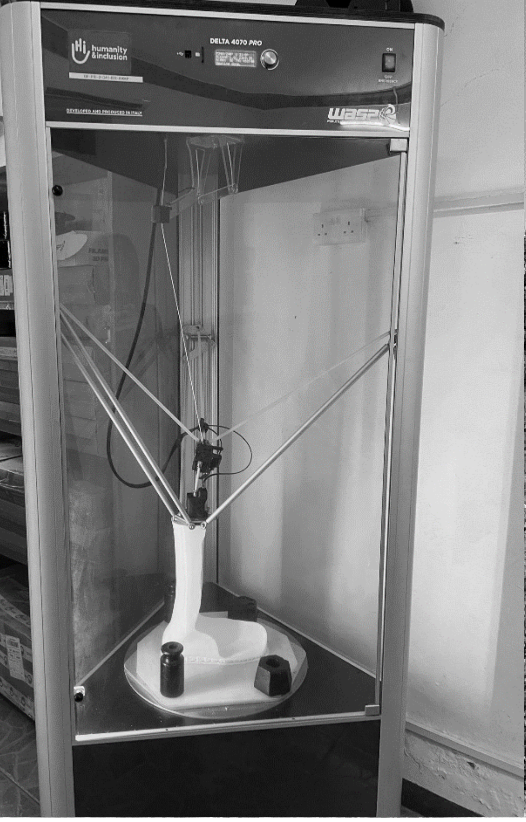

Research & Studies
From project

Cost analysis of 3D printing services implementation into public services to produce orthoses: An Ugandan case-study

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Content

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Abstract

Context

3D printing is a new technology and there is a need for producing evidence to justify and demonstrate its associated costs and benefits.

Humanity and Inclusion has been implementing an innovative 3D printing project in Uganda, in the Omugo Refugee Settlement, to address the unmet rehabilitation needs of people with disabilities (PETRA Project) since November 2018. This project is implemented in collaboration with the public hospital of the Arua District (Arua Regional Referral Hospital).

General and specific objectives

This study aims to calculate implementation and running costs of 3D printing services to produce orthoses in a public service (here ARRH), in addition to traditional services, in a developing context.

Specific objectives:

- To define and detail all phases of the patient pathway for the 3D printed orthosis provision(from patients' identification to orthoses delivery);
- To evaluate costs of the 3D printed orthosis procurement (from patients' identification to orthoses delivery) based on lifetime of digital material;
- To give a better understanding on how to implement such a digital service in a public health structure.

The results of this study will allow HI, other organisations, States or potential donor to enrich their decisions on the implementation of 3D-printed orthoses production in their context of intervention - embedded in addition to traditional services or in remote areas where there is no traditional services.

Methods

Hypotheses, choices and data are based on the information collected through multiple sources and methodologies (desk review, semi-structured interviews, surveys, workshop, and literature review) and are specific to the context of Arua, Uganda. To calculate all the costs related to the service that produces and delivers 3D-printed orthoses, a matrix has been created.

Findings

A patient pathway has been developed to represent the hypothetical implementation of 3D printing services in ARRH. This step was crucial to be able to identify the exhaustive list of costs associated with 3D printing services (material, staff members involved, coverage, etc.).

Every step of the 3D-printed orthoses production process has been clearly defined and roles and responsibilities of orthopaedic technicians and physiotherapists have been defined for every phase of production.

Preliminary calculation showed that the printing time and capacity represented the limiting factor in this context. The maximum number of 3D produced orthoses per year by the 3D printing service is 192. As the estimated need of orthoses per patient is 1,2, it means that the service would be able to cover the needs of 160 patients maximum per year.

The cost analysis results are presented per cost category, per patient, and per orthosis, along with their spread over time (4 years – estimated lifespan of the 3D printers). The cost analysis shows that to produce 768 3D-printed orthoses in Arua Regional Referral Hospital (ARRH) over 4 years, 1,210,224.25€ are required. The highest costs incurred are allocated to Human Resources (66.67% of the total costs, or 806,887.50€), followed by device materials (10.71% of the total costs, or 129,634.08€), and administrative costs (9.87% of the total costs, or 119,429.37€). There is an average cost of 1,890.98€ per patient regardless of the type of orthoses, and an average cost of 1,575.81€ per orthosis regardless of the type of orthoses.

Conditions to ensure the successful implementation of 3D printing services have been identified, amongst which an enabling environment with access to budget for electricity and materials and the training of the staff.

Conclusion

When considering 3D printing in rehabilitation services, a cost analysis and an assessment are crucial to analyse the added-value of this technology in a specific context and to verify that the conditions of implementation are respected. This cost analysis is based on the Ugandan case-study, but its principles and lessons learned can be replicated to other contexts and/or countries.

Abbreviations

- **AFO**: Ankle Foot Orthosis
- **ARRH**: Arua Regional Referral Hospital
- **CBW**: Community Based Worker
- **CoRSU**: Comprehensive Rehabilitation Services for People with Disability in Uganda
- **GRRH**: Gulu Regional Referral Hospital
- **HI**: Humanity & Inclusion
- **ICT**: Information and communication technology
- **KAFO**: Knee Ankle Foot Orthosis
- **P&O**: Prosthetist & Orthothist
- **PETRA** project: Appropriate, Life Changing orthopaedic devices - 3D Printing through Emergency Tele Rehab Access
- **PM**: Project Manager
- **PT**: Physiotherapist
- **PSS**: Psycho Social Support officers
- **RCAF**: Rehabilitation Cost Analysis & Forecast
- **WHO**: Wrist Hand Orthosis

Part 1 – Introduction

1. Context & evidence

According to the World Health Organisation (WHO), only 5 to 15% of the global population in need in 2010 had access to assistive products[1]. WHO also mentions that 0.5% of any population globally requires prostheses, orthoses and rehabilitation treatment[2]. This 0.5% estimation corresponds to 35 to 40 million people globally. Moreover, two to four times more people need orthotics treatment than prosthetic treatment. There is therefore a real need to provide orthotics treatment services[3].

Tele-rehabilitation is defined as the use of Information and communication technology (ICT) to provide rehabilitation services to persons in remote, in their own environments[4]. In the last years, Humanity & Inclusion (HI) has integrated the use of ICTs in several rehabilitation projects, especially for the production of 3D orthoses.

The World Health Organisation mentioned the opportunities brought by the new 3D printing technology such as the environmental benefits, and the reliability of the measurements.[5] However, there is a need for producing evidence to justify and demonstrate its benefits in specific contexts such as Low- and Middle-income Countries.

HI previously conducted research investing the clinical effects of 3D-printed orthoses and prostheses and their social acceptance and impacts. A first pilot project conducted in Madagascar, Togo and Syria[6] showed encouraging findings on the benefits for patients and professionals of 3D prosthesis production, facilitating the access to care of people living in complex contexts. This study also confirmed that the 3D-printed sockets met the structural and mechanical requirements for such orthopaedic devices. As part of another project in Mali, Niger and Togo[7], further research provided evidence on the added-value of 3D- printed

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[1] World Health Organisation (WHO), Community-based rehabilitation: CBR guidelines. Geneva, 2010

[2] World Health Organisation (WHO), Guidelines on Provision of manual wheelchairs in less resourced setting. Geneva, 2008

[3] International Committee of the Red Cross, Physical rehabilitation programme: annual report 2013. Geneva, 2013

[4] Brennan, David M., Mawson S., and Brownsell S. « Telerehabilitation: Enabling the Remote Delivery of Healthcare, Rehabilitation, and Self Management ». 2009

[5] World Health Organisation (WHO), Standards for prosthetics and orthotics, Part 2: Implementation Manual. Geneva, 2017

[6] CANICAVE Jerôme; TAN Danielle. Pilot Testing of 3D Printing Technology for Transtibial Prosthesis in Complex Contexts (Togo, Madagascar and Syria). Lyon: Handicap International, 2017

[7] The IMP&ACTE 3D Project (3DPrinting & Access to Telerehabilitation) was implemented between November 2017 and April 2019 in 3 countries, namely Togo, Mali and Niger, funded by the Belgium Cooperation.

orthoses production, first at the clinical level[8] and then at the social level[9]. The later showed, amongst other, the positive impact on the equity, social justice for the beneficiaries and also the benefits of 3D printing on the health professional shortage. The professionals are willing to learn and to appropriate the new technologies and the acceptance amongst the beneficiaries is high.

While the positive outcomes of this new technology are being recognized slowly, there is still a need for evidence on the costs of using 3D printing technology to produce orthoses in Low- and Middle-income Countries.

2. Research presentation

2.1 Operational project

Since November 2018, HI has been implementing an innovative 3D printing and tele-rehabilitation project in Uganda, in Omugo Refugee Settlement to address the unmet rehabilitation needs of refugees with disabilities (PETRA Project)[10]. In 2021, this project has been extended to Imvepi camp in a second phase of the project. This project is implemented in collaboration with the public hospital of the Arua District (Arua Regional Referral Hospital - ARRH) The study presented in this report is an activity associated with this 2nd phase.

Arua is located on the north-West part of Uganda.

[8] Kris Cuppens. Imp&Acte3D: Introduction of 3D printing technology for manufacturing of orthoses in West Africa – Clinical aspects. Lyon: Humanity & Inclusion, 2019.

[9] Daniel Tan. Etude d'impact social de la télé-réadaptation dans le cadre du projet IMP&ACTE 3D : Introduction de la technologie d'impression 3D pour la fabrication d'orthèses en Afrique de l'Ouest. Lyon : Humanité & Inclusion, 2019.

[10] Appropriate, Life Changing orthopaedic devices -3D Printing through Emergency Tele Rehab Access; 3D-PETRA Project, funded by Innovation hub, Symphasis, MAE Lux

2.2 Research objectives

General objective: This study aims to analyse costs of 3D printing services to produce orthoses in a public service and in complement to traditional services, in a fragile context..

Specific objectives:

- To define and detail all phases of the patient pathway for the 3D printed orthosis provision in Arua: This study will first present the optimal patient pathway (from patients' identification to orthoses delivery)
- To evaluate costs of the 3D printed orthosis provision (from patients' identification to orthoses delivery) based on lifetime of digital material: This report will present an in-depth cost analysis of a 3D printing orthosis production process, from patient identification to delivery. This analysis will take into consideration all parameters including cost linked to installation, process, human resources, transportation and logistics, stakeholders' involvement and participation, and fitting. The results will provide evidence on the costs per device produced using 3D technology and costs per patient.
- To give a better understanding on how to implement such a digital service in a public health structure and what the main conditions of this implementation are.

2.3 Research findings uses

The results of this study provide an initial view of the costs engaged in providing a 3D orthoses production service and detail the possible options for the operating arrangements for such a service.

Although those results are specific to the Uganda context - and more specifically to the PETRA project implementation area and public partners involved - the approach of the study can be considered for other applications in another context.

Indeed, the cost calculation here followed a month-by-month logic based on the lifespan of the determining equipment: the 3D printers. Embedding a 3D orthoses production service within a traditional public service poses some challenges. Therefore this is relevant to consider that the service will not be operational from the first day and will not be able to reach its maximum patient capacity until after some time. That's why the month-by-month presentation allows calculating how long it would take for the 3D service to cost as much (or even less) per month than the traditional service and to identify the factors influencing this time to make the most relevant decisions in terms of operating procedures. Finally, this monthly breakdown allows reconstruction of the cash flow requirements for the assimilation of this 3D service in addition to the traditional service.

Research findings are based on new material. This methodology - and related tools - can be reused by diverse stakeholders (HI, potential donors, other organizations, Ministries of Health, or States) to enrich their decisions on the implementation of 3D printed orthoses production in their intervention area.

