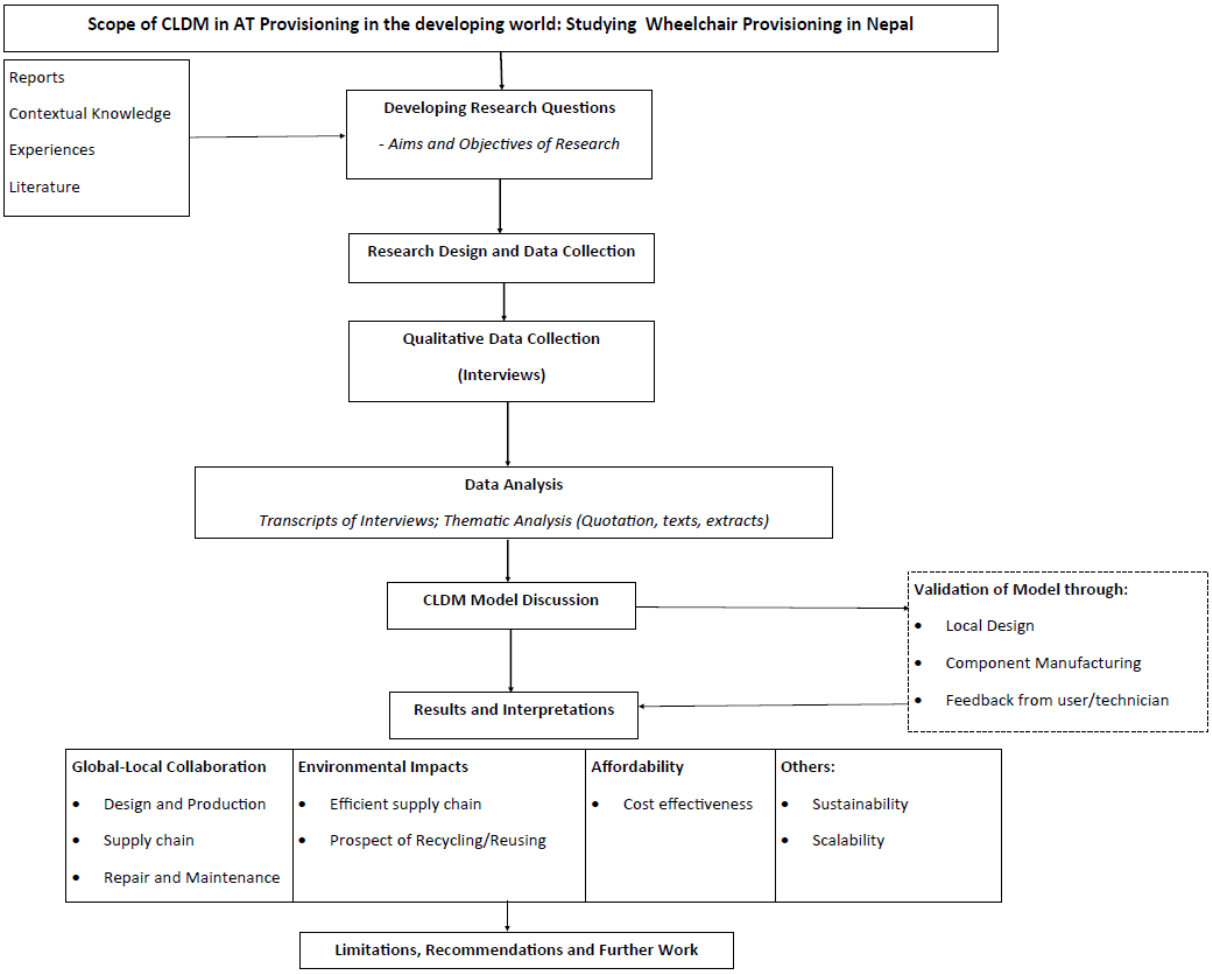

Figure 5 Mixed Research flow diagram

In a design and local production experiment, five common wheelchair spare parts were designed, and 3D printed in partnership with the Kathmandu University Design Lab[4], simulating a *local production hub*, and Centre for Disabled Children Assistance (CDCA)[5], a Nepali wheelchair provider which distributes around 250-300 wheelchair annually, simulate a role of a *distribution*

[4] Design lab is a part of Design and Manufacturing Group in Department of Mechanical Engineering, Kathmandu University, established with the purpose of providing students and researchers a platform to create ideas and prototypes. More information: https://designlab.ku.edu.np/about-us/

[5] CDCA is a non-profit company based in Kathmandu which provides shelter and education support to children with disabilities, and has been partnering with International Wheelchair Foundation and local service providers for wheelchair distributions in Nepal. More information: https://www.cdcakapan.org/

hub. This exploratory experiment offers real-world validation of the feasibility, costs and challenges involved in localized on-demand spare parts production.

The sequencing of the methods moves from broad insights on the wheelchair ecosystem to specifics of production abilities and demonstration. All the interviews were recorded and then translated and transcribed with appropriate consent. The interviews were then coded in segments according to the identified themes: *WHO GATE 5P's framework* and summarized in *Microsoft Excel* for analysis. A thematic analysis synthesizes findings from three phases to shape a collaborative framework balancing global and local elements. While qualitative with limited sample sizes and production experiment limited to simpler parts using only one process, the triangulation between global, national and local sources yields rich perspectives on the subject. Overall, the use of interviews and an applied project is an appropriate methodology for this exploratory research on enhancing wheelchair provision through global-local collaboration.

4. Ethics

This research expands on the project of Global Disability Innovation Hub (GDI Hub) which is a UCL based research and practice centre driving disability innovation for a fairer world[6]. However, this research doesn't incorporate any thoughts or recommendations of these partner institutions.

Ethics approval was obtained from the ethics review committee at UCL under the GDI Hub project (16149/001). Interviewees were provided with a soft copy of consent form and participant information sheet along with the list of semi structured questions, transcribed in both English and local language (Nepali) were shared through email few days prior to the interview and were again clarified verbally before recording the interviews. Whereas physical copies were handed to the wheelchair users during the physical interviews. Everyone agreed to be recorded for research. Anonymity is maintained throughout this report with due respect to respondent's personal privacy.

[6] GDI Hub is a WHO collaborating centre which works alongside local partners, supporting products and innovators to deliver impact through FCDO UK aid funded AT2030 programme. More information: https://www.disabilityinnovation.com/

5. Results and Findings

5.1 Objective 1: Understand the situation of wheelchair provision in Nepal and identify opportunities and challenges.

14 professionals from 9 wheelchair service providing institutions were interviewed of whom 5 were physiotherapists, 4 were project managers and 2 were wheelchair users who also worked as staff with the service provider institutions. Most of the interviewees were from Kathmandu and Pokhara, two largest and densely populated cities in Nepal, representing 4 from each city. There were participations from 4 of 7 provinces in Nepal: Bagmati (n=6), Gandaki (n=4), Koshi (n=3) and Karnali (n=1). Service provider participants were identified from the details obtained through a disability related workshop organized in Dhulikhel by the GDI hub team. Out of 10 invitations sent through email, 8 of them accepted online interviews and 5 others were contacted based on the connections built through those interviews. Of the total 14 interviews, 12 interviews were conducted online though secured zoom call and 2 user interviews were conducted physically at Pokhara during the visit to Nepal in May 2023. Each interview lasted between 45 minutes to 60 minutes which were recorded and stored in the UCL one drive and later transcribed in English. Most of the interviews were conducted jointly by three researchers of GDI Hub, a Senior Occupational Therapist and a Senior Research Fellow.

Interviewees were asked semi structured questions broadly around their experience on wheelchair provisioning in Nepal and explored around the 5Ps of WHO/ISWP wheelchair service provision guidelines – ***Policy, Personnel, Products and Provision with People*** at the center. Sample of the interview questions is attached in *Appendix 1.* Sample of this interview can be found in *Appendix 2.* Most of the interviewees highlighted the need for national level training through standard curriculum, need for local manufacturing and sustainable repair and maintenance services in the country as the key priorities. *Figure 6* summarizes the situation of wheelchair provisioning in Nepal which helps in understanding strength, weaknesses, opportunities, and threats (SWOT) of the current situation.

In this section, we discuss findings related to 5P's.

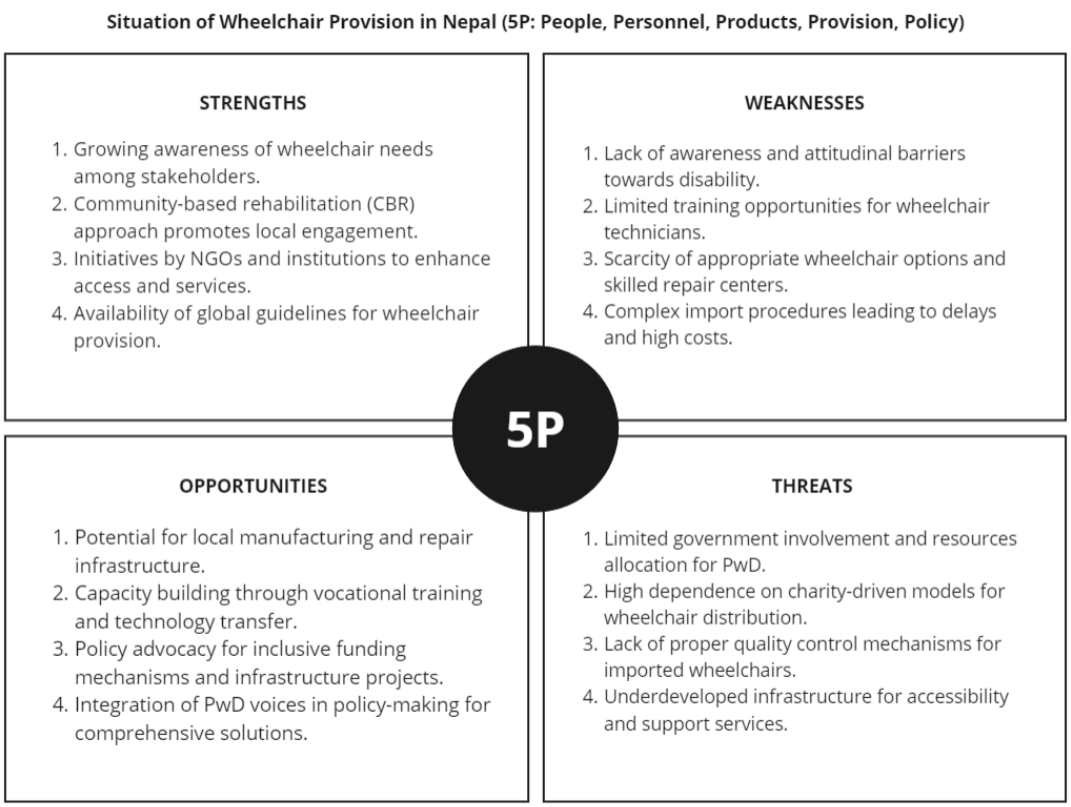

Figure 6 Summary of the situation of current wheelchair provision in Nepal identified through user and service provider interviews.

5.1.1 People

Increasing Disability Cases

The spectrum of wheelchair users encompasses diverse categories, including Children with Disabilities, those with neurological disorders, spinal cord injuries, geriatric populations, severe orthopedic cases, cerebral palsy patients, and more, with spinal injuries and cerebral palsy emerging as predominant disabilities. Disability cases due to fall injury and road accident is increasing.

Social Stigma and Lack of Awareness

There is a prevalent social stigma surrounding disability in Nepal. Disability is often viewed as a family burden, which perpetuates feelings of humiliation among people with disabilities (PwD) and their family members. Although some changes have occurred in recent years, there is still a need for greater awareness campaigns and education to bring about a shift in societal attitudes. Otherwise, it can have consequences on social inclusion. Referring to the social context and lack of accessibility, a service provider interviewee quoted, *"We used to travel 6-7 hours to reach communities for assessment and I would find a person literally lying on bed in the same position and not being able to move out from there for years."*

Inaccessible Infrastructure and Rugged Terrain

The unsuitable roads, buildings and public infrastructure like schools and health clinics pose major accessibility challenges. The hilly and mountainous terrain of Nepal also makes it extremely difficult for wheelchair users to navigate and move around independently. As one service provider mentioned, *"WC use is difficult in Nepal due to complex landscape and terrain. Disability solution requires intervention across home, people's mindset and the environment they live in, and it is more complex than we assume."*

Health Complications

Long-term wheelchair users, especially those with spinal injuries, face health issues like pressure sores. Lack of education among users on different wheelchair options also undermines the need for appropriate wheelchairs to mitigate health concerns. Even for those who have access to WC, accessibility is a challenge. A WC user shared his experience in an interview quoting, *"I remained in a wheelchair for the entire day and would not be able to access toilet. I used to starve myself*

from drinking water and that caused several issues like urinary tract infection and pressure sores almost every month. It was a routine in my life."

Economic Hardships

The high medical expenses associated with disabilities, coupled with financial struggles faced by families from low-income backgrounds, compound the difficulties for PwD in Nepal. The focus must be on fostering independence, social integration and wellbeing of PwD. As one service provider explained, *"If you are rich and in Kathmandu, you may get branded WCs but poor and marginalized users in the remote communities are not able to access wheelchair due to financial situation and lack of accessibility. I have seen these problems throughout my career."*

5.1.2 Personnel

Expertise and Experience of Personnel

The insights from the interview data reveal that a majority of the personnel interviewed have significant expertise, with over 10 years of experience in the field. Many have undergone training and education abroad, especially in India from WHO certified training center at various levels (mostly basic level 1). While lacking certification, practical experience gained through apprenticeships has equipped them with modification and posture skills.

Training Gaps and Local Capacity Building Needs

There is an unfortunate lack of comprehensive local training opportunities in Nepal for wheelchair professionals. With only two WHO certified master trainers, but now overseas, there is a void in domestic training resources. Personnel can handle basic modifications but need more training, especially as most users require customized chairs. Local capacity building through a national curriculum is identified as a need by most.

Motivations Driving Wheelchair Professionals

Despite challenges, wheelchair personnel are motivated by the transformative impact of their services in fostering independence, social interaction, health, empowerment, education and livelihoods for PwD. Some institutions even train wheelchair users as technicians as they are empowered and understand wheelchair issues better than non-users. But lack of spare parts lowers technicians' confidence in repairs. One service provider shared his motivation as *"When we were able to support them (users) assistive devices such as wheelchair and crutches and see them move around their space to see the surroundings for the first time in their life, that brings great joy and happiness to me."*

5.1.3 Product

Limited Access and Availability of Wheelchairs

WHO has estimated 80 million people (or 1% of the world's population) are likely to require a wheelchair to assist their mobility and is increasing yearly (World Health Organization, 2023). In Nepal, around 37% of the total disability population have physical impairment (Nepal Census, 2021) who are the direct potential beneficiaries for wheelchairs. This figure is more than 250,000 population in need of AT to support mobility, but the exact data is missing. Access to wheelchair in Nepal currently meets only 10-15% of the total demand as per the interviews. Wheelchair users face difficulties in locating proper rehabilitation and repair facilities, leading to restricted mobility and autonomy. The reliance on charitable organizations for wheelchairs is high due to funding constraints and product scarcity in the country.

Scarcity of Suitable Wheelchair Options

The scarcity of appropriate wheelchairs is unanimously cited as the most significant challenge, exacerbated by the absence of wheelchair manufacturing companies in Nepal. The prevailing scenario is marked by a shortage of appropriate wheelchairs, with a heavy reliance on basic hospital models or orthopedic chairs designed primarily for patient transfers at hospitals, unsuitable for long-term use due to their fixed features, uncomfortable cushioning, and lack of adherence to WHO accessibility product standards. *"Motivation WC"* is widely cited as a model of an appropriate wheelchair. Its unique attributes, such as the 3-wheeled rough rider version, prove suitable for Nepal's uneven terrains, yet its scarcity remains a significant concern. The demand far exceeds the supply. Charitable organizations cannot meet the rising needs, restricting accessibility. Only fortunate individuals can access suitable wheelchairs based on their needs. As one service provider shared, *"There are no options for appropriate wheelchairs. Even if you have money and are willing to buy one, you do not have access to an appropriate wheelchair."*

High Costs and Lack of Local Manufacturing

With no local manufacturers, costs have surged due to global shortages and shipping expenses, making wheelchairs unaffordable for many. Some Indian brands although available at stores but are expensive and limited to Kathmandu. Local production initiatives have struggled to be sustainable due to challenges with skilled manpower, raw materials, and spare parts. The perception of free wheelchairs through charitable means hinders potential income from repair services. One service provider and a distributor shared, *"We have more than 150 demands from*

Lumbini Province alone. We need more than 1500 wheelchairs per year. But our annual distribution capacity is only around 300 WCs now."

Spare Parts Shortage Affecting Maintenance

Sourcing spare parts, which is critical for maintenance, is difficult - especially for unique charitable models as their resellers are not based in the country. Technicians often salvage useful parts from abandoned wheelchairs as a last resort solution. The inability to produce parts locally hampers entire service ecosystems. Users are facing unnecessary hassles trying to source parts for repairing. When asked how a wheelchair is repaired once broken, a user shared:

"If I couldn't fix my wheelchair here, I go searching after parts like bearings in the local market, search for gas welding to fix a broken frame, visit a tire shop for fixing tires. If not, speak to my friends who are in Kathmandu. Once, I couldn't fix it through any means and had to make a post on a (renowned) Facebook page. Finding spare parts and repair service is a worst challenge."

Situation of damaged WC which was shared by an NGO during an interview is presented in *Appendix 6*.

5.1.4 Provision

Service Provision Approaches

Many institutions follow WHO guidelines such as 5x5 Community-Based Rehabilitation (CBR) matrix and 8-steps service provision approach to facilitate comprehensive service delivery, focusing on rehabilitation rather than just treatment. However, some NGOs and local clubs distribute inappropriate basic medical wheelchairs without adhering to WHO's recommended provision steps. This underscores the need for responsible wheelchair provision. Several institutions have introduced co-funding options to ease costs for users, but financial barriers remain due to limited means.