3. Report's structure

The report contains three main parts:

- **Methodology:** Hypotheses, choices and data for the cost analysis and the patient pathway are based on the information collected through multiple sources and methodologies (desk review, semi-structured interviews, surveys, workshop, and literature review) and are specific to the context of Arua, Uganda.
- **Patient pathway:** A patient pathway has been developed and is explained in Part 3. This pathway represents the hypothetical implementation of 3D printing services in ARRH, and is fed by the PETRA project experience and lessons learned. This step was crucial to be able to identify the exhaustive list of costs of 3D printing services (materials, staff members involved, coverage, etc.)
- **Cost Analysis:** This chapter explains in details the hypotheses, assumptions and choices linked to the cost analysis. The cost analysis results are shown in Part 4 and developed per category. Costs of 3D printing services in a public service per patient, per orthosis and over time are shown and explained.

Three types of boxes are provided in this report and allow for a focus on specific topics:

These boxes refer to alternatives and explain other options that can be considered in others contexts.

These boxes show focus, as for example further explanation on calculations.

These boxes contain testimonies with quotes from people interviewed.

Part 2 – Methodology

1. Design of the study

This study is a prospective cost analysis[11].

The aim of this analysis is to project the running costs over time, and not only the implementation costs, of the integration and maintain of a digital production of orthoses in a public service. This cost analysis also aims to be as complete and pertinent as possible, which is why data and information has been collected through diverse methodologies and sources.

2. What is covered by this cost analysis

To calculate all the costs related to the service to produce and deliver 3D-printed orthoses, a matrix has been created[12]. Costs categories are the same as in an existing HI tool that allows calculating functioning costs of rehabilitation services/ centres: the Rehabilitation Cost Analysis & Forecast (RCAF) tool[13]. The table 1 shows the list of costs categories.

[11] After a review of various methodologies (Cost-Benefit Analysis (CBA), Social CBA, Social Return on Investment (SROI), Cost-Effectiveness Analysis (CEA), Cost-Utility Analysis (CUA) and Social Impact Assessment (SIA)), the methodology which was the most relevant, suitable and feasible in this context is a prospective Cost Analysis.

[12] Available here.

[13] RCAF is a tool composed of two interconnected Excel forms, developed by HI for the valuation of the costs of rehabilitation services. The tool was developed by HI following literature review, interviews with several people and adaptation from previous tools developed by other organisations.

Table 1 – Costs categories

1. Implementation costs	
	1.A. Building and general investment
	1.B. Fixed machinery
	1.C. Mobile machinery
	1.D. Office- Implementation - Service furniture
	1.E. Hand tools
2. Running Costs	
	2.A. Rent of land - building
	2.B. Maintenance of technical services
	2.C. Transport Costs
	2.D Electricity and Water
3. Administrative Costs	
	3.A Communication equipment's
	3.B. Teaching aids
	3.C. Telephone, internet and license
	3.D Stationery, small equipment, office supplies
	3.E. Exceptional travel costs
	3.F. Cleaning materials
	3.G. Kitchen provision
	3.H. Banking Fees
	3.I. Permanents training of staff
4. Costs - Devices materials	
5. Imports	
	5.A. Import of 3D printers
	5.B. Import of 3D materials
6. Human resources	
	6.A. Professional short term training
	6.B. Salary - gross monthly salary
	6.C. Pension scheme
	6.D. Health Insurance
	6.E. GPA - Insurance work accident
	6.F. 13th month
	6.G. Reallocation allowance
	6.H. First aid kits

Why use the RCAF cost categories?

The RCAF allows understanding the costs of providing rehabilitation services; identifying parameters that directly impact the cost of services; and making economic and financial forecasts of the budget planning for rehabilitation services. RCAF calculates the investment and operating costs of all rehabilitation services including mobility products (prostheses, orthoses, wheelchairs as well as seating and postural support and walking aids) and therapy services (Physiotherapy, Occupational therapy and Speech therapy)[14].

To calculate the general cost, the operating cost categories of the orthoses production service remain the same in this study as those foreseen by the RCAF. However, some adjustments were needed to adapt the calculation tool to the specific context of this study (meaning Arua, public hospital) and include all assumptions made for the future integration of a new technology-based service in a state structure. As mentioned, the main difference between the RCAF and the matrix used for this study is that the costs are presented month by month so that the effects of certain decisions/assumptions on the cost structure are more visible (and so that these choices can be modified if necessary).

The current study presents the projected costs for the implementation and running of digital orthoses production in an existing and functional public service. Therefore costs are assessed on the basis of an estimate of the orthoses demand (in the population) and the capacity of the future service (in terms of human resources and technology). Amongst other, this tailored cost calculation will allow to calculate costs per patient, make an informed decision on the resources required (number of printers or human resources), understand delay between investment and functional service, required training, materials procurement etc.

[14] Anna Boisgillot. Conducting a cost analysis of rehabilitation services. Humanity & Inclusion, Lyon, 2021.

3. Data sources

To be able to fill correctly the matrix, triangulate information and also get a complete insight of the process of implementing a digital solution in a public service (crossing health professional, beneficiaries and experts' perspectives), multiple data sources have been used.

3.1 HI PETRA project: Desk review, semi-structured interviews and surveys

Some data used for the cost analysis is from HI's programme since November 2018 (Phase1 of PETRA project) to June 2022 (Phase 2). A retrospective review of project budget, completed by specific quantitative surveys amongst HI staff involved in the different phases of the patient pathway has been done.

The types of orthoses selected for this study are Ankle Foot Orthosis (AFO), Knee Ankle Foot Orthosis (KAFO), and special seat. The Wrist Hand Orthosis (WHO) has been excluded from the analysis because not enough data was available. The selection criteria was the type of orthoses printed during phases 1 and 2 of PETRA project.

Forms on Survey CTO[15] were created. The field team was assigned to collect data on the time of the following steps of production of 3D printed orthoses: general and clinical assessment, measurement and scanning, designing, printing, assembly, fittings, adjustment and delivery. Tools to collect data and measure the timing (with clear instructions on when to start and stop the timer for example) were developed and are available in the appendices. The average time required per step has been calculated based on the measured timing.

The printer technician collected the quantity of filament used, as reported on the software, before the printing and timed the printing process himself. The software also reports the estimated printing time. However, this time is usually much lower compared to reality. The real time has therefore been recorded to reduce this reliability limitation.

To ensure the quality of data collected, all information was then reviewed with the team members and HI local experts.

Semi-structured interviews with HI staff members involved in PETRA (technical advisors, physiotherapists, community based workers, printer technician, Psycho Social Support officers, Project Manager) were also needed to discuss more specifically on their daily tasks and related dedicated time per steps of production, and to describe a typical week of activity. The discussion also included the benefits but also challenges and limitations of the 3D-printed orthoses and patient pathway as implemented for the PETRA project.

[15] https://www.surveycto.com/

Interview guides for the semi-structured interviews with the various stakeholders, HI staff members, and beneficiaries have been developed and are available in the appendices.

3.2 HI Beneficiaries: semi-structured interviews and quantitative survey

Beneficiaries who received a 3D-printed orthosis in phase 1 or 2 of the PETRA programme have been interviewed to discuss about their experience with 3D printing services. The interview included questions like their feedback on whether their device and the service met their expectations, their thoughts on the whole process, and if they would have sought traditional services. Other questions asked were on acceptation of 3D-printed orthoses in the community, their limitations and benefits.

Visual support was used for the semi-structured interviews with the beneficiaries, to help with the flow of the discussion. Images recreating the pathway were printed.

Community Based Worker (CBW) involved in another HI project helped with the translation when meeting with beneficiaries. A 1-day training has been conducted on the qualitative method, good practices and ethical rules.

The selection of beneficiaries includes patients from phase 1 and 2 of the project, for various localities (Imvepi, Omugo and Arua), adults and children, AFO and KAFO. The sample, although limited, is representative of the beneficiaries of the 3D programme delivering orthoses. A total of nine beneficiaries have been met, from the 1st and 2nd phase of the programme. Caregivers were interviewed for youngest children. The table 2 summarises the sample of the semi-structured interviews conducted with beneficiaries.

Table 2 – Profile on interviewed beneficiaries

Orthoses type	Age	Gender	Zone	Phase
AFO + Seating brace	7	M	Imvepi - Zone 2	1
AFO	8	F	Imvepi - Zone 3	1
KAFO (left + right)	3	F	Imvepi - Zone 3	2
AFO	10	M	Imvepi - Zone 3	2
AFO	7	M	Imvepi - Zone 3	2
KAFO	25	F	Omugo	1
KAFO (left + right)	30	F	Omugo	1
AFO	8	M	Arua	1
KAFO (left + right)	12	F	Arua	2

A retrospective survey has also been implemented amongst beneficiaries of phase 1 of the project to collect data on delivered orthoses and understand if these are used, and the reasons if they are not. A total of 40 beneficiaries responded to the survey, 22 of which received AFO, 9 received KAFO, and 9 received seating brace.

3.3 Arua Regional Referral Hospital staff members: 2-Day workshop

The cost analysis is based on the projection of the implementation of 3D printing services in the orthopaedic workshop in Arua Regional Referral Hospital. A workshop has then been organised to discuss directly with the future implementers at public service level. The workshop took place on the 09 and 10 of May 2022. Two prosthetist & orthotist (P&O) and one senior P&O attended it.

A detailed agenda was defined for the workshop with ARRH staff members, and is available in the appendices. This workshop was participative, dynamic and based on interactions with the participants. Flipcharts, sticky notes and PowerPoint support were used.

Specific objectives were:

- *Objective 1:* Detail the actual functioning of the traditional service in ARRH - challenges and opportunities
- *Objective 2:* Get a common understanding of the patient pathway for 3D printing orthoses provision
- *Objective 3:* Define scenario to include digital solutions in a public services (from patient identification to follow-up: what? how? where? who?) – Prioritise and identify the most relevant options to include digital services in ARRH, based on clear and relevant criteria
- *Objective 4:* Identify resources and challenges related to such an organisation & provide solutions
- *Objective 5:* Work on bridges between both approaches

3.4 Others key informants: semi-structured interview and observation

Others partners and stakeholders have been met to triangulate information and have a deep understanding of the context, 3D service opportunities and limitation.

- Momentum wheels for humanity (technical advisor and finance manager): Organisation based in Kamapala and who has a good knowledge of the context, rehabilitation services and challenges in the country. Therefore, meeting them was helpful to supplement the understanding of these in the context of this research.
- Comprehensive Rehabilitation Services for People with Disability in Uganda (CoRSU; Medical director, head of rehabilitation services, and 4 P&Os); CoRSU produces 3D printed prosthesis. Meeting them allow the researcher to understand the challenges they are facing and to compare these limitations and benefits of 3D printing services.

- Gulu Regional Referral Hospital (GRRH; three P&O, one senior P&O, introduction to the hospital director) & AVSI (one physiotherapist, programme manager and technical advisor): GRRH and AVSI are both based in Gulu and have a functional rehabilitation services. Meeting with GRRH and AVSI for half a day allowed the researcher to understand why this public service was functional and the staff members' thoughts on 3D printing services.

3.5 Others reports & research

Information from international reports and findings from another HI project (IMP&ACTE project) conducted in West Africa were used. The context of implementation is similar. Therefore, the results of the clinical trial were useful to triangulate information, for example on the timing of 3D orthoses production. These researches and the literature review also gave additional information on technical aspects and requirements of 3D printing technology.

4. Qualitative data treatment

For every semi-structured interview, notes were taken by the team members. The research officer always led the discussion during the meeting with stakeholders and supported the note taking.

For the semi-structured interviews with beneficiaries, a translator helped for the translation, a person took note and the Research Officer led the discussion. The notes were retyped at the end of the day. Finally, every notes were organised and analysed in an Excel form. Because of the low number of SSI, the saturation matrix has not been used.

For the workshop with ARRH, the MEAL officer supported the note taking and the Research officer animated the workshop. The support used during the activities such as flipcharts and post-it were taken to keep track of the exchanges.