Assessment, Fitting and Training Processes

The wheelchair provision process involves identifying disability issues at the community level, conducting assessments, engaging families, providing modification recommendations, procurement, fitting, basic training on use, follow-up visits, and even tele-rehabilitation services for therapeutic needs in some cases. These are as indicated in the CBR guidelines and Wheelchair provision guidelines. However, timelines vary greatly from a few months to 2-3 years for wheelchair support depending on factors like product availability and budget. Government processes tend to be even more lengthy and complex compared to provisioning by NGOs.

Dependence on Imported Wheelchairs and Lack of Local Options

The prevailing approach relies heavily on NGO distribution of imported wheelchairs from abroad, as local purchasing options are extremely limited due to unavailability of appropriate models and manufacturing constraints. Dependency on time-bound grant funding for NGO distribution raises serious sustainability concerns, often resulting in a decline in wheelchair availability after project phase out.

Repair, Maintenance and Durability Challenges

Charitable wheelchairs tend to have short usable lifespans and lack available spare parts, rendering them non-functional in a short period. The absence of established institutions and systems for timely repair and maintenance poses major challenges. Centralized supply chains in Kathmandu increase costs due to transportation and complex logistics for the users and service providers in rural areas. In these challenges, users often resort to local bike repair workshops for maintenance, but this is an unsustainable solution due to the lack of their expertise in proper fitting

and adjustments. The charity-centric mindset has resulted in damaged wheelchairs being abandoned instead of repaired. A shift towards responsible wheelchair ownership and repair practices is imperative to tackle this issue.

5.1.5 Policy

Absence of Reliable Data and Policies

Most of the interviewees mentioned the lack of reliable data on PwD and their needs in local and national level which hampers the formulation of effective policies and programs to support them. There is a need for robust data to guide relevant policy reforms and initiatives.

Barriers to Accessing Constitutional Benefits

While the Constitution guarantees various rights and benefits for PwD including free healthcare, education, and subsidized transportation, the process for obtaining them is often unknown to many. There are provisions for financial support, such as an allowance for spinal injury patients and social security allowances for disability cardholders but such support is deemed insufficient to meet the basic needs and high medical costs of the users.

Complex Import Regulations and Taxation

The import of wheelchairs and spare parts is hindered by a complex taxation process. The institutions must navigate a multi-layered procedure involving various governmental bodies to obtain necessary documents for tax exemptions. However, there is no provision for tax free import of spare parts and raw materials. This intricate process contributes to delays and inefficiencies in the provisioning of wheelchairs. One of the service providers shared an experience,

"The shipment comes from China and we need to acquire certain documents. We first visit local government (ward office), then to municipality, then to social welfare council (as it is the governing body of NGOs in Nepal), then to ministry of women, children and senior citizen, then to the ministry of finance, then to the ministry of industry, commerce and supplies, and after that we go to department of custom. Only after these, we receive goods clearing documents from the custom department and then we can release wheelchairs from the port. Each consignment takes between 3 months to 6 months due to this lengthy process."

Figure 7 shows the regulatory approval stages for tax exemption on the imports of wheelchairs.

Figure 7 Current import procedures for tax free wheelchair import (Left to right).

Inadequate Fund Allocation and Local Implementation

Despite the presence of a National Disability Fund (NDF) offering free assistive technology support, the funding allocation for PwD from the government is deemed inadequate. Local authorities' lack of involvement in building disability-related policies and accessible infrastructure is a significant concern. Additionally, the lack of awareness and knowledge about disability, accessibility, and mobility results in exclusion from educational institutions for many individuals with disabilities. A wheelchair user shared his problem:

“Most schools do not accept admissions for wheelchair users because they lack accessible ramps and chairs to accommodate PwD. I didn't have an accessible toilet in school, and I couldn't use it. I remained in a wheelchair for the entire day. I used to starve myself from drinking water to stop my urge for urination and that caused several issues like urinary tract infection and pressure source almost every month. It was a routine in my life.”

Need for Quality Control and User-Centric Policies

The absence of quality control mechanisms for wheelchair suppliers is a pressing issue, as inappropriate wheelchairs are often imported and sold without considering users' needs. In response, strong regulation and oversight are recommended to ensure the provision of suitable and quality products.

5.2 Objective 2: Study global-local collaboration model for sustainable wheelchair provisioning in Nepal.

We try to understand this by interviewing a global wheelchair manufacturer and local makers in Nepal.

5.2.1 Global Manufacturer's Perspective on Local Production

As mentioned in the above section, 'Motivation UK' wheelchair was mentioned to be the preferred product by many users and service providers. Thus, it was necessary to understand how 'Motivation UK' works and how their vision aligns with the local users' aspirations on sustainable product provisioning in developing countries. Motivation UK was contacted through email through the existing GDI hub connection as they had piloted a project together in Kenya regarding the use of additive manufacturing process (3D Printing) to better inform their design and manufacturing processes and apply it to wheelchair provision (GDI Hub, 2023). A Product Manager and Technical Specialist of Motivation UK agreed to take part in the online interview which lasted for around 60 minutes. Highlights from the interview informed us following:

Evolution of Manufacturing and Distribution Approaches

The manufacturer initially set up local workshops in developing countries for small-scale production, training and maintenance. However, inconsistent demand, quality issues and loss of technicians led them to shift to centralized manufacturing in China for economies of scale and quality control. But reliance on one country poses risks. High shipping costs from central hubs, especially for spare parts, add to product costs. Stressing on the global supply chain risk, the interviewee mentioned, *"Reliance on concentrated production in one country (China) poses risks of supply chain disruptions due to geopolitical issues such as China-Taiwan conflict, Russa-Ukraine war, natural disasters, etc."*

Limitations of Centralized Model

The centralized model makes customization for individual users difficult by hindering user feedback to manufacturers. Due to heavy reliance on importation, local capacity ceases at one point. Lack of local skills and infrastructure leads to breakdowns and wastage, overlooking the maintenance aspect. Donated products disrupt local revenue streams and market sustainability.

Benefits of Balanced Global-Local Approach

Strategic collaboration combines global quality and scale with localization to meet context-specific needs. Regional models allow incremental capacity building. Vocational training partnerships with

governments and national training provider institutions are vital for skilled technician pools. Localization facilitates procurement justification and policy compliance for local/national government to pay from taxpayers' money. Recalling his experience, the interviewee mentioned, *"Regional/national production allows leveraging the strengths of both global and localized entities"*

Challenges in Accessing Repair Services

Poverty, transport issues and lack of local infrastructure impede users' access to spare parts and repairs. Localized service delivery is needed to address this. The interviewee suggest that licensing agreements between local makers and global manufacturers can enable localization of simpler parts production, creating opportunities for business and technology transfer.

In summary, a blended model is recommended by a prominent global manufacturer of wheelchairs to sustainably provide quality products while building local capacity and maintaining context-specific appropriateness.

5.2.2 Local Manufacturer's Perspective on Local Production

A complete wheelchair is made up of several smaller components which are assembled following certain standards before dispatching to users. Such components are mostly manufactured in producer nations like China and assembled elsewhere. Production of assistive products away from users' location negatively impacts on the lives of users when spare parts are not available timely during breakdown. Literature has shown that wheelchair breakdown is a recurring issue and unavailability of spare parts results in the complete abandonment of a product. Hence, it is important to explore local solutions for sourcing spare parts. To understand this, 12 local makers were contacted through email and social media of which 9 participated by submitting answers to the questionnaires asked around production capabilities, material, experience of distributed or contract manufacturing, material waste and use of recycled materials, supply-chain, challenges and opportunities of local production in Nepal. Samples of these interviews can be referred to *Appendix 3 and 4.* This section highlights the important findings of the local production sector.

Existing Manufacturing Capabilities and Processes

The interviews reveal a range of design and production capabilities for plastic, metal and general fabrication. Common processes include plastic recycling, metal casting, injection molding, machining (lathe, milling, grinding, welding, etc.), 3D printing, laser cutting, CNC (Computer Numeric Control machine) and hand fabrication. This demonstrates diverse technical capacity for manufacturing both plastic and metal wheelchair components using both conventional and modern digital techniques.

Material Sourcing and Supply Chains

Most raw materials are sourced domestically, especially metals and plastics from local vendors. Existing local recycling center produces high quality recycled plastic granules for injection molding from scrap plastics. Some specialty materials such as 3D printer filaments, sheets for laser cutting, etc. are imported from India or China. Damaged parts during the production process are often recycled or reused. However, sourcing high quality materials locally remains a challenge.

Bespoke Production to Mass Production

As a local die maker and manufacturer stated, they have *"successfully finished work on electrical kettle, bike accessories and safety helmets in Nepal"* with local made die/mold and local machines. This demonstrates technical capacity for scaling complex production. Some digital

manufacturing companies also highlighted growth in digital fabrication using design and 3D printing process, stating *"as people know about value of prototyping, design and digital fabrication, more will follow."* As a representative from the research center said, they use 3D printing for prototypes before mass production techniques like injection molding. Another representative from digital manufacturing facility explained that 3D printing enables *"custom-made according to individual customer requirements."* This shows Nepal's local technical capacity to make customized to mass produced products.

Distributed Manufacturing System Resilience

Distributed manufacturing enables local system resilience. Collaboration between local industries can offset weaknesses of intercontinental supply chain model and amplify strengths. For example, relying more on domestic materials reduces foreign dependency. There has been evidence of knowledge and technology exchange between India and Nepal as local die makers order complex molds for products from India and the short distance and single journey between them enables easy access to such facilities to Nepali industries. There is also a mold making facility with experienced machining skills and CNC facility for complex molds. Availability of tooling center is a catalyst for the growth of the local production sector.

Quality Control and Repeatability is a Challenge

Quality control and repeatability of parts and components is a major challenge faced by local makers for scaling production. Production of parts like wheelchair castor wheels, footrest and bearings will require expertise and careful testing. A representative from the metal casting facility pointed to their *"in-house testing and quality control lab"* with sophisticated composition analysis equipment and hardness testing setup, showing the type of quality control infrastructure required.

Barriers to Local Production Expansion

High taxes on materials, unreliable electricity, lack of skilled workforce, lack of government support, and difficulty accessing finance hinder local production growth. Cheap imports due to open borders between Nepal and India present a threat to local producers to remain in competition.

Figure 8 shows the SWOT highlights of local production sector in Nepal.

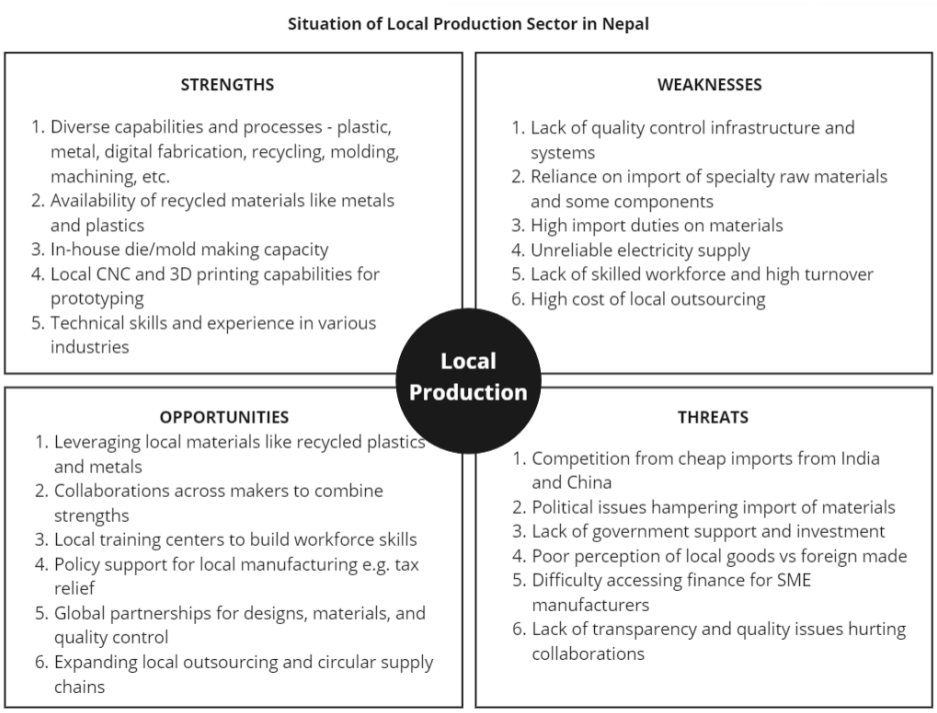

Figure 8 SWOT analysis of current situation of local production in Nepal

5.3 Objective 3: Study the feasibility of localized spare parts production for sustainable wheelchair repair and maintenance.

5.3.1 Local Design and Production of Wheelchair Spare Parts: Demonstration/Pilot

After completing the interview series, we identified local partners for a small demonstration of spare parts production which is an exploratory piece of work in this study. For this pilot, we involved with the Center for Disabled Children Assistance (CDCA). During the interview, CDCA identified 5 spare parts which would require frequent replacement as they wear out during use. A follow up visit to their wheelchair repairing facility was made to understand the nature of parts/components and how they interact with other major components of the wheelchair. These components were plastic parts and possess very low risk to user but were important to maintain functionality of the wheelchair to ensure its safety and durability. As mentioned earlier, CDCA receives wheelchair from a Chinese manufacturer (Drive) through the USA based donors and had identified spare parts availability, import procedures and cost to be the major challenges to wheelchair repairs. Although many other parts such as castor wheels, tires, armrest, footrest and seats were also of high interest, these simple 5 components were recommended by the CDCA for the pilot considering manufacturability and time limitations. Details of those 5 components are provided in *figures 10 and 11, and table 1.*

This study involved three main activities – ***Design, Production and Fitting/Testing.***

Digital Manufacturing: Design and Production

Five components of varying shape and size were first designed using SolidWorks Computer Aided Design (CAD) software and printed using Tiertime UP300 3D printer in recyclable polylactic acid (PLA) filament and thermoplastic polyurethane (TPU) rubber filament. It took an estimated 7 hours' time (equivale to one full day) for a fresh graduate mechanical engineer working at the design lab to produce designs of all components and estimated 3.3 hours to produce with a 3D printer. Design time and print time varies depending on complexity of a component and size of it. The samples provided were worn out and there were issues during measurement with vernier caliper which increased design time. All components were printed at 0.2mm layer thickness with 99% infill and fast print speed (default speed of the specific 3d printer model). Print speed is inversely proportional to the layer thickness and infill density which can be controlled through print software. The print quality and surface finish were obtained to be the best for those components with higher wall thickness (around 2mm) compared to those with 1mm thickness or less.

Figure 9 shows wheelchair parts and components needing frequent repairs/replacements. Part 1-5 were addressed in this pilot. The upper and lower rows show the original image and part's position of parts in a wheelchair. The Middle row shows 3D printed parts in white PLA filament.

Figure 9 (1) Seat Clamp (2) Castor ring cap (3) Wheel cap (4) Ring cap A (5) Ring cap B (6) Armrest (7) Footrest (8) Caster wheel (9) Brake (10) Arm rest side panel (11) Push grip

Table 1 List of wheelchair components for repairs with detailed specifications and 3d printing production details. (Conversion: 1GBP = NPR 165)

Item No.	Part/Component	Production Time	Design Time	Material Consumption	Physical dimension mm	Cost in NPR (Material + Production)
1	Seat Clamp	1.8 Hour	4Hour	46g (PLA)	61.35x41.76x34 V=27.47cc	320 (£20)
2	Caster ring cap	25 min, 35 min	1 Hour	9g (PLA/TPU)	24x33x33 Dia 33 V=3.65cc	70 (£0.42)
3	Wheel Cap	28min	1 Hour	8g (PLA)	15x40x40 Dia 33.7,40 V=2.84cc	65 (£0.40)
4	Ring Cap A	17min	30 min	7g (PLA)	23x18x23 Dia19, 23 V=4.13cc	50 (0.30)
5	Ring Cap B	11min	30 min	4g (PLA)	22x13x22 Dia19, 22 V=1.62cc	29 (0.18)

Testing/Fitting

3D printed spare parts were tested on a wheelchair by replacing old parts and it showed great fit *(see figure 10)*. The technician who is also a regular wheelchair user did the fit test and visual inspection to compare against its intended function. The technician was satisfied with the quality of print and its durability as it performed well on several fit tests. However, caps seemed to meet its intended function in a flexible TPU material than a rigid PLA print because PLA is brittle when printed with thin wall. The larger component, seat clamp, performed well in PLA but it is not recommended for outdoor use as PLA is not resistant to heat (glass transition temperature around 60 degrees Celsius). Stronger and temperature resistant materials like ABS or nylon are recommended for this purpose.

Figure 10 Wheelchair components (1) CAD model prepared for 3D printing (Upper) and original damaged seat clamp sample (Lower) (2) 3d printed ring cap

Alternative Production for Scale

As an alternative approach, a local die/mold maker with injection molding facility was approached to discuss the cost of tooling and production. It was found feasible to scale production of these spare parts by making die and mold for manual (hand powered) injection molding. It takes around 5 days to make each die/mold and costs around NPR 30,000 (equivalent to GBP 180) which will reach its breakeven after 200 parts production compared to the cost of 3D printed parts. Manual injection molding can make up to 100 parts in a day. Whereas 3D printing makes between 10-20 parts depending on size and density.

Challenges and Recommendations

Some technical challenges identified during this pilot were design challenges as the worn-out parts made it difficult to measure the dimensions of a product, CAD modelling challenge based on complexity, and logistical challenges between repair center and the design and production center as it involved numerous testing and design iterations. The pilot project demonstrated the complexities and possibilities within the wheelchair spare parts production sector in Nepal. Small scale injection molding for smaller components seems to be highly cost effective and efficient than 3D printing, and the availability of cheaper recycled material makes it a viable mode of production. However, flexibility and quick turn around time of 3D printing process makes prototyping and custom design appropriate in the low resource setting.

6. Discussion

Need for shift from charitable distribution model.