5. How costs are calculated

Before any cost analysis, it is essential to define clearly the patient's pathway to identify the exhaustive list of costs of 3D printing services (materials, staff members involved, coverage, etc.). Following these thoughts, catchment area, demand and offer are calculated. Based on the pathway, every minute of working time for each step and for each professional is measured. This is crucial to understand the working time per step of production of the 3D-printed orthoses, from identification to delivery. With this understanding and calculations, a chronogram is defined and the human resources required per month is calculated.

This cost analysis aims to measure costs of 3D orthoses procurement (from patients' identification to orthoses delivery) in a public service (in this analysis ARRH has been chosen). Some assumptions had to be made and are based on informed choices and existing evidence.

All these elements are detailed in the matrix that includes different shits, including instructions and explanation on the data used in calculations, hypotheses made and calculation & detailed costs. As shared above, the list of categories of costs were based on the RCAF.

Costs are shown over 4 years, which is the estimated lifespan of the 3D printers[16] and can be then split in a second step per patient and device. In the matrix, costs are staggered according to depreciation rules. However, it is possible to calculate from the matrix the investment capital required, and therefore the cash flow requirements at the time of setting up the 3D service.

Every cost line in the matrix has been cautiously considered. All the choices, assumptions and calculation are explained in Part 4: Cost Analysis. Results are also reported in this report by costs per patient, costs per device.

6. Ethical aspects

The following analysis had followed HI's recommendation and international protocols on ethical rules in research and data management.[17] Every participant had received information before their participation about the purpose of the analysis, the confidentiality, and their right to stop whenever they want. All participants gave their free and informed consent to participate. When children have been involved in the study, the parents have been informed and signed a consent form, and responded for their children. The security of personal and sensitive data has been ensured at all stages of the research process: interviews were lead in a way to ensure the privacy of participants and the participants' names have been coded and changed in the report. Staff recruited to collect data were trained and signed a code of conduct to ensure the reliability and confidentiality of information.

When the team met other stakeholders, the study's objectives have been presented to them and the ethics rules always explained to them before the interview.

7. Research limitations

Firstly, the planning of the analysis itself is a limitation. The research has been implemented in the middle of the PETRA project, some data was therefore not collected before the implementation of the research and was lost. For example, the identification was fully completed and the general assessment almost finalised by the time the analysis started.

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[16] More detail in the section: *Part 4 – Cost Analysis / 1- Initial assumptions, choices & sourcing* of this report.

[17] Brus A. Studies and research at Handicap International: Promoting ethical data management. Humanity & Inclusion, Lyon, 2016.

Furthermore, the project faced serious delays because of logistics issues. This affected the research because the assembly and fitting of devices had been postponed multiple times. That is the reason why our sample of time per step is small. Furthermore, the HI team members had to compensate for this delay and had a heavy workload when the data collection was initiated. This heavy workload impacted the quality of data collected by the field team. Because only a small number of devices were delivered in phase 2 when the data collection was carried out, this also affected the number of beneficiaries met from phase 2. In addition, because of a high turnover within the team (especially in the MEAL and logistics department), some information was retraced with high difficulty or lacking, such as the monitoring data of PETRA.

The scope of the study had to be redefined multiple times. There was a gap in the understanding of the PETRA project design, implementation and context amongst diverse key informants. This caused a delay on getting a clear view of the local situation and context, and on adapting the methodology. To overcome this challenge, all information was constantly triangulated and meetings were organised regularly.

A comparison between traditional and 3D printing methods could not be implemented for various reasons. Firstly, the ARRH orthopaedic service is not functional and has a very limited number of beneficiaries. Furthermore, the Memorandum of Understanding (MoU) between HI and ARRH was not signed during the data collection period. This has also affected the participation of ARRH to the workshop. There is no partnership with GRRH and it was impossible to request their partnership for the research within the timeframe. GRRH has the support of AVSI and hence is not representative of an independent public service. CoRSU, which is a private hospital in Kampala and HI's partner, provides mainly prosthetics devices using traditional and different 3D printing methods (to print prosthetic sockets), also making it irrelevant to compare their services.

Data on the quantity of filament used was collected directly through the software. This information might not be completely reliable.

Because of the various changes to the methodology, the workshop was organised on short notice. Only a few people from ARRH were available, and the research officer was unable to gather people with different profiles, such as organisation representative of disabled people, to confront the point of view. To overcome this, the workshop was participative, dynamic and well structured.

To translate the semi-structured interviews with beneficiaries, CBWs were working as translators. They received a one-day training, but do not have official training or education as translator. Some information might have been mistranslated or missed. Furthermore, these workers are from the community, so their neutrality regarding the interviewed person is also affected. A code of conduct has been signed by every translator to ensure their neutrality and respect towards the beneficiary.

Part 3 – Patient Pathway & other key information

In order to carry out the most exhaustive and relevant cost analysis possible, it is essential to start by clarifying and defining the different stages required for the delivery of the service.

This process of determining all these steps was crucial to identify the resources required and their allocation for the optimal operations of every step of the service (e.g. materials and human resources). These resources depend on key decisions on the implementation and organisation of the service. For example, the location of the intervention will cause the costs to fluctuate (e.g. if the services are delivered at the beneficiary's home or at the hospital) and required resources and person involved in the process to be different. The number of experts, level of expertise of the staff members, number of professionals per patient, amongst others, will depend on the organisation of the service.

Identifying the patient's pathway is also important to confirm that the solution (meaning the service projection), the feasible care coverage and the service capacity match with the actual population needs.

The main steps of the 3D printing orthoses service are known quite well from experience implementing such service. The steps are different from a traditional approach to orthoses production, both in the techniques used (e.g. plaster measurement versus scanning) and in the way care is provided (e.g. scanning, done through a tablet and a sensor, can be done anywhere and not necessarily in the hospital workshop).

For this research, the model of intervention has been fine-tuned, based on the PETRA project experience but also on ARRH orthopaedic specialists and other experts' feedback.

1. From identification to patients' follow-up: What, Who, Where

The figure 1 shows the patient's pathway as defined for this research to allow the projection of 3D services integration within ARRH orthopaedic services.

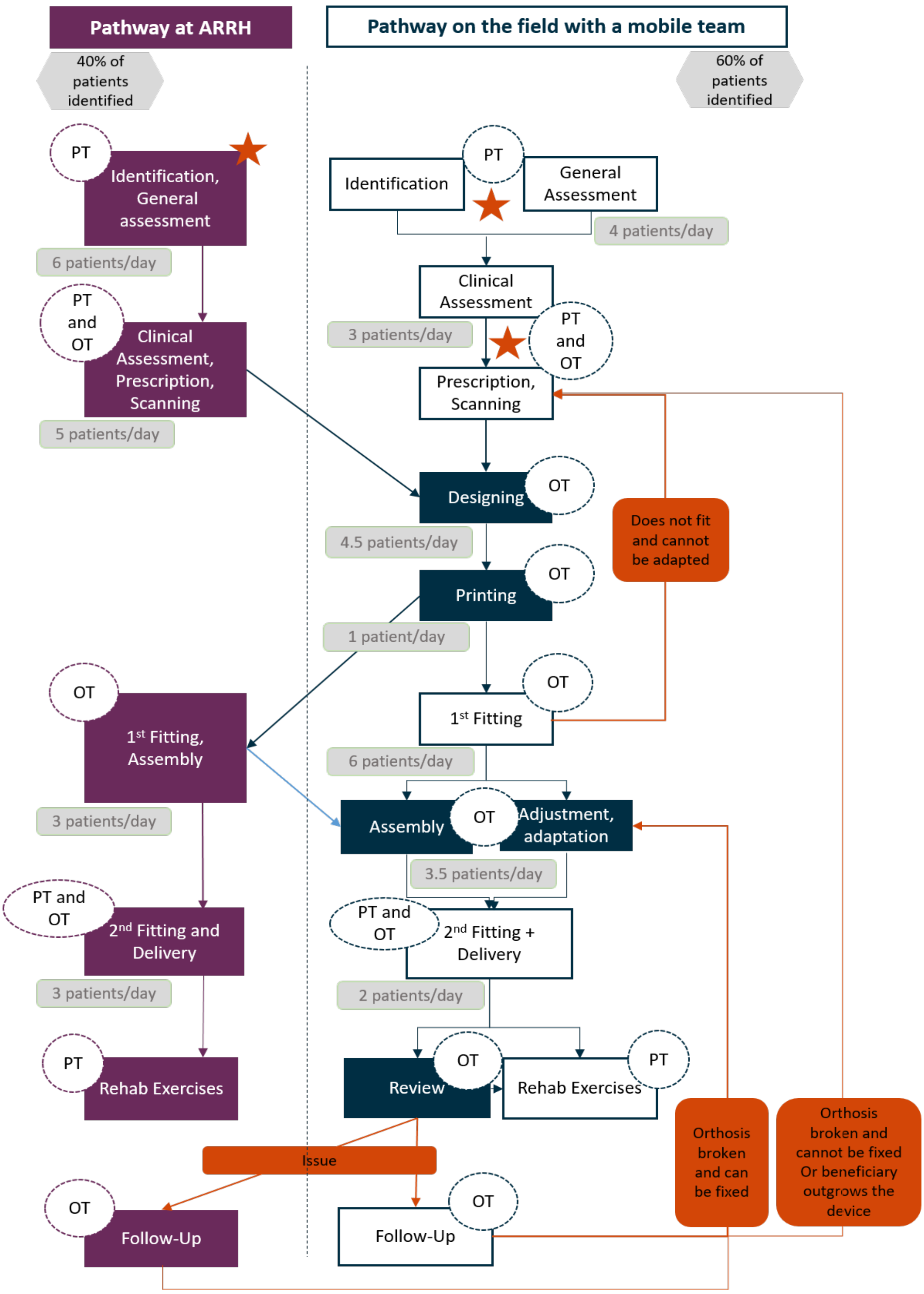
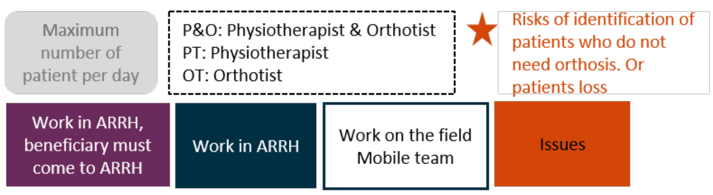


Figure 1: Patient's pathway defined for this research (Uganda case)/ human resources needed/ daily capacity. Legend:



First, traditional and 3D-printed services can be complementary, and the ARRH staff members were willing to have a complementary approach and be able to respect the patient's preferences to maintain a patient-centred approach.

Moreover, the proposed pathway, adapted to ARRH case, includes **a double gateway**: one at hospital level and the other at community level. In this projection, 40% of the patients would be identified and enrolled through ARRH. The remaining 60% of patients enrolled in the service would be identified on the field, thanks to a mobile team.

Why maintaining both identification streams?

Traditional and 3D-printed services can be complementary. The ARRH staff members are willing to have a complementary approach and respect the patient's preferences. When the identification is carried out in ARRH, the patient will get the choice between the traditional or 3D-printed services as there would also be prosthetics services for patients in need.

According to the CoRSU staff members (Uganda), the majority of people would prefer 3D printed devices, because the full process is faster. However, these preferences would vary from one context to the other. Other research[18] showed that patients who already had both types of devices in their lives (traditional and 3D printed devices) would be more likely to want a traditional orthosis.

Communicate with patients

One of the challenges in this context is the language barrier. There are multiple languages spoken in the region and it is difficult to recruit skilled translators when not offering full time positions. The decision made is hence to work with anyone who can translate, just as ARRH is currently doing.

However, to respect the medical confidentiality and quality in translation, ground rules should be established by the service: (1) Translate exactly what you hear; (2) Do not judge ; (3) Do not repeat what has been said (confidentiality/ medical secret).

[18] Daniel Tan. Etude d'impact social de la télé-réadaptation dans le cadre du projet IMP&ACTE 3D : Introduction de la technologie d'impression 3D pour la fabrication d'orthèses en Afrique de l'Ouest. Lyon : Humanité & Inclusion, 2019.