The literature review systematically built the case for transforming wheelchair provisioning approaches in developing countries like Nepal through sustainable, localized production and circular economy models. The rationale was clear - conventional charity-based models overlooked user needs, lacked customizability and repairability, and proved unsustainable. The Nepal interview findings validate many of the concerns raised in academic studies. The shortage of appropriate wheelchairs, reliance on charitable distribution without sufficient training or follow-up, limited rural accessibility and repair issues were consistent themes. Inaccessibility of repair centers and unavailability of spare parts, especially in rural areas, were key challenges identified by researchers. Nepal interviewees also highlighted the centralized supply chain and lack of service centers outside major cities as barriers. Despite having experience and motivation for service amongst service providers, product unavailability and reliance on imports hinders service quality and appropriateness. This highlights an urgent need to improve access to assistive products globally, especially in lower resource settings, to fulfil the rights and inclusion of people with disabilities.

Global mass manufacturing is vulnerable.

Despite its intercontinental networks and well-established supply system, this conventional approach to product and service delivery leaves local economy and sustainable service to users vulnerable to modern day uncertainties. This obviously lay foundation for the discussion of alternative model of product and service delivery particularly in developing countries in the global south who have long been a global consumer despite representing more than two-third of the earth's population. Inability to ensure access to AT devices such as wheelchairs means people with disability or mobility challenges are excluded from discussion, participation and are left behind. It poses risk to achieving several sustainable development goals as they all interconnect with each other.

Local/National production is the hope.

Our study shows the potential of localized production and distributed manufacturing to address context-specific needs and accessibility issues which were highlighted in both theory and practice. The literature proposed leveraging 3D printing for customization and on-site production. Local makers interviewed also recognized opportunities for manufacturing spare parts in Nepal and the survey showed that the capability for complex production lies within distributed network of makers.

However, the complex web of regulatory approvals required for subsidized wheelchair imports highlights policy level barriers, and this could affect the supply of complex components which would otherwise not be within the scope of local manufacturing at least during the initial phase of transitioning to local model.

Users and Communities should be involved in discussions.

While the literature focused on service delivery aspects, interviews underscored that holistic solutions require tackling stigma, increasing awareness and mainstreaming disability rights. The literature overlooks frugal innovation success stories from developing countries. For instance, the provision of sport wheelchairs can inspire social inclusion and community participation, as highlighted by an interviewee. Such locally informed solutions demand exploration into provisioning models which address individual users' needs which can only be ensured through user-manufacturer-service provider feedback mechanisms.

"In a society where people stigmatize Disability and take it as a burden, seeing them challenge each other through sports can change people's perspective; And sport brings physical fitness and contribute in users well-being." - Wheelchair User

Backing with these context informed solutions, we propose a globally connected local production model for the resource constrained place like Nepal.

7. Globally Connected Circular Local Distributed Manufacturing Model (CLDM)

A collaborative framework is proposed, combining global and local strengths. Centralized facilities focus on standardized parts production and quality control and can be transferred to regional or local partners. Localized facilities customize products to user needs and provide repair services, enabled through licensing agreements. This nurtures local capacity development to production and repair services, necessary to increase the life of a product.

Figure 11 envisions a globally connected local production model in which users, local makers, local wheelchair service providers and global service providers (international manufacturers and donors) are part of the localized supply chain where each brings unique value through the exchange of product (black arrow) and information (blue arrow). The prevailing wheelchair provision is built on linear model (from left to right in the upper half) where global manufacturers and donors supply wheelchairs to a national distributor or NGOs taking 3-6 months. NGOs work

with local government to collect demand in the communities and distribute to the users at home and hospital settings. It has been found that wheelchair breakdown occurs in less than 3 months' time after use in some cases and repair services are the most challenging bits. Users and service providers do minor fixing with the help of local bike shops but those that require complex fixes or parts replacement are abandoned and scrapped. Basically, it shows that a wheelchair product has a very short life due to unavailability of spare parts and repair facilities.

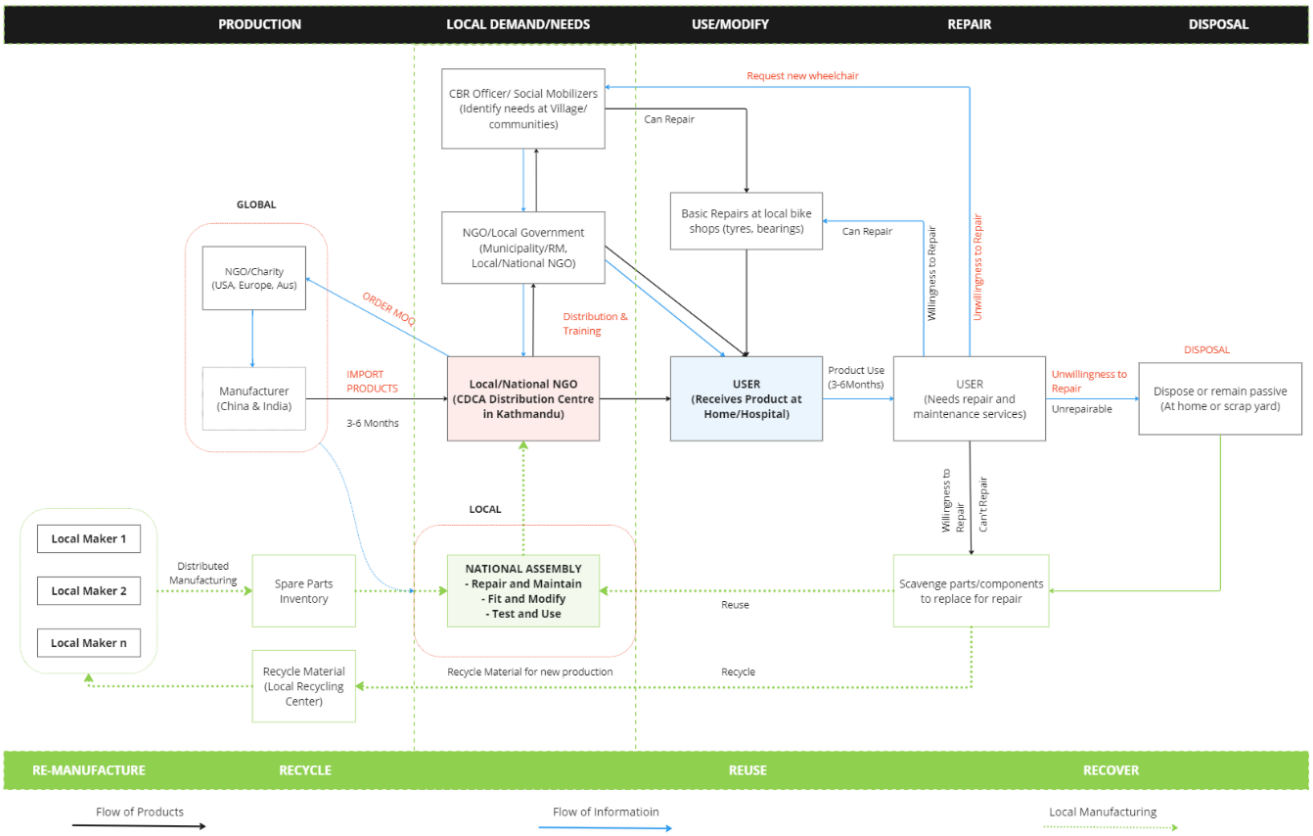

Figure 11 Circular Local Distributed Manufacturing Model (CLDM) (Source: Author)

The lower half elements are the suggested intervention connected with dotted green arrows representing circular economy where material flows back to local makers/manufacturers for recycling and remanufacturing. Unrepairable wheelchairs after use can be scavenged to recover useful parts whereas damaged parts can be recycled and fed into new production through local recycling center.

For this model to work, existence of well performing recycling center and an assembly center is key. In the case of Nepal, there are evidence of industries making quality recycled raw materials for local industries and a distributor like CDCA who is repairing wheelchairs but at a very small

scale. For smooth service, coordination between multiple local makers for distributed manufacturing of components, its quality control and parts inventory management are critical. The assembly center can coordinate with NGOs and national distributors for demand collection and work closely with global manufacturers for the supply of complex components that are unfeasible to manufacture locally. Each step of the value chain should be supported by service friendly policies as the interruption in one step delays the outcome of the other.

To shift from a charity model to market driven practice, pay-per-use models can be promoted to improve wheelchair and spare parts affordability for users in Nepal. Rather than purchasing wheelchairs outright, users would pay a monthly rental fee covering maintenance costs. For spare parts, users would pay a small fee per repair rather than buying the part. This avoids large upfront expenses for low-income users. The service provider would manage an inventory of wheelchairs and parts, earning revenue from the user fees to sustain operations. This model incentivizes maximizing product lifespans through repair and reuse, aligning with circular economy principles. However, gathering user trust and pricing affordably while remaining profitable will be challenges to address. To compensate this, impact investors and donor organizations can support up front investment in equipment and parts, and users pay from their monthly social security allowances.

8. Conclusions and Recommendations

This study explored approaches for improving wheelchair provisioning in Nepal through a systems perspective, combining insights from academic literature, global and local stakeholders. The research emphasizes the need for transformation from conventional charity-based models to sustainable, collaborative frameworks for assistive technology access to catalyze local production and repair ecosystems. The literature review reveals widespread issues in wheelchair provisioning practices in low-resource contexts resulting in product abandonment, immobility, and exclusion of people with disabilities. The literature argues for increased localization and distributed manufacturing enabled by 3D printing to address context-specific needs.

Findings from Nepal affirm challenges around product scarcity, the absence of local production, inefficient centralized supply chains, limited rural accessibility, lack of quality control policies, complex import procedures, and repair and maintenance issues among the common ones. Despite progress through disability related national laws and policies, change is impeded by reliance on charitable models like the ones found in several literatures. Interviews with global manufacturers recognize the weaknesses of centralized manufacturing and highlight the value of user-centered local production through collaborative approaches. Local Maker's survey reveals that Nepal's local production sector has technical capacity across materials and processes but faces barriers like taxation in import of raw materials, skill gaps, and quality control infrastructures. An exploratory spare parts design and production pilot showed 3D printing's potential for distributed manufacturing despite limitations in cost and quality.

In response, a framework of globally connected local production is proposed, combining global scale and quality with localization for accessibility, appropriateness, and sustainability. This fosters user-centric solutions through community participation and empowers local partners through licensing agreements, vocational training, and policy advocacy. Principles of circular economy such as recycling and remanufacturing can enhance resource efficiency and lower the cost of production. Pay-per-use financial models improve affordability alongside impact investment. Ultimately, systems-level transformation calls for multi-stakeholder synergy between users, communities, governments, manufacturers, donors, and makers.

Given that 15% of world's population lives with disabilities, 80% of whom represent developing countries, improving access to assistive technologies becomes a moral imperative and an integral facet of sustainable development. The study unveils pathways to uplift lives through innovative models that harmonize global insights with local creativity. Wheelchair provisioning exemplifies broader challenges in assistive technology access. This study is already contributing on a wider

piece of research analysing the overall situation of manual wheelchair provision in Nepal for the UKAid Programme AT2030. Future research avenues from this will explore the scalability of this approach across different regions, and expand to wider testing across diverse local production technologies and materials, surveying affordability amongst users and gauge isocietal impact. This research offers a collaborative roadmap for human-centered, contextual innovation and policy to enable access for people with disabilities through localization. Exploring these pathways can uplift communities worldwide.

Recommendations

Next on this journey would be to conduct a full-scale demonstration of globally connected circular local distributed manufacturing (CLDM) model by bringing together global and local stakeholders to solve larger quantities of repair issues in a community and inform policy makers from a wider study. It involves identifying users and their repair issues, a partner to coordinate local manufacturing and imports, global manufacturer to support design and standards, and fund to scale project. Through this research, we have been able to identify them and build a consensus to act for change. A successful demonstration engaging these stakeholders can uplift many lives through improved access, empowerment, and livelihoods.

To address the shortage of skilled technicians in wheelchair assembly, repair and maintenance sector, free of cost vocational training initiatives through national training programs like Centre for Technical Education and Vocational Training (CTEVT) focused on wheelchair production and repair skills are imperative for building expertise. Wheelchair users can be capacitated through training and certification, and they can be empowered through technician jobs as was evident in some of the local service providers' interviews. Government advocacy to provide preferential policies, tax incentives and establishments of testing facilities would catalyze growth. With care and strategic collaboration, this collective effort can realize the vision of an equitable, resilient and circular wheelchair provision system in Nepal.

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Appendix 1: Interview Guide – Situational Analysis of Manual WC Provision in Nepal

The following questions are just a guide to what we want to discuss with you in the interview, and the interviewer may request you to expand on your experiences on the following topics. You may also have some information that you think is important to include in the interview.

1. Demographic questions: age, role, length of time working with or attending the service, previous experience.

2. Semi Structured Questions

What do you do on a typical day at work? Describe it.
Can you share a bit about the organizational structure and your team? (Size, roles)

What activities do you attend/ do you engage in?

- What do you think about it?
- How do you feel about it?
- Tell me about what you like and dislike about being involved in the wheelchair service.

Tell me about why you got involved in the wheelchair service.

Describe an experience that motivates you about what you are doing.

Describe an experience that frustrates you about what you are doing.

What changes, (if any) would you like to see in service delivery?

Section on wheelchair value chain (if not already answered)

- How are the WCs in your service supplied to you? Who are the suppliers/ manufacturers and logistics involved in it?
- Tell me about the types of WCs that are available
- How are the WCs maintained or repaired across their lifespan?
- Do you have a supply of spare parts as well as WCs? How are after-sales-services offered to the users?

Is there data that your centre has on its service that you are able to share?

Appendix 2: Sample of Wheelchair Provider Interview Response

Interview 13: Wheelchair User as well as a service provider (Code: LSP13)

Ram: Namaskar! We welcome you to this interview. So, are you happy to be recorded and do you accept our consent to interview you?
LSP13: Yes, thank you! I am happy to be interviewed and recorded.

Ram: Can you give us your brief introduction please?
LSP13: My name is LSP13. I was born in Lamjung. *I have a spinal cord injury which I got from falling from a tree when I was 10 years old.* My house is in the hills. And that would affect my education and day-to-day living so we came down to cities for my education. We stayed in Kathmandu and then in Pokhara and then back to Besi Sahar, and now finally at Pokhara. So, when I had spinal injury, I was brought to this hospital where I got treatment, and I have recently completed my bachelor's degree and now working here at the front desk as a cashier and I take admissions of new patients. I'm now 28 years old.

Ram: Thank you! So you look quite healthy now. And did your injury and your condition impact on your education?
LSP13: Oh yes it did. I was in grade 5 when I fell for injury, and *I couldn't go to school for the next two years.* So, we came down to Pokhara and I started again from grade 4 so that I could study together with my brother who was also in grade 4, believing it would be easier to commute from home to school and back assisted by my brother.

Ram: What does your typical day look like at work and at home?
LSP13: I wake up in the morning and do my morning chores, I read papers and use social media, *I exercise at home on my wheelchair pulling weights on my window because I'm also a sportsman.* And then I have my Big Breakfast and come to office at 9:30 and work until 4 in the afternoon and go back home afterwards. *Because I sit in a single position on wheelchair all day long, I get completely exhausted.* So, when I get back home, I take shower and lay down on bed facing down on my stomach. Then I speak with friends and read novels and that's it.
During Saturdays, it's our day off, *we play basketball together with other colleagues of the hospital. It's good for physical fitness and general well-being.*
While at work, I'm in the role of a cashier but I'm also involved in the disability related discussions, and mainly look around when there are accessibility related infrastructure projects within our premises. Personally, just more than my work responsibility, I also provide disability related counseling to my age group when I see them around.

Ram: What interests and hobbies have you got now?
LSP13: Mainly playing basketball and reading novels. I also play table tennis. Sometimes I also play badminton but mainly basketball. *I do love to travel around and go to places, but I can't go everywhere I wish to go because of my situation and our geographic limitations.* But I try to reach places where I can go to. Like, *I have been to Kushma and swung on the world's highest*

swing with my wheelchair. I think this is the first time any wheelchair user has done that, and this was covered in some papers as well.

Ram: since you are both wheelchair user and a service provider, what problems and challenges do the wheelchair users face in Nepal?

LSP13: First thing is, we have challenges in studies because *school infrastructures are not accessible. Most schools do not accept admissions for wheelchair users because of the environment.* Many of my friends and even myself was rejected for admissions in several schools and had to lobby a lot to get place at one. Because our school infrastructures do not have ramps and accessible chairs to accommodate persons with disabilities. Our schools, rather than improving accessibility to accommodate these users, they deprive users of education and justify their infrastructural challenges in spite of upgrading for better. For example, until grade 8, *my school didn't have an accessible toilet and I couldn't use it.* I remained on a wheelchair for the entire day and I would have to build my mindset not to use the school's toilet. So, from 10 AM until 5:00 PM I accessed no toilet. From these *I used to starve myself from drinking water and that caused several issues like urinary tract infection and pressure sores almost every month.* It was a routine in my life. On days when I drank water and urged for urination, I would return back home in the middle of the school hour and not go back to school that day. I changed several schools and all of them were about 15 minutes walking from my home on a wheelchair. Another thing is social humiliation, that people stigmatize disability in our society, that many of my friends and other users have shared. Even my mom was *stigmatized by society and tell her not to spend on my education because disability was then considered a burden.* She got suggested that I abandon my schooling at Pokhara to return back to village and work on farm. *So, one thing is the physical infrastructures, and the other thing is the mental awareness on disability.*

Ram: Have you seen or witnessed any changes now?

LSP13: Yes, a lot has changed now. *Now I'm educated and into job* and I'm independent on my own, my relatives and people in this *society kind of admire* that my mom raised me and that *I am independent and contributing.*

Ram: How difficult was it for you to obtain wheelchair although you were small then? If someone must get a wheelchair now what is the situation like?