Focus on travels

- The patients enrolled in ARRH would go through all the steps of the pathway within the hospital. They should come to the hospital at least 3 times:
  (1) the first time for the general assessment,
  (2) the second time for the clinical assessment, prescription and scanning,
  (3) and finally for the fittings: The first fitting, assembly and second fitting could be done on the same day, according to ARRH and HI staff members. The patient will have to wait until the team has assembled and modified the device before fitting it for the second time and eventually going home with the device if it fits well. However, researchers encourage dividing these steps into two so that the patient does not have to wait a full day in the hospital, and then propose 4 visits to the service.
- The mobile team will go to the beneficiary's place at least 4 times: for the general assessment, for the clinical assessment and scanning, for the first fitting, and finally for the second fitting and delivery.

The **red stars** in the figure 1 represent the steps where we might lose track of patients along the full pathway, and patients that have been identified but do not need orthoses. These patients must be referred to the appropriate services. There is approximately 2% of patients actively identified and treated remotely who might not complete the full pathway until delivery, compared to 20% of patients identified and treated in ARRH. This difference is explained by the distance factor. Transport costs are reduced when the mobile team provides services at the beneficiaries' homes. These shares of patients also include the potential mistakes made when identifying patients. According to the HI physiotherapists, there are still approximately 20% of patients that are identified in the general and clinical assessments but who do not meet the criteria to benefit from an orthosis. The loss of patients is mainly occurring at the beginning of the pathway, after the assessments.

A detailed explanation of **each step of the pathway** is proposed.

1. Identification phase:

At ARRH, either the patients would come by themselves at the orthopaedic services (50% of the identification and admission in ARRH), or they would be referred by other services in the hospital or other organisations (the other 50% in ARRH).

An active identification is the first step of the remote service, when the pathway is delivered at the beneficiary's place. This step is conducted by the physiotherapists, and considered as a needs assessment. The calculations here concern six districts (coverage explained below). They will be in contact with the health facilities, teachers, religious representatives, and authorities amongst others, to gather a list of people with disabilities and who might need an orthosis, along with their contact details. This investigation will allow the needs assessment of the area to be carried out, and help organising their field trips and care plans for the following months. Afterwards, they will follow the patient pathway and go to the beneficiaries' houses to conduct the identification and general assessment. One field trip in every site that the service covers is required to ensure the success of this active identification and collaboration with stakeholders should be conducted.

Whatever where the identification will take place, the identification and general assessment are always the physiotherapists' responsibilities. However, physiotherapists do not always have the full skills and knowledge to identify patients who need an orthosis or other treatments. Before getting some practice and on-job training, the percentage of misidentified patients (currently 20%) was as high as 40%, according to the physiotherapists. Even if no other data sources was available to triangulate these rates, this feedback highlights the need of training before launching the activities.

Alternatives: Identification

Several options are possible for identification of future patients: at home, at a fixed point, at a primary health centre, or at a hospital. In the model, two of those possibilities were considered because of the context and based on patients' feedback.

In the Uganda case study, a mobile team has been chosen to reach the majority of the beneficiaries. The team would directly go to the individual beneficiary's place, and would therefore not gather patients in a fixed point. The patients who come directly and by themselves to the hospital can receive the 3D printing services in ARRH. However, the mobile team can also deliver 3D printing services to families who live nearby the centre. Beneficiaries might live next to the hospital but would be unable to move to the hospital. This approach aims to reinforce the adherence to treatment, to provide services to the most vulnerable and isolated families, and reduce the loss of patients.

The alternative shared by ARRH staff members during the workshop was to identify beneficiaries and carry out the whole pathway in a primary health centre, school or any structure in a central location within the community. In this context, this approaches includes many limitation. Firstly, physiotherapists do not work in local primary health facilities. This is legally not allowed. Additionally, the beneficiaries shared in the semi-structured interviews that distance and transport costs are limiting factors and important challenges. We might lose track of more beneficiaries if we do not go home to home. HI staff members had the same opinion.

"[...] My daughter transportation is not easy. It costs 5000UGX for one way with a 3-wheels motorcycle, and the other girl must come with us to help because my daughter is weak. It is very complicated. I would prefer to receive the care from home. [...]". Mother, Arua

"[...] It took 2 hours one way to go there on foot. That is how it is, there is no other option. I would prefer if they would have done it at home. [...]" Mother, Imvepi

However, GRRH and AVSI implemented a mobile clinic for their rehabilitation services in the past. This service turned out not to be sustainable which led them to stop this activity.

In another context, the alternative of gathering beneficiaries in a fixed point might be more relevant and must be considered. Moreover, interviewed beneficiaries explained the positive impact of meeting with other families who face similar challenges. **Support groups** for these families should be considered and could be combined with other steps of the pathway (scanning or fitting) in another context.

"[...] I felt happy because I saw it was not only my child who would get the device, but many others. There is no support in the community, unless for activities such as farming, where you can receive planting seeds. [...]" Mother, Imvepi.

"[...] Because my child doesn't talk, I was really stressed but the PSS helped me and told me that many people are in this situation. [...]" Mother, Imvepi

"[...] I like to be with other women even if I stay 2 hours. I like to be with other women who face the same challenges. [...]" Mother, Imvepi

2. Clinical assessment:

The clinical assessment can be done either at ARRH service, either on the field and can be conducted by physiotherapists (PTs) once they have been trained and gained experience, otherwise this would be done by P&Os.

3. Scanning:

P&Os will also conduct the scanning. These two steps can be done on the same day, at ARRH or on the field. When retracing the pathway with beneficiaries, a quarter of them forgot the scanning step. The new technology does not seem to impress the community or to impact the quality of care in this context, as also shown in previous researches.

Testimony

"[...] I felt good with the IPad because the scan is done to improve the life of my child. [...]" Mother, Imvepi

4. Designing, printing, assembly and adjustment:

The designing, printing, assembly and adjustment steps are always carried out by P&Os, in ARRH.

5. First fitting:

First fitting can be easily done on the field and and is always carried out by P&Os, because there is a need of technical orthopaedic knowledge to ensure the quality of the device and assess the modification required.

Going back and forth from the first fitting to the scanning can happen if the pathway's timeframe (explained below) is not respected, or if the scan quality is not good enough. According to orthopaedic experts, the measurements taken when scanning must be enlarge a little bit when designing the devices to avoid this additional work and to ensure a beneficiary wears the device for at least 6 months. The communication after the fitting is important to ensure the beneficiary and their family understand why the team has to take back the device and to reduce frustration.

Testimony – 1st Fitting

"[...] It was not right, it was hard to give it back but they said they had to make some work on it. I felt happy and good, even when they took it back, because they explained I would get it back. [...]" Mother, Imvepi

"[...] It wasn't fitting well so they had to take it back. The joint at the ankle was causing bruises. They took it back the same day. I didn't feel bad. If it wasn't fitting well, they had to change it so it can fit well. [...]" Mother, Omugo

Alternatives: Phases order

Patient's pathway is based on HI's experience and ARRH staff members' feedback during the workshop. However, the steps following the printing phase can differ according to experts. In the PETRA context, the team has chosen to conduct a first fitting before the assembly. These steps could be reversed, if the pathway is fulfilled in maximum 4 weeks. This timeframe would avoid issues such as the fact that patients already outgrow the device on the first fitting.

6. Second fitting & delivery:

The second fitting and delivery can be done at ARRH service or on the field. These steps are conducted by both a P&O and a PT. The PT is helpful in this step, as he will advise the beneficiary and teach them some physio exercises. The rehab sessions must also be scheduled during this field visit.

Testimony – Delay and delivery

"[...] I even forgot I would get something. I could not believe that day would come, because many organisations come, do assessment and never deliver what they say they will. [...]" Beneficiary, Omugo

"[...] This process takes a long time, it took 1 year. [...]" Mother, Imvepi

7. Need for review and follow-up:

The complications and number of devices that broke after delivery are high (42.5% in Phase 1 according to the questionnaire delivered in regard to this analysis). That is why it is crucial to ensure a robust review and follow-up after the delivery, and to consider those issues when running the 3D service.

Data on reparations

Unfortunately, we do not have any data on the exact rate of reparations carried out on the delivered orthoses, on the rate of scan repeated, on the number of children that outgrew their device, or on the frequency and time passed before failure. This should be included in further research.

Once the device has been delivered, regular reviews must be conducted for every patient. Review can be conducted through a phone call. If the beneficiary shares an issue or concerns regarding their device, a follow-up visit must be organised and actions such as reparation or replacement of the device must be taken if required. Every beneficiary must receive the 3D printing team's contact phone number, so that they can call to share any concerns, or ask any questions to the P&O.

Testimony – Communication

"[...] There is no option of communication. I must meet them physically. There is no other way. [...]" Mother, Imvepi

"[...]I don't know the CBV. I don't have his phone number. I can only wait for him to come check on me. I suppose if I would have a phone number, it would be better as I could call them directly. It is not good. That way of communication is not good. I would like to be able to call them and to communicate.[...]" Mother, Imvepi

"[...] If there is an issue, I call the CBV but sometimes I call them and they don't come. It happened once. I called the CBVs, they said they will inform the rest of the team and will come to see him, but they never came. [...]" Mother, Imvepi

Alternatives: Psychosocial Support worker (PSS)

In this pathway and cost analysis, the choice has been made to exclude PSS workers.

After additional training on their responsibilities and on patient care and support, this psychosocial support could be carried out by the P&O or PT. They are in close contact with the vulnerable families and should have the skills to reassure and support patients. They should also refer them to psychosocial services if needed. Furthermore, having too many people around one beneficiary for 3D services is not optimal and affects the therapeutic relationship. The principle "Do no harm" must be ensured and respected, and this requires P&Os and PTs of being aware of ethics and privacy rules, beneficiaries' needs including psycho-social needs and referral to adapted services when needed. Beneficiaries met during the PETRA programme have highlighted the importance for them to receive psychosocial support to reassure them and guide them through the scanning process, along with information on the orthoses production process.

2. Catchment area, needs in orthotics devices per patient and offer

The first assumption made is in regard with the distance and time covered by the mobile team. The projected travel time is maximum two hours away from Arua, which is an average of 1 hour for one way, and one hour to return (so an average of 2hours roundtrip). ARRH staff members shared the same projection of travel time with us during the workshop.

Taking into account the maximum travel time of two hours one way from ARRH, the active identification and 3D printing service could cover these six districts: Arua, Maracha, Terego, Madi Okollo, Nebbi, Pakwach.

The total surface area to cover for these 6 districts is 7,830 km², according to data in 2016 by the organisation OpenAFRICA[19], and the approximate population in the districts in 2020 is 1,320,300 people, according to the Ugandan Bureau of Statistics[20] (see Appendice 1).

UNICEF stated that 15% of the world's population has some form of disability.[21] According to the report written by UKAID, UNFPA and UBOS, 14% of people over 5 years old in Uganda suffer from disability (any type).[22] In 2005, according to a report written by the British Association of Prosthetics and Orthotics (BAPO) in 2005, a ratio of 15 per 1000 population[23] can be used to overcome the lack of data and help estimating the needs of orthotics devices. This means there is 2% of orthoses needs in the global population. This rate is higher than the one estimated by the World Health Organisation (WHO), which is 0.5%. However, the WHO's rate includes prostheses in addition to orthoses.[24] WHO also mentioned that this rate does not take into consideration factors such as access to health services, traffic injuries and displaced people[25]. That is why the 2% ratio has been considered in this context.

When using this ratio of 2%, and when it is assumed that the distribution of people in needs of orthoses is homogenous in the covering area, the results indicate that a total of 19,804 patients are in need of orthoses in the six districts covered by the service.