LSP13: For the six to seven months after my injury I was completely lying on my bed. I got in a wheelchair for the first time in a hospital in Besi Sahar, which is the headquarter of my district. It was a hospital chair. Then I came to this hospital for further treatment and I was provided with red colored wheelchair. I was 11 years old and I still remember that. Many people at this hospital know me since then. So honestly, I don't remember what challenges existed back then because I was small and I was provided that wheelchair and that was OK. But I do remember that *I used to face a lot of problems when I had to repair a wheelchair.* When there was any damage in the wheelchair frame, finding a place to weld it was really very difficult and finding or fixing a tire upon puncture sas a nightmare. *Finding parts was really very difficult. And I don't feel that any big change has happened yet.* I see that the problem is still similar. The same institutions are distributing wheelchairs, the process is almost the same, the same challenges, *we still don't*

have any manufacturer that makes wheelchair locally. Although I have heard of some making, repair and maintenance related initiatives but that might also have closed, I don't know. *I don't think there is easy access to getting wheelchairs here. Someone who has connection to the distributing organizations might receive wheelchair otherwise in normal person with disability mainly the one from the villages who are uneducated and not involved in in institutions we'll have hard time getting a wheelchair because there is high demand and short supply.*\

Ram: How long have you been using this wheelchair? And how many wheelchairs have you used so far?
LSP13: I've been using wheelchairs for a long time so I don't know exactly how many, but I think *I have used around 8 wheelchairs. This wheelchair is a three wheeled chair I've been using for one and half a year for the office purpose. So, I use this wheelchair while at office, leave it here after office and go back home by my scooter. My office security personnels assist me to get on and off the scooter. When I reach home, I have another wheelchair which was brought by one of my brothers from Japan five years ago.* It's an aluminum wheelchair, a manual type. I don't think I'm a type of person who wants to use an electric wheelchair because I love to propel a manual wheelchair which keeps me active, engaged and fit. *It's easy, lightweight, foldable and I can pack that in my scooter.*

Ram: Have you faced any problem with that wheelchair?
LSP13: Yes. Even though someone brought a wheelchair from another country, once it is broken, I can't find spare parts such as bearings and tires, because it's different and not available in local market. *So, the charitable wheelchairs, even though someone gives that to me for free, I'll only be able to use that for one or 1 1/2 years, and then I'll have to discard it because you can't fix it.* So, of what use!
Like, the caster wheel of my wheelchair that I use at home is broken but I have managed to still use it after tying with a saline tube. *Even the tires have worn off and I don't know what to do after it's gone.*

Ram: Where do you think you can fix or make your wheelchair as a user? Where do you go?
LSP13: Other users feel like they can fix in these centers but I know what can be done here and what not. *So if I can't fix my wheelchair here I go searching for parts like bearings in the local market, search for gas welding to fix a broken frame, visit a tire shop for fixing tires, if not speak to my friends who are in Kathmandu. Once, I couldn't fix it through any means and then I had to make a Facebook post in a MRR (Men's Room Reloaded) page. Such is the situation. Finding spare parts and repair service is a worst challenge.*

Ram: Is there not any platform or database where you can find who has wheelchair of what model and what spare parts? Would such a platform help?
LSP13: *A website or application like such which could have user and supplier related data would be highly convenient.*

Ram: As a wheelchair user and a service provider what do you think could be done so that it could create a positive impact in the wheelchair product and service provisioning?
LSP13: First thing is *I wish there was a factory which produces wheelchairs in Nepal.* It doesn't have to be a nonprofit company, it can be a profitable wheelchair manufacturing company that charges users and provide a good wheelchair. Because *the situation is that you can't even get a good quality appropriate wheelchair even though you want to pay for it.* That's why *I prioritize local manufacturing at first*. *Otherwise, local governments could coordinate with other companies to build that supply chain and they should keep records of users in their areas.* Until COVID, there was a person called Rakesh Hamal, who used to import good quality wheelchairs and provide them to users, but he passed away. And now the supplies are even more terrible. I have used many wheelchairs that were brought by him. *But now, you can only get charitable wheelchairs and some refurbishment.* These days I'm not hearing much about large scale wheelchair distributions. *I think the supply and distribution has massively reduced these days.*

Ram: what supports are available to the wheelchair users from the public sector? I know there is a provision for disability cards and some social security allowances.
LSP13: There are four types of disability cards – red, blue, yellow and white. The red and blue which comes under severe disability only receives social security allowances from the government. *Based on severity, they get around NPR 4000 (GBP 25) and NPR 2200 (GBP 13). There is a process for distributing disability cards which is decided by the local government. I receive around NPR 2200.*

Ram: I understand the poverty within users. What do you think, would this Social Security allowance that the users receive on a monthly basis be sufficient for repair and maintenance of their wheelchairs?
LSP13: No, I don't think so. That won't be sufficient. Because two sets of tires cost a lot. And users from the remote villages need to drive down to the cities for repairs and that involves *cost in transportation.* These stipends go into users account in 3 months' time interval. And the users will also have their own priorities such as into their *basic needs and medical expenses* such as expenses on cathedral tubes, diapers, etc. *So, the social security allowance alone is not sufficient.*

Ram: What is your motivation as a user to work in this institution which works in the disability sector? Like, you are educated and could have worked in a banking sector or in an education sector!
LSP13: Yeah, I could have. *My main motivation is that I am the made of this hospital. It provided me with all the life skills such as donning and doffing clothes on my own, using stairs, using wheelchair, transferring skills, etc.* Even this hospital provided me expenses for my school uniform and shoes, crowdsourcing by staff of this hospital. *So, I wished to work together with these staffs and this hospital to support other people with disabilities.*

Ram: Is there anything you may want to share that you didn't have opportunity because we didn't ask you?

LSP13: Yes, sure. When we are discussing wheelchairs, *sport is also important to a person with disability and there comes special sports wheelchairs for them. I think we should also particularly focus on this when we are working and advocating wheelchair development.* Obviously, these sorts of manual wheelchairs should be the first priority but sports wheelchairs should also be considered because different people have different needs and to me sports mean a lot. *Sports wheelchairs need to be light, maneuverable and foldable.*

Ram: Interesting. So, what inter-relation do find between disability and sports? What impacts can it have on each other?
LSP13: You have raised a great question, indeed. I think sports are a gateway for the users to expose with the outside environment. To expose yourself to the community and socialize with people. *In a society where people stigmatize Disability and take it as a burden, seeing them challenge each other through sports can change people's perspective. As a wheelchair user you are mostly on a wheelchair and working on the computer (if you are working at all) and that builds stress due to sedentary lifestyle. And sports bring physical fitness and contribute in users well-being.* For example, I have been seven times wheelchair racing defending champion in Pokhara and I'm also a national wheelchair basketball player. I love to move around, I love to play, I love to visit places, like I had done the world's highest swing in wheelchair, and I want to do Bungee jumping soon. I have done paragliding and rafting. I'm not doing this for publicity but because I love it. We can do some of these together.

Ram: Thank you very much for sharing your experiences with us. We are looking forward to organizing workshops and learning sessions in the future and our researchers might want to connect with users at one point, would you love to be contacted?
LSP13: Yes, I am keen to be involved in workshops and trainings. You can contact me through my phone number and my email that I have provided. And do visit us while in Pokhara.

End of the Interview.

Appendix 3: Local Maker/manufacturer Questionnaire and Response (Code: LM2)

Questions:

1. Production Process and material

1.1. What are the different production processes at your factory? How are products made? Steps.

- Lathe, cutting, milling, surface grinder, drill and welding
- People and industries bring their plastic/rubber product samples and we create rough drawings for machining of die and mold
- Simple molds are made within our workshop while we also outsource to Indian die makers in Delhi for complex molds requiring high finishing and tight tolerances. It requires chrome plating.
- There is a local CNC machine shop where we work together for complex machining. For the CNC operation, there is a designer and an operator who produces CAD designs in computer software and runs machine to automatically cut parts for die and molds
- CNC cut cores and cavities are assembled at our machine shop.
- Simple mold for hand powered manual injection molding machine takes around 5 days and complex molds take between 15 days to 1.5 months.

1.2. What products are being made currently and in the past?

- Steel die for injection molding
- Blow molding die for PET and HDPE materials
- Aluminium die casting molds
- Die/mold for the products such as kitchen wares, bike accessories, safety helmets, home appliances, bins, jars and caps

1.3. What is the market? How are products delivered to customers?

- People and local industries contact through word of mouth and local connections, and they visit to make die/mold for their product with a sample.
- We make die/mold based on industry's need

1.4. What materials are used for production? Where do materials come from?

- Mild steel and aluminum Metal blocks for blow molding are available in Nepal.
- Hard steel material for special die/molds are imported from Delhi, India. It takes around 7-10 days to arrive metal components from India to Nepal on a direct bus between Delhi-Kathmandu.
- Sometimes, we also recover metal blocks from local scrap yards.

1.5. What happens to the damaged parts/products during production?

- Any damaged metal during machining can be rewelded and fixed with lathe or mill.
- Other die making components such as pins and inserts need to be replaced.

1.6. Is there use/reuse of recycled materials in your production system? How much? Where do they come from?

- Metal blocks can be reused.
- Ejector pins can also be reused in molds.

2. Production capacity

2.1. What is the current production capacity of your factory?

- Around 10 – 12 die/molds are made per month by 6 machinist staffs

2.2. What is the current production output compared to total production capacity?

- This is the full capacity.