Alternatives: Coverage area working with Community Based Workers

If the pathway includes the work of CBWs, such as is currently done for the project PETRA for the identification of the beneficiaries, they walk in average 10km one way, so 20km in total in a working day. This is equivalent to a total coverage of 314.16km² on foot. The team of CBWs could cover 25 sites[26]. According to the CBWs involved in PETRA, they identified an average of two beneficiaries (and maximum 5) per day.

[19] https://africaopendata.org/dataset/size-of-uganda-districts-in-square-kilometers
[20] Details per district available in annex.
[21] UNICEF, Seen, Counted, Included. Using data to shed light on the well-being of children with disabilities. New York, 2021.
[22] UKAID, UNFPA and UBOS, Persons with disability. Bridging the gap through statistics. Kampala, 2014
[23] British Association of Prosthetics and Orthotics (BAPO), Empowering the Professional to Enable the User, data and research resources
[24] World Health Organisation (WHO), Standards for Prosthetics and Orthotics. Part1: Standards. Geneva, 2017.
[25] World Health Organisation (WHO), Standards for prosthetics and orthotics, Part 2: Implementation Manual. Geneva, 2017
[26] OpenAFRICA, Size of Uganda districts in square kilometres, data set, 2016

This distance and number of beneficiaries identified are of course representative of PETRA and Ugandan context, calculation and assessment must be conducted in another context.

Another option would be to calculate coverage area per village, if data is available.

When meeting GRRH staff members, they explained that they were providing approximately 5 to 10 orthoses per month. They also have a waiting list of approximately 3 months. There is hence an average demand of 7.5 orthoses, multiplied by 3 (for the 3 months of wait), which is equal to 22.5 orthoses per month. According to our model, 50% of the orthoses produced in the hospital will be produced using the traditional method. There is hence an approximate demand of 11.25 3D-printed orthoses per month in ARRH (22.5/2). The needs and demand of prosthetics device must also take into consideration.

In May 2022, the percentage of beneficiaries with two devices was 16% (12 out of 74 beneficiaries), after confrontation with other sources and review from expert, the number of patients who need two devices has been increased to 20%. Therefore, there is a need of approximately **1.2 orthosis per patient**.

Regarding the hypothetical demands in ARRH, there would be approximately nine patients per month who would need an orthosis produced using the 3D printing technology in ARRH.

According to experts and to PETRA (phase 1 and 2) data and admissions, 2% of the beneficiaries should benefit from upper-limbs orthotic devices. No other data were available to triangulate this information.

Below are the percent average need of orthoses per type of devices, calculated based on the admission data from PETRA phase 1 and 2:

- Seating brace: 8%
- AFO: 60%
- KAFO: 30%
- WHO: 2% (excluded in this analysis)

Data from PETRA also shows there is 70% of children and 30% of adults who are admitted in the 3D printed programme.

The cost analysis is based on the percentage of average need of orthoses per patient, and age from PETRA, and on the fact that a patient needs 1.2 orthosis.

3. Materials capacity

The average printing time per type of orthosis is shown below in Table 2.

Table 2 – Printing time

Orthoses (n)	Printing time Median (min)	Printing time Median (day, hours, min)	Quantity of filament used Median (m)
All (36)	2,744	1 day 23 hours	129.35
AFO (23)	2,344.5	1 day 15 hours	139.9
KAFO (10)	2,824	1 day 23 hours	111.06
Seating braces (3)	340	5 hours 40 minutes	176.88

The printing time and quantity of filaments used might seem contradictory. However, the number of issues that arise is high. Amongst the 36 printings, 22% (8) faced issues and the printing had to be restarted. The printing time also includes the time before the printing was restarted, which explains why the printing time is sometimes higher.

Two working days are required to print one orthosis, on average. Hence one device can be printed per day (or four per week), with the availability of two printers. **The limiting factor to produce the orthoses using 3D technology is therefore the printing time.**

The recommendations for sustainable utilisation of the 3D printers are to print maximum 5 hours per day. In this context, this is impossible to respect this recommendation.[27] To overcome this fact and to manage the printers, it has been decided that there will not be any printing on the weekends. The printers will be working only on working days. Furthermore, in Uganda some Fridays are off and this day will be used to carry out maintenance work on the printers.

The cost analysis is hence based on the use of **two printers from Monday to Thursday**.

[27] The recommendation on the use and maintenance of printers are available in the printers' manuals.

4. Human Resources capacity

A chronogram has been developed to calculate and estimate the ideal running model. This chronogram retraces the patient pathway and schedules the human resources needed. To be able to develop this chronogram, time taken by the team members for every step has been calculated (Table 3).

4.1 Timing calculation

3D services can technically produce all types of orthoses and orthopaedic devices: AFO, KAFO, WHO, corset, seating braces, for adults and children (this was confirmed by Experts). Therefore, timing was measured for all types of orthoses and patients' profiles.

The timing does not only include the technical act, but also integrates the holistic view and a patient-centred approach. They hence include greetings, sharing of advices, and any unexpected events that have happened.

Table 3 – **Timing in minutes, PETRA- Median**

	Clinical Assessment (n)	2nd assessment, prescription and scng (n)	Designing (n)	1st Fitting (n)	Assembly (n)	2nd Fitting – Delivery (n)	Total time in minutes
AFO (children and adults)	**34 (6)**	**29 (10)**	**59.5 (18)**	**17.5 (12)**	**55 (10)**	**30 (8)**	**225**
AFO Children	31.5 (2)	29 (6)	66.5(10)	13 (8)	38 (7)	30 (5)	208
AFO Adults	35.5 (4)	39.5 (4)	55 (8)	15 (9)	61 (3)	20 (3)	226
KAFO (children and adults)	**32 (4)**	**40 (7)**	**78 (7)**	**16 (13)**	**110.5 (10)**	**39 (3)**	**315.5**
KAFO Children	32(4)	40 (7)	78 (7)	14 (12)	110.5 (10)	39 (3)	313.5
KAFO Adults	No data (0)	No data (0)	No data (0)	20 (1)	No data (0)	No data (0)	-
Seating braces	**No data (0)**	**26 (1)**	**27 (2)**	**38 (1)**	**No data (0)**	**No data (0)**	**-**

Because the data collection started when some steps had already been completed such as the identification and almost all the clinical assessments, some data was unfortunately not available. The programme also faced delays in the provision of materials, this also impacted the data collection on the assembly, fittings and delivery steps. So data from previous were used when necessary and relevant. Some data has been also excluded:

- 12 data points for the scanning because the time collected was only for the technical act of scanning and not the full process (greetings, positioning of the beneficiary, etc.);
- Data points equal to or lower than 10 minutes for the fitting and delivery, because this is not possible to carry out the work in such short time.

4.2 Service team composition

According to ARRH and GRRH staff members, in Uganda the HR quota in rehabilitation services is a team of five P&Os and five physiotherapists (with at least two senior staff members). The number of team members to cover the 3D printing services and also the traditional production of orthoses and prosthesis is based on this national quota.

Alternatives: Quota of staff

In another context, there might be a quota for a maximum number of patients per health professional, or a different quota of staff members per service depending of factors such as the geographical distribution of needs, whether the service is decentralised or not, for example.[28] This must be taken into consideration and can be a key factor in future cost analyses and in the planning of 3D services implementation.

When implementing 3D services in ARRH, a P&O will work partly on the printing (launching the printers, removing the device, carrying out maintenance work, etc.). Physiotherapists will work for other services and treatments, not only for the 3D services. According to PETRA, the timing and the projection, a 3D service would approximately need one full time physio to cover the needs.

Challenges - Incentives

The number of patients in ARRH will increase if the 3D printing services are implemented. The workload of the team will be higher. However, in this projection, it is assumed that salaries will remain the same. The team members could be less motivated if they do not have some economic incentives.

[28] WHO, Standards for prosthetics and orthotics, Part 2: Implementation Manual. Geneva, 2017

4.3 3D dedicated team

This result of HR needs has been calculated using the creation of a chronogram that schedules every step of production per patient per day. This is based on the maximum number of patients that can be included per day, and also on the time required per steps per P&O or physiotherapist. The time allocation of the mobile and fixed teams has also been taken into consideration in the chronogram.

Alternatives

In this analysis, there is no time taken into consideration for training, building of the 3D printing space, or for raising awareness within the community. Patients are enrolled from the day one and the number of patients remains the same throughout the 4 years. This decision is specific to the Uganda case: ARRH has already been trained so the service should be immediately able to admit patients.

This time allocated to the implementation of the service (HR training, material procurement, building the space) before enrolling patients must be taken into consideration in another context as the number of patients will be significantly inferior in the first year. Having fewer patients in the first year would increase the cost per patient for that year. According to HI experience, it can take up to 6 months to receive the 3D printers and for the team to be fully trained.

To run a 3D service and deliver **16 3D-printed orthoses per month (meaning 192 per year, i.e. 160 patients[29])**, there is a need of **two P&Os and 1 physiotherapist working full time** on the 3D printing service, on average. This team must be stable and able to cover any absence due to sickness, or other reasons to reach the projected targets.

The 3D printing service can be fully functional after approximately two months. There is never more than one month between the scanning and the delivery of the device, as recommended by experts. After two months of implementing the 3D services, the time between scanning and delivery should theoretically only be around two to three weeks.

Calculation details

A day of eight working hours was considered, in which one hour for lunch and one additional hour for breakfast and small breaks must be subtracted. The total number of working hours per day is hence six hours, in this context. The time was calculated per patient and not per device (one patient has on average 1.2 devices).

[29] 1,2 devices/ patient is equivalent to 192 devices per 160 patients

The recommended practice is to take a scan for every limb that requires a device, this has been taken into account.

The needs assessment and first identification conducted in collaboration with stakeholders are not included in the chronogram, because they are sporadic activities. Details on the calculation of every step on the HR required for the 3D services are available in the appendices.

Challenges - Demand and needs higher than the material and HR capacities

The approximate projected needs of orthoses in the six districts is much higher than the potential production of the 3D service in ARRH, when respecting the quota of staff members. There is hence no saturation of the demand, but a saturation of the capacity to deliver orthoses to satisfy the demand.

Challenges – Timing of the full pathway

The maximum time between scanning and delivery must be one month. A child gains on average five to six cm per year from age four to puberty.[30] Consequently, if there is a high delay between scanning and delivery, the chances are high that the device will not fit the beneficiary when conducting the 1st fitting. Moreover, people who require orthopaedic devices must be treated as soon as possible to avoid further complications. Additionally, this 1-month timeframe respects the families' and beneficiaries' hope and expectations. The calculation of time to fulfil the pathway has been made through a chronogram and it shows that this 1-month timeframe is achievable. This information has been validated by experts.

This section explained the ideal patient pathway, from identification to orthosis delivery, as defined with the future public service implementer (in our case AARH). It shows also all the needed initial calculations to be able to define health needs, catchment areas, service capacity and needed human resources. The maximum number of 3D produced orthoses per year by the 3D printing service is 192, which is equivalent 160 patients maximum per year.

[30] Rogol A. Clark P.Roemmich J. Growth and pubertal development in children and adolescents: effects of diet and physical activity. In the American Journal of Clinical Nutrition, 2000

All these projections are valid only if politics and hospital direction support rehabilitation services. In an unfavourable context, there is a high risk that the 3D services will not be functional. Materials and budget must be available and sufficient. If this is not the case for traditional rehabilitation services, the first activity should be to advocate rehabilitation needs to the government and stakeholders and ensure the procurement of required resources. Infrastructure issues must also be limited. For instance, electricity must be reliable (with a generator and batteries), and WIFI must be accessible. Alternatively, the service could benefit from a collaboration with other external organisation to support them, as it is currently the case in GRRH where AVSI actively supports the rehabilitation services.

Part 4 – Cost analysis

In this part 4, assumptions and choices made for the costs calculations are explained. Alternatives relevant in other context are also mentioned. Results of the cost analysis of the Ugandan case-analysis are also presented in this chapter.

1. Initial assumptions, choices & sourcing

This section detailed costs categories and calculations. Additional information on the calculation is available in the appendices.

1.1 Exchange rate

Exchange rates used are from a reliable website[31].

On the 03/06/2022, 1€ = 3866.675 UGX Ugandan Shillings

1.2 Lifespan of materials

The starting point for the analysis is the lifetime of a 3D printer. While the manufacturer considers the printer to have a life of 5 years, it also stated that it was important to keep the equipment free from dust and heat. In low and middle income countries, it seems appropriate to give this equipment a shorter life span. For this case in Uganda, the life of the printer was estimated at 4 years.

Every other items have been reviewed with the field team (PM P&O, P&Os) and experts to ensure the list of materials required for a 3D printing workshop/service is exhaustive and to confirm the lifespan of each machine, tool and materials. The equipment did not all have the same lifespan, and therefore the replacement costs had to be included in the 4 years (not using an average lifespan for all the equipment, as it would inflate the final cost).

1.3 Implementation Costs

Building and general investment:

ARRH workshop must be adapted to be able to deliver a 3D printing service. A printer room needs to be built. There is enough space in the workshop to adapt and build a printing room. The costs have been based on HI costs to adapt the office and construct a building for a generator, for example.

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[31] https://ec.europa.eu/info/funding-tenders/procedures-guidelines-tenders/information-contractors-and-beneficiaries/exchange-rate-inforeuro_fr

There is no rent fees to include as the workshop will be integrated in a public hospital.

The office implementation, building and general investment costs are based on the cost to implement the 3D printing programme within HI[32]. The same approach has been followed for the services furniture.[33] These costs in ARRH should be similar.

Payment and expenses of construction of building is only reported once, as the depreciation will be over many years.

Challenges: Calculation

Calculation of the cost to build the printing and storage room per m^2 would have been more accurate. Unfortunately, not enough data is available to make this calculation.

No guesthouse has been included in the cost analysis. As explained in Part 3, the mobile team will come back to Arua after every field mission.

Alternatives: Inclusion of a guesthouse

In another context, it might be relevant to include a guesthouse or a budget for accommodation and a per diem so that the mobile team is able to stay several days in a remote area. For example, if the team covers a lager zone and needs to travel for a longer period.

Fixed machinery and Material capacity:

To maximise the materials capacity, to increase the efficiency and to be able to print any type of device with one printer and in one piece, two big 3D printers (Delta 4070) have been considered in this analysis.

1.4 Running costs

Maintenance of technical services:

The change of battery for drill machines is not included in this analysis because no information is available. But according to experts, the drill machines' batteries should be changed in order to keep the drill machines longer. The lifespan of the drill machine has been reduced to compensate the fact that the battery will not be changed.

[32] Costs to build the blocks and fencings for the office and guesthouse in Omugo; this total has been divided by four to only represent a cost representative of the surface that would be required for a 3D printing room and storage the costs for the office. Same costs for the building for generator and installation of lights in the 3D room, as these will be similar.

[33] Costs are based on HI, PETRA expenses and needs for 3D printing services.

Alternatives: Change of batteries

In another context, it could be considered to include the cost of batteries for the drill machines, every 5 years, and to increase the lifespan of these drill machines.

HI bought different generators, the one with the largest capacity has been chosen because it must be reliable and will be used almost every day. The inverter bought by HI in Arua is not functional anymore. This is crucial to ensure a reliable power source for the 3D printers, hence the cost included is a better inverter bought in Kampala by HI. Similarly, the batteries must be replaced every 2 years, although they have a lifespan of 3 to 4 years. Because of this context and the high rate of utilisation, they must be replaced more frequently.

The company, WASP, which provided the 3D printers, has been contacted to collect information on the lifetime of the 3D printers. The impacts of the maintenance, utilisation and condition of storage on the lifetime of the printers have therefore been considered. The warranty is valid for one year if the storage and maintenance recommendations have been respected. WASP advised to store spare parts. The list of spare parts and costs is issued from their website.[34]

Because of the environmental conditions and the 4-5 consecutive days of use of the printers, some parts must be replaced:

- Every year: Teflon tube fitting, nozzles, aluminium printing bed;
- After 2 years: Extruder, spitfire cartridge, filament drivers;
- After 4 years: the 3D printers.

Materials availability:

One car is available and dedicated to the mobile team of the rehabilitation services. It has been decided to buy the car (instead of rent it).

Alternatives: Rental car

According to the context and the information shared during the workshop with ARRH staff members, the hospital can and should buy a car for the 3D printing service. Furthermore, it would be less expensive on a long term. But in another context, rent a car could be a relevant alternative.

[34] WASP – Tools & Replacements

Parts and materials (AC, generator, fuel, filaments, tools, etc.) should be available and maintenance should be carried out as required and recommended by manufacturer. The maintenance costs for the office are based on HI budget for every programme. The costs for the maintenance of the AC is the same as HI's.

Quality of filaments and the conditions of storage are decisive because the quality of orthoses and the frequency of issues while printing depend on these. Recommended maintenance and storage must be respected. According to a study published in 2019[35], the filaments must be stored in a hermetic transparent box with dehumidifier. This is relevant in this tropical environment. Printing issues could have been avoided using these storage conditions. Hermetic boxes and dehumidifiers have been added to the cost analysis and must be considered.

The hand tools were listed and reviewed by PM P&O to ensure the full list of necessary equipment.

Fuel – Distance covered:

Calculation of the fuel needed for the service, based on the cost of fuel per L, and the average distance the mobile team will have to travel is available in the appendices.

Electricity and Water:

The electricity and water costs are based on the average monthly consumption in Arua office, in 2022 (January to April).[36] The printers were working a lot during this period, this is representative of the need for fuel for the generator when implementing a 3D service. The use of the generator by HI in 2021, 2022 is similar to the use that will be done in a public service.[37] This is hence appropriate to use the real costs of generator repair in Arua in the end of 2021 - and 2022. The maintenance and repair of generator includes the replacement of oil pressure every quarter and a general repair every year.

Alternatives: Calculation L/month

In another context, the exact litres of fuel needed for the generator could be estimated and the cost linked to this quantity of fuel calculated. The average need for 3D printing service in Arua is 40L/month.

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[35] Fabrice Djodji ; Tom Saey. IMP&ACTE 3D : Introduction de la technologie d'impression 3D pour la fabrication d'orthèses en Afrique de l'Ouest - Cahier des charges techniques. Lyon : Humanité & Inclusion, 2019.

[36] The water bills are for the full office in Arua, to be representative of the 3D programme, the amount has been divided by 4 (number of programmes run by HI in Arua).

[37] The electricity bills increased because of and since the use of the 3D printers. The highest bill has been chosen, to be representative of the electricity costs required to run a 3D service. The main use of electricity in HI office is for the 3D programme. The full bill has been taken into account.

The rubbish service cost is also based on HI's expense.[38]

1.5 Administrative costs

Communication:

It has been judged that there is a need for a smartphone for the P&Os, PTs, logistics, accountant and HR, to have access to the internet, to fill a survey on the phone if needed, to take pictures, to have video calls, to contact anyone for technical support and for ongoing capacity building. The drivers, guards and cleaners must be reachable, but do not need access to the internet.

MIFi connection is also included because the Wi-Fi and remote connection through a phone are not always reliable or sufficient in this context.

Alternatives: Number of smartphone

Number of smartphone can variate, every staff could be provided with one to be equitable if the budget is not a constraint, or only the P&O is there is a limit.

License:

The same license and software used by the HI team have been included in the analysis. The team seems to appreciate it, and this is an accessible software.

Alternatives: Use of a different software

Other software and applications are available on the market. Another choice can be made depending on the costs of the software and the skills of staff members. However, from PETRA's experience, PROTEOR and Orthenshape can be easily learned and met the expectations of the team.

Stationery and office supplies:

The list of office supplies, small equipment and stationery are based on a monthly list given by HI - Arua, and adapted to represent the needs of a 3D printing service only. The quantity of items and costs were listed for a period of 1 month. This list should be similar in ARRH.

[38] The main use of the rubbish service is for the 3D programme. The full bill has been taken into consideration.

Exceptional travel costs:

Exceptional travel costs (including travel, per diem and accommodations) were included to allow the 3D team (two members every quarter) to assist to technical workshops, meetings or technical events taking place in Kampala every quarter. This desire was shared by ARRH staff members at the workshop. This is also important to ensure the capacity building of the team, as they need continuous trainings and to be up-to-date on best practices and identification criteria, for example. Costs include the accommodation, per diem and travel costs.

Cleaning materials and kitchen provision:

Quantity and list of materials based on HI purchases and based on anticipation of challenges.

Banking fees:

The banking fees is listed by transaction ranges and receivers. The calculation of the average banking fees has been made, using the Airtel Payment charges given by HI finance team.[39]

Interest rate:

There is no need to get a loan, as the necessary treasury is available.

Permanent training of staffs:

Trainings of the 3D team is crucial to ensure the quality of the service, and to ensure the proper use of the applications and the respect of the recommended good practices. The training should be in person. The accommodation, flight tickets and travel costs of the trainers are hence included.

Alternatives: Different training

Different types of trainings are offered by various organisations and can be considered. In another context, the team could also travel instead of the trainers. However, this might cause some administrative (such as visa process) and operational challenges.

According to ARRH, GRRH and AVSI, there is usually no training, nor training budget in public services. Therefore, there is no expense allocated to the "Professional short-term training" line in this context.

[39] The average banking fees, regardless the transaction range and type of receiver is 4.15%. This percentage has been applied for every line.

Alternatives: Capacity Building - Trainings

Local team capacity building is a key factor to ensure the success of the implementation of the 3D printing orthoses production. Every staff member involved at every stage of the patient pathway should be trained. The PETRA project has highlighted this need for teams to be quickly confident in their practice, precisely because of its weaknesses.

Indeed:

- None of the four CBWs interviewed has received training on the criteria to benefit from orthoses. It took them around four months of practice before getting more confident in identifying beneficiaries.
- The PTs got a first training of a few hours in phase 1 to understand the standard of assessment, the inclusion criteria and the scanning. According to them, this was not enough and they would have preferred a 2-day training. The training took part approximately 5 months before they could practice, so they forgot some information in the meantime. The practice is crucial for their learning process, according to them. They did not feel confident enough to train the CBWs themselves on the identification.
- Regarding the technical act of scanning, the PTs got the technical support of the PM P&O for approximately two months. They firstly watched how the PM P&O was doing the scanning (including the positioning of the beneficiary), then performed approximately eight times this act by themselves with the presence and support of the PM P&O. Once they started to carry out the scanning by themselves without the PM P&O presence, it took approximately a week before they became confident.In phase 1 and the time when the team was working with the support of a remote consultant, they took two scans for each device to be sure one will be good. According to the team members, working with a remote consultant was time consuming because of internet connection issues of challenges on the logistics side and with the communication. The physical presence and support of the PM P&O helped them to become confident and to gain skills.
- The PM P&O benefit the Proteor software has a training package. HI supported and trained the PM P&O (with 6 sessions) on designing. This training gave the skills to the PM P&O to design AFO (dynamic and rigid), KAFO (dynamic and rigid), and special seats. He was satisfied with this training. According to him, the factor to learn quickly depends on the computer skills, motivation and orthopaedic knowledge of the person. In only two months, he was able to design seven devices per day. According to him, to ensure the quality of care and for being efficient, this is recommended to have the same professional for one patient from scanning to delivery.

- The printer technician did not receive any formal training. A formal training was scheduled in Italy, but because of visa problem, this did not happen. That is why this more appropriate to make the trainers come to train the team. The WASP Company has given remote support when required to guide the printer technician on the reparation or maintenance work. However, some challenges were encountered and could have been avoided with a proper training at the beginning of the implementation of 3D printing service. According to the printer technician, it took one year before he felt confident in his work.

With proper training, support and practices, approximately three months are required before a 3D printing service can run smoothly and before the team members are confident and able to deliver quality services.