3. Did COVID-19 change the way you work? How did it impact you? How did you tackle it?

- Die/mold making work has reduced by around 25% after COVID

4. Where is die/mold made for your products? How is it made?

- Cost of raw material for making die/mold is expensive to get it in Nepal because blocks of metal for mold weigh around 600kg and the cost of transportation from Delhi to Kathmandu adds up
- Whereas a finished die/mold from Delhi can weigh around 300kg and easier to transport and saves in transportation as it can arrive in 2 days from Delhi to Kathmandu.
- Thus, some die/mold work is outsourced to Delhi based die makers and some are made in Nepal through manual as well as CNC cutting process.
- There is a CNC operator and CAD model developer in Kathmandu. Design is created locally including mold designs to suit local production. Whereas complex molds are made/cut from India. Local design and CNC capacity has shortened supply chain to almost half as it eliminates the need for shipping samples to India and miscommunication during work. Also, it saves a lot of money in transportation and travel time.

5. How do you see the Nepal-India open boarder situation to impact on local production in Nepal? Does it benefit or harm local production?

- There is difficulty in product import for small companies like us because there is requirement for high documentation for imports such as Nepal's Import-Export certificate (EXIM code) for local companies. Furthermore, there is a long banking process and legal requirements to pay tax, GST and VAT in Nepal and India. Boarder rules and trade rules makes import challenging and complex.

- Although we can get services in Delhi, there is also flow of cheap finished products from India to Nepal and high raw material import tax and shipping cost makes production cost relatively high in Nepal. It is not good for small local manufacturers.

6. How is quality controlled or maintained in your factory?

- Die/mold is made at high precision and tested through sample production before dispatching it to industries.

- Our staff are highly experienced, and I have hot over 20 years of experience in die/mold making. So, we work with precision.

7. What challenges do you see in the local production sector in Nepal? (Related to your industry)

- Cost of raw material is high and import taxes are high for raw materials

- There is high regulation for small businesses to thrive and compete with larger importers wo brings in ready made products from china and india.

8. What should be done to enhance/improve/promote local production?

- Invest in more CNC, good designers, and a complete tool room setup with chrome facility as we still need to import sophisticated die/mold from India. It could require around GBP 100,000 investment.

- Investment in raw materials such as hard steels – P20 and P31 steel for making injection die/mold.

- Tax relief in die/mold making steel imports from India

9. Are there supporting industries and diverse production sector in Nepal whom you can collaborate with for new product development that involves more complex processes and materials?

- There is a local CNC center where there is a CNC machine and a designer with 5 years of experience. He took training from Delhi, India. It is the first CNC center to make die/mold in Nepal.

- There still is skill shortage in proper CNC operation and design but his presence has contributed a lot in local die/mold making. We work together as he designs and cut metal in CNC, and I instruct him about the injection and blow molding die/mold process and do the final assembly at my workshop.

10. What would be the challenges in collaborating with other local makers to make products?

- Cost of production and outsourcing is high in Nepal.

Appendix 4: Local Maker/manufacturer Questionnaire and Response (Code: LM4)

Questions:

1. Production Process and material

1.1. What are the different production processes at your factory? How are products made? Steps.

- Production Process depends upon the nature of products to be made. Since we are based on digital fabrication process almost every unique case starts with ideation and digital design. Production tools and machines includes: FDM 3D Printers, SLA 3D Printers as additive manufacturing tools; CO2 Laser cutter, Plasma Cutter as Subtractive manufacturing tools.
- Simple designs are replicated into 3d digital files using manual measuring techniques while complex designs are replicated through reverse engineering using 3D scanning and metrology.
- A particular manufacturing tool is then selected depending upon the nature of object for example some plastic brackets, covers etc. are produced through FDM 3D Printers using suitable material. Some intricate and minute parts such as gears, fits etc. are best produced with SLA 3D Printers. Heavy metal flanges, joints, profiles and cut using Plasma Cutters selecting suitable metal sheets. Other relatively large plastic having planer shapes are produced using laser cutting process sleeting plastic sheets such as acrylic of suitable thickness.
- Almost every method follows the process of design, prototype, iteration, production and modifications.

1.2. What products are being made currently and in the past?

- Using 3d printer spare parts like brackets, mounts, gears, casting patterns, demonstration models etc. are made. While plasma cutter is being used mostly for metal structure plates, flanges, section profile cutting, machine parts, base plates. Similarly, laser cutter is being mostly used for design for plastic covers, transparent housing, mounts, in many cases for decorative interior as well as advertisement purposes as well.

1.3. What is the market? How are products delivered to customers?

- Market ranges from industrial spare part design, casting part design, 3d digitization, architectural sector, education sector, metal fabrication sector and advertising sectors.

- Products are produced through process as mentioned in ***Question 1.1.*** Delivery in literal terms includes pickup at workshop, 2 Wheelers for light goods, 4-wheeler trucks for heavy items.

1.4. What materials are used for production? Where do materials come from?

- Production materials includes: Plastic Filaments, and UV sensitive resins for 3D Printers which needs to be imported for China, where we handle the imports ourselves. For Plasma cutters and laser cutters raw materials like metal sheets and acrylic/wooden sheets are available locally at different vendors.

1.5. **What happens to the damaged parts/products during production?**
- If by damaged parts during production means parts that failed during production, such parts are used for other similar items in case of metal sheets or plastic sheets, also such parts if cannot be used for other products goes to scraps.

1.6. Is there use/reuse of recycled materials in your production system? How much? Where do they come from?

- Very rarely during improvising, which is hard to quantity.

2. Production capacity
2.1. What is the current production capacity of your factory?

- Since its mostly custom production and batch production of different products rather than mass production of single item, the production capacity cannot be a definite number for us. Unless we are speaking of a specific product the production capacity is hard to define in general.

2.2. What is the current production output compared to total production capacity?

- As mentioned in *Question 2.1.* there is not a general capacity.

3. Did COVID-19 change the way you work? How did it impact you? How did you tackle it?

- COVIED-19 did affect the operation process due to restriction in mobility and months long lockdown. While the design part was possible with work from home model, the production and machine operation was not possible. Also customer visit was not possible.

- We were more focused in digital designs rather than physical production during COVID-19. Also the production of COVID-19 related goods such as face shields, PPE as well as supply chain for such materials was in priority both due to demands and some relax in mobility related restriction for COVID-19 related work.

4. Where is die/mold made for your products? How is it made?

- We make digital design for die/molds. It rather comes under our service section.

5. How do you see the Nepal-India open boarder situation to impact on local production in Nepal? Does it benefit or harm local production?

- Many a time its cheaper to import items from India due to high tax in raw material imports, which is a challenge for local production. An open border also facilitates the goods to be passed from India to Nepal without customs duties and taxes which in turn makes such items cheaper making it harder for locally produced items hard to compete in the market.

6. How is quality controlled or maintained in your factory?

- Machine calibration is the key for quality control for us. Depending upon the machines and issues manual and auto calibration are carried out intermittently. Parameters such as dimensional accuracy, deformation, kerfs are observed and taken care of.

7. What challenges do you see in the local production sector in Nepal? (Related to your industry)

- Getting skilled manpower related to this particular industry is a major challenge. While one can be trained and well prepared for the jobs, there is a commitment issue where an employee leaves within a very short period of time whether for abroad or to other industries. This is a serious problem for many sectors in Nepal. Similarly, the government policies are unfavorable to local production and innovative industries in some cases a hinderance as well.

8. What should be done to enhance/improve/promote local production?

- Goods that are produced locally should get market priority than imported one.
- Import tax and custom exemption for raw materials and for machines used in production and innovation.
- Foreign investment incentives for industries and production sectors.
- Monetary policies related to international fund transaction should be made hassle free and accessible.
- Government backed loan and investment facilities for production sector.

9. Are there supporting industries and diverse production sector in Nepal whom you can collaborate with for new product development that involves more complex processes and materials?

- Yes, but through a hard way. There is a challenge of time, effort, process, professionalism and investment. New production and complex products in many cases requires import of certain parts and materials.

10. What would be the challenges in collaborating with other local makers to make products?

- There is a challenge of time, effort, process, professionalism and investment. New production and complex products in many cases require import of certain parts and materials. Also, the dedication till the final version of the products.

Appendix 5: Fate of Charitable Wheelchair in a rural area in India

Mukherjee et al. (2005) found that more than 57% users abandoned wheelchair primarily due to discomfort (28.57%), inaccessible environment (33.92%) and damage (15.17%) as they were distributed through charity without considering user needs and assessment.

Table I. Fate of the donated wheelchairs.

Fate of the wheelchairs ($n = 162$)	(n)	%
1. Attendant-dependent ambulation	17	10.49
2. Left without use	93	57.40
3. Sold	23	14.19
4. Occasional use	17	10.49
5. Regular use	12	7.4

Table II. Cause of rejection of the donated wheelchairs.

Causes of rejection ($n = 112$)	No. of users	%
1. Pain, fatigue and discomfort	32	28.57
2. Upper limb involvement	13	11.6
3. Habitat adaptability	38	33.92
4. Frequent damage	17	15.17
5. Unable to drive	12	10.71

Source: Mukherjee *et al.* (2005)

Appendix 6: Situation of Damaged Wheelchairs in Nepal

Figure: Situation of damaged wheelchairs at user's home in Nepal

Source: Karuna Foundation Nepal (shared during interview)