In case of a high turn-over within the team and due to the need for constant capacity building, the training may take place every year. But given that in the traditional public service considered here there is no investment in team training, it was not considered realistic to include any training other than the initial one (which is absolutely essential, as just explained above).

1.6 Component, devices materials

The quantity of materials is based on the production of 192 devices per year (16 per month)[40], because of the printing time, which is the limiting factor. This quantity and percentage of materials required per type of orthoses have been calculated using PETRA's (phase 1 and 2) shares of devices, and with the help of HI team and experts. The calculation of every piece of materials required for 1 year is available in the appendices.

Table 4 shows the proportion and quantity for each type of devices produced every year.

Table 4 – Quantity of devices per type

	AFO (60%)	KAFO (30%)	Seating braces (8%)	WHO (2%)
Adults (30%)	34	17	4	1
Children (70 %)	81	41	11	3
Total	115	58	15	4

[40] See calculation Part 4

According to data from PETRA project, there is a percentage of 34% of dynamic KAFO among the production of KAFO. This equals to 20 devices of this type (14 for children and 6 for adults). Furthermore, 70% of the total devices produced will be for children and 30% for adults. The WHOs have been excluded of this analysis because of lack of data.

All calculations to estimate the quantities of materials required to run 3D printing services are based on these figures.

In this context, the majority of people cannot afford to buy stockings nor shoes. For the ideal use of the orthosis, every beneficiaries must receive stockings and shoes. So one pair of shoes and stockings have been considered per beneficiary.

1.7 Imports costs and taxes

Taxes:

The import taxes are not included in the costs because the materials will be bought through ARRH and considered as medical materials. According to the various stakeholders met, medical items are not subject to taxes.

Import and transport costs of 3D printers:

The imports and transport costs of 3D printers are based on the costs incurred in phase 1 of PETRA project to import and deliver the 3D printers to Arua, including a truck to transport the printer from Kampala to Arua. These costs will be similar.

Import of 3D materials:

In Uganda, the costs paid for the storage of materials when arrived at the airport depend on the duration of the storage in the airport, and the quantity of materials stored. An average cost from phase 1 and 2 has been calculated and used for the cost analysis.

Costs from phase 1 were used to calculate the shipping costs. However, with additional information on the weight of every single item, the exact cost per weight of materials imported could be found.

The Duty customs clearance taxes have been included in the cost analysis. Moreover, all the Bioport documents used in phase 1 have been added up, as it should be a similar cost for these documents.

1.8 Human resources

In this cost analysis, the number of team members is based on the national quota to cover the 3D printing services and the traditional production of orthoses and prostheses.

Below are the number of team members included in the analysis:

- Office Cleaner : 1

- Security Guard: 2 (2 guards are required because there is a need for security surveillance 24/7).
- Driver: 1
- P&O (Not senior): 3.
- Senior P&O : 2
- Physiotherapist: 5
- Logistics Officer: 1 (Because of the needs for strong support on the logistical side, there is a need for a full-time staff working on the logistics aspects of the 3D printing service).
- Human Resources Assistant: 1 working 20% of their time (1 working day per week) for orthopaedic services
- Accountant : 1 working 20% of their time (1 working day per week) for orthopaedic services.

Alternatives: Work with external organisation

The human resources assistant, the logistics officer and the accountant could be excluded if there is a collaboration with an external organisation who would be in charge of the logistics management.

Salary and benefits are based on HI's. The assumptions that HI salaries and benefits are representative of public salaries was made.

For the P&Os, the information and values are based on the salaries and benefits of the 3D printer technician; for the Senior P&O, the salaries and benefits are based on the Programme manager's because the values are slightly higher.

One reallocation allowance per year has been considered.

2. Costs - Results

2.1. Total cost of the public 3D orthoses production (over 4 years)

The cost analysis shows that, based on the previous presented patient pathway, to produce 768 orthoses over 4 years, 1,210,224.25€ would be required.

2.2 Costs repartition per category (over 4 years)

The figure 2 details total cost distribution by main cost categories. The largest share of the cost is the human resources (66.67%), followed by materials required to produce orthoses (10.71%), the administrative costs (9.87%), the implementation costs (6.21%), the running costs (4.29%) and finally the import costs (2.24%).

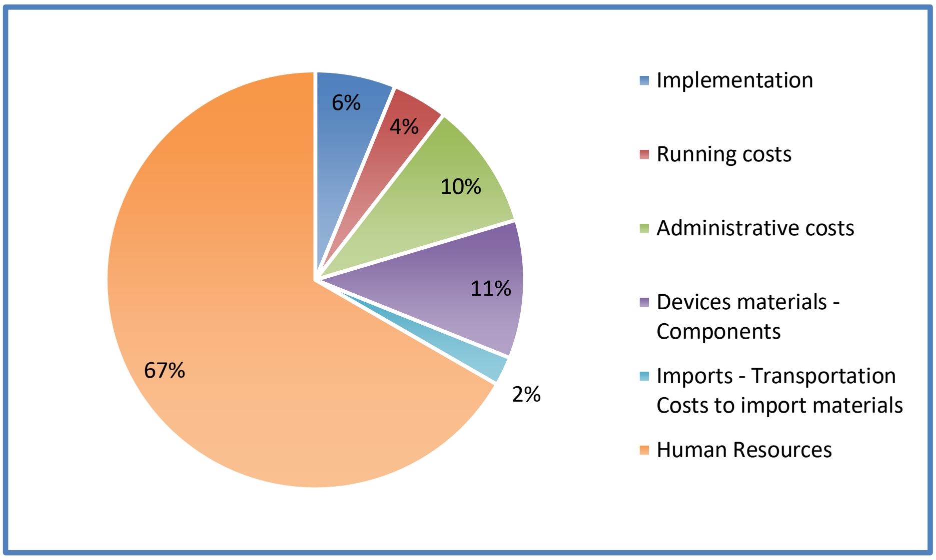

Figure 2: **Share of total costs over 4 years**

The table 5 lists the different categories, and the total costs over 4 years and the share of total costs over 4 years. A detailed presentation per category will follow.

Table 5 – **Share of total costs over 4 years per costs categories**

	Share of total costs (total costs) over 4 years
1. Implementation costs	**6.21% (€ 75,185.27)**
1.A. Building and general investment	*0.67% (€ 8,068.30)*
1.B. Fixed machinery	*2.58% (€ 31,235.45)*
1.C. Mobile machinery	*1.67% (€ 20,267.18)*
1.D. Office- Implementation - Service furniture	*0.09% (€ 1,038.81)*
1.E. Hand tools	*1.20% (€ 14,575.53)*
2. Running Costs	**4.29% (€ 51,948.21)**
2.A. Rent of land - building	*0.00% (€ 0.00)*
2.B. Maintenance of technical services	*0.26% (€ 3,148.75)*
2.C. Transport Costs	*2.25% (€ 27,232.65)*
2.D Electricity and Water	*1.78% (€ 21,566.81)*

3. Administrative Costs	**9.87% (€ 119,429.37)**
3.A Communication equipment's	*0.11% (€ 1,342.14)*
3.B. Teaching aids	*0.03% (€ 400.86)*
3.C. Telephone, internet and license	*3.03% (€ 36,713.04)*
3.D Stationery, small equipment, office supplies	*0.26% (€ 3,145.47)*
3.E. Exceptional travel costs	*0.60% (€ 7,274.48)*
3.F. Cleaning materials	*0.27% (€ 3,250.34)*
3.G. Kitchen provision	*0.15% (€ 1,780.00)*
3.H Banking Fees	*3.98%(€ 48,223.05)*
3.I. Permanents training of staff	*1.43% (€ 17,300.00)*
4. Costs - Devices materials	**10.71% (€ 129,634.08)**
5. Imports	**2.24% (€ 27,139.81)**
5.A. Import of 3D printers	*0.44% (€ 5,366.27)*
5.B. Import of 3D materials	*1.80% (€ 21,773.54)*
6. Human resources	**66.67% (€ 806,887.50)**
6.A. Professional short term training	*0.00% (€ 0.00)*
6.B. Salary - gross monthly salary	*53.29% (€ 644,959.86)*
6.C. Pension scheme	*5.33% (€ 64,496.01)*
6.D Health Insurance	*4.12% (€ 49,853.33)*
6.E. GPA - Insurance work accident	*0.85% (€ 10,274.43)*
6.F. 13th month	*3.00% (€ 36,269.39)*
6.G. Reallocation allowance	*0.04% (€ 517.24)*
6.H. First aid kits	*0.03% (€ 517.24)*

Implementation Costs:

The share of total costs for implementation costs is 6.21%, for a total costs of 75,185.27€ over 4 years. Over 4 years, 2.58% of the costs are allocated to the fixed machinery (31,235.45€). This cost includes the 3D printers, which must renewed after 4 years, and other machines such as the generator, inverter, batteries and AC.

The mobile machinery represents 1.67% of the costs over 4years (20,267.18€). The software Proteor is included in this category and represent an important share of the cost, along with the 3D-sensor (scanner).

Office implementation and hand tools represent only a small percentage of the costs, respectively 0.09% and 1.20%.

Alternatives: Software

To reduce the costs, alternative software and materials could be considered.

Running costs:

The share of total costs for running costs is 4.29%, for a total costs of 51,948.21€ over 4 years.

The main cost in this category is the transportation, i.e the operating cost of the mobile team (2.25% of total costs; 27,232.65€ over 4 years), followed by the electricity and water costs (1.78% of total costs; 21,566.81€ over 4 years).

Administrative costs:

The share of total costs for administrative costs is 9.87%, for a total costs of 119,429.37€ over 4 years.

The most important cost in this category of costs is the banking fees (3.98% of the total costs; 48,223.95€ over 4 years). The second highest cost in the administrative costs is the telephone, internet and license costs (3.03% of the total costs; 36,713.04€ over 4 years), mainly because of the phone credit (12,103.42€ over 4 years), the internet connection through WI-FI (13456.52€ over 4 years), and the application Orthenshape (2000€ per year).

Devices, materials, components:

The share of total costs for devices materials is 10.71%, for a total costs of 129,634.08€ over 4 years. This cost includes materials for 192 orthoses per year, meaning 160 beneficiaries.

Costs of material for orthoses

If only the costs of materials is included, regardless the type of orthoses, the average cost are the following: 455.80€ per patient and 379.83€ per orthoses. But this average costs hide significant disparities depending the type of orthoses. If only the materials costs is considered, the prices of the diverse type of orthoses are:

- KAFO Adults: 495.5€
- KAFO Children: 477.87€
- KAFO Dynamic Adults: 735.22€
- KAFO Dynamic Children: 717.59€
- AFO Adults: 71.56€
- Seating brace: 96.41€

Imports costs and taxes:

The share of total costs for import and taxes costs is 2.24%, for a total costs of 27,139.81€ over 4 years. The total costs to import 3D material is estimated at 21,773.54€ which represents 1.80% over 4 years.

Alternatives: Use of local materials

Imports costs are significant and could be reduced by using materials found locally.

Human resources:

Human resources is the main costs amongst all categories, it costs 66.67% of the total costs which equals to 806,887.50€ over 4 years. The main cost is allocated to the gross monthly salary (53.29%, or 644,959.86€ over 4 years).

Cost for the mobile team

It has been decided to get a mobile team. This team will travel several time:

- Once per site for the exploratory mission, to contact the CBWs and collect list of potential beneficiaries. This mission is not included in the routine work and pathway.
- 1 trip for identification and general assessment
- 1 trip for clinical assessment and scanning
- 1 trip for 1st fitting
- 1 trip 2nd fitting and delivery

There is approximately one field trip per day, according to the chronogram.

There are some costs linked to the mobile team:

- Vehicle and affectation of this vehicle only for these mobile activities
- Driver
- Fuel
- Maintenance
- Affectation of the team: P&O or PT depending on the purpose of the trip.
- Working time allocated for the planning and organisation of the field trips.

Despite the costs allocated to this mobile team, the benefits are important. Vulnerable and isolated people are given access to orthopaedic services.

Alternatives: Human resources optimisation

HR costs, which are the most significant costs, could be optimised. To avoid a higher cost per patient in the first year, the initial time required to implement and start the 3D printing service must be reduced as much as possible.

The current HR team is specific to Uganda, and could be adapted in another context, by reducing the number of team members. Increasing the number of printers could also be considered to optimise the HR.

The training time before implementing the activity is vital to provide quality services, but also to invest in the skills and efficiency of the team.

2.3. Specific costs allocated to 3D printing services

This cost analysis focuses exclusively on the costs of integrating a 3D orthotic production service into a traditional service. Two main types of costs are to be distinguished:

- Firstly, the costs linked to the increase in the management capacity of the service: the integration of a new service offer obliges to increase the number of health professionals so that the traditional as the 3D services can perform under good conditions. Thus, these are costs that already exist for the traditional service, but which generally become higher when the 3D service will be embedded as more people will work.
- Secondly, the costs that would have not existed if only the traditional service were available: for example, the 3D printers, and for the specific case of Uganda, the costs related to the mobile team (vehicle, fuel, etc.).

Below are presented figures for this second category, i.e. costs specific to the 3D service. These specific costs represent about 26% (322,306 €) of the total costs necessary to integrate a 3D service with a traditional service and are distributed as follows:

- Implementation costs : Building an general investment, fixed machinery, mobile machinery : 4.92 % - 59,570.93€;
- Running cost: Maintenance of technical services, transport costs, electricity and water : 4.29% 51,948.21€;
- Administrative cost : internet and license and training of staffs: 4.46% 54,013.04€;
- Devices materials: 10.71% - 129,634.08€;
- Imports taxes and costs 2.24% - 27,139.81€.

2.4. Costs per patient

Costs per patient would depend on the type of orthosis they would require. The maximum number of patients possible to include in the 3D printing service is 160 per year. This is hence 640 patients over 4 years. If the total costs allocated for 3D services over 4 years (1,210,224.25€) is divided by this maximum number of patients over 4 years (640), regardless the type of orthoses they need, there is an average cost of 1,890.98€ per patient.

Alternatives: Patient's contribution

In another context, it might be relevant to request the patient to pay for the costs of materials to produce their orthoses. This would reduce the service's costs. A social service could support less fortunate patients and ensure an equitable service.

2.5 Costs per orthosis

Cost per orthosis is the sum of diverse variable: cost of material (type and quantity of materials required per type of orthosis, time spent by team members per step of production - from general assessment[41] to delivery[42], but also the traveling time spent by the team per orthosis: 120 minutes on average).

When no data on the time disaggregated by age was available, the average time for the KAFO, regardless of the age, was used. Data was lacking for the seating brace, so the average time required for every device (regardless of the type) was integrated for the clinical assessment, assembly and delivery.

If the total costs allocated for 3D services over 4 years (1,210,224.25€) is divided by the maximum number of orthoses that can be produces (768) over 4 years, regardless the type of orthoses, the average cost per orthoses is 1,575.81€.

[41] For the general assessment, an average duration of 1 hour was taken into consideration, based on the SSI with the HI team and the workshop with ARRH.

[42] The time spent for follow-ups is not included because no data was available.

3. Patient's experience: benefits & challenges

The context of this study did not allow for a financial evaluation of the benefits. . However, beneficiaries' feedback was collected through qualitative interviews and a survey. These provided insights on the mind-set of patients towards digital solution and inform about their preference in terms of care pathway.

3.1. Benefits

One benefit of 3D printing services is to reach vulnerable beneficiaries who would not have had access to treatment with traditional service. Beneficiaries confirmed that go to the primary health centre or the hospital can be challenging for them and highly appreciated to save time and money to get access to care. They were also opened and not disturbed by the use of new technologies during the different phases of the pathway. Some of the patients even forgot the scanning phase when the pathway was reviewed with them. These findings are in line with previous research.[43]

3.2. Challenges

However, this research also highlighted some challenges such as the rate of broken devices.

A questionnaire to collect beneficiaries' feedback from PETRA phase 1 was delivered to 40 people. The results show that:

- 75% (i.e. 30 beneficiaries) of interviews beneficiaries faced complications (75%). Amongst these beneficiaries who faced complications with their devices, 60% suffered of skin irritation (18), 13% had the straps or small parts of their devices broken (4), 3% got their devices stolen (1), 27% think that their devices was not comfortable (8).
- 42.5% responded that their devices broke. According to them, their devices broke at the earliest four days after the delivery, and at the latest eight months after delivery.
- 60% (24) of the 40 beneficiaries did not wear their orthosis, because it was broken, did not fit anymore or was too painful.
- 22.5% of the beneficiaries (9) did not get any follow-up from HI team, including the Community Based Worker.

[43] Daniel Tan. Etude d'impact social de la télé-réadaptation dans le cadre du projet IMP&ACTE 3D : Introduction de la technologie d'impression 3D pour la fabrication d'orthèses en Afrique de l'Ouest. Lyon : Humanité & Inclusion, 2019.

Regardless of the numbers, patients were disappointed. Some expectations were raised at the beginning of the PETRA project, especially amongst mothers of disabled children, and the lack of follow-up left them in an uncomfortable position for the future. Follow-ups are crucial and must always be ensured to produce quality services and to assess the quality of the delivered device. Vulnerable and isolated communities can access orthopaedic services through 3D printing service, but these must provide quality services and devices, and access to physiotherapy sessions. These are crucial to ensure the positive impact of their actions.

Testimony

"[...] The orthosis is rough, it hurts me on the malleolus (showed where), and it can wound me. I wear it, even if it hurts, if I get a wound I stop to wear it the time it heals.[...]" Beneficiary, Omugo

"[...] We didn't get anything good from this 3D printing programme, we only got the orthosis and it broke after 2 weeks of delivery. [...] I even cried when it broke, because it is supposed to help my child.[...]" Mother, Imvepi

"[...] It broke after 2 months and it doesn't fit anymore. I was happy when we received the device, but now it is not working.[...]" Mother, Imvepi

Part 5 – Conclusion

3D printing is an innovative technology that can allow delivering of orthopaedic services to the most vulnerable and isolated families. One of the benefits of this service is its possibility to be conducted remotely at the beneficiaries' home, and to reach families who would not have sought treatment without the mobile aid (either because they are too far from health services or unable to move around because of severe functional limitations, for example).

1. Main findings

This study had several aims: (1) to define and describe the patient pathway to be integrated into an existing and functional public service, in order to (2) size the offer according to an estimated maximum number of patients and orthoses, and then (3) to evaluate the costs of such a service (here proposed over 4 years, the lifetime of the printer, in order to smooth out the implementation costs). This is not a calculation of the functioning costs of an existing service, or an estimate of costs per type of care involving several types of services. HI has developed a tool to address such an exercise (see the RCAF[44]).

In order to conduct a cost analysis on 3D printing services, it is indeed essential to start by clarifying steps of the patient pathways and by identifying related and required resources. In this hypothetical implementation of 3D printing services in the public hospital of Arua, the use of mobile team has been selected for example. Another pathways based on others alternatives would have another cost. Other elements to be included in the preliminary calculations are the demands, the population needs of the area and the material capacity to deliver the services.

This cost analysis of the projected implementation of 3D printing services in ARRH has revealed that to produce 768 orthoses over 4 years, 1,210,224.25€ are required. This is equivalent to 1,890.98€ per patient regardless the type of orthoses. The highest costs incurred are allocated to Human Resources (66.67% - 806,887.50€ over 4 years), followed by device materials (and its import) and administrative costs (especially banking fees and licenses). Moreover, 26,26% of the total costs (322,306.07 € over 4 years) is specifically allocated to 3D printing services that would not be integrated in a traditional service.

[44] https://hinside.hi.org/intranet/jcms/prod_2403688/en/rcaf-toolbox

2. Options for changing this cost

In this case study, the limiting factor of the 3D printing services was the printing capacity. The demand and need within the community surpass the offer and the actual printing capacity. Moreover, the team members are not spending 100% of their working time with the identified setting of implementing 3D service in ARRH. It would be possible to increase the number of printers and beneficiaries while maintaining the same team setup and working space. Additionally, if the number of printers were increased - and therefore the number of devices produced - the costs per beneficiary could decrease. Some costs could also be reduced if solutions like the use of local materials are found.

3. Key elements for a successful implementation

At the time of the study, the public hospital in ARRH was facing operational challenges.

These difficulties enabled the identification of some essential elements for the successful integration of the digital solution, namely (non exhaustive list):

- Politics and hospital direction must support rehabilitation services.
- Materials and budget must be available and sufficient, for both options of production (3D printing and traditional rehabilitation services)
- Infrastructure issues must also be limited. For instance, electricity must be reliable (with a generator and batteries), and WIFI must be accessible.
- 3D printing requires good logistical organisation and support to avoid any delay in materials procurement and to maintain a patient centred approach that respect the delivery timeframe. If a logistics department is not available, an external organisation could support the service in these tasks and responsibilities and could be highly beneficial.
- Strengthen capacity building of all staff involved in the patient pathways (PTs on identification (orthopaedic devices needs and referral to other services); P&Os on scanning, designing, printing and general knowledge on orthopaedic devices; …)
- Include the follow-up of the patients (if the device broke or hurts, if rehabilitation exercises and/or psychosocial support are necessary…)

4. Replication of such a cost analysis & research perspectives

This cost analysis is based on the Ugandan case study, but its principles and lessons learned can be replicated to other countries. The detailed presentation of the different phases, the hypotheses and choices made in terms of care, service functioning, logistics, etc., the mention of alternatives, as well as the availability of the calculation matrix itself, are all elements that could enable a third party to reproduce the exercise in a new context. Generated information could help deciders to make an informed-based decision to invest 3D printing services in public services or not.

5. To be continued…

This study shows a detailed approach to evaluate the costs of delivering 3D printed orthoses. However, based on the results of this study and the high rate of complication after delivery, all future researches should include the follow-up and not only until the delivery.

If future researches allow measuring the impact of this innovative solution, on health staff and/ or on patient, it would be interesting to conduct cost effectiveness analysis or cost benefit analysis. This type of analysis would allow us to take into account aspects not covered here but which we know are essential, such as the (comparative) quality of the brace produced, the gains for the patient in terms of pain reduction, a reduction in complications, to name but a few.

Appendice 1: Details of the calculation

1. Initial calculations

1.1 Catchment area, surface and population total for six districts

There is no up-to-date data on the surface area per district. The districts have been reorganised multiple times in the country.

According to data in 2016, the surface area of the districts are[45] :

- Arua (and Terego): 4,343 km²
- Maracha : 1,572 km²
- Nebbi (Madi Okollo, Pakwach): 1,915 km²
- **Total**= 7,830 km²

According to the Ugandan Bureau of Statistics, the approximate population in the districts in 2020 is:

- Arua (and Terego): 751,000
- Maracha : 208,300
- Nebbi (and Pakwach): 196,800
- Madi Okollo:164,200
- **Total**= 1,320,300

1.2 Mobile team: number of patients per phase and per day

- **Identification and general assessment**: No data on the general assessment and identification. Time estimated with the help of P&O PT and CBW. Approximately 1h per patient ➔ 4 patients per day per PT, including travel time (2hours in average way and return).
- **Clinical Assessment and Scanning**: Clinical Assessment : time median= 33min ; Prescription and scanning, every devices confounding: time median= 29 min per device ➔ 1.2 orthoses per patient ➔ 29 *1.2 = 34.8 minutes per patient
  - Addition Clinical assessment and scanning = 68 minutes. Slight increase to reinforce the communication of the team and the psycho-social support to the family ➔ 3 patients per day per PT and OT, including the travel time.
- **Designing**: Every devices confounding, time median= 62 minutes per orthosis. ➔ 62x1.2 = 74.4 minutes per patient. ➔ 4.5 patients per day per P&O.
- **Printing time**: Time median: 45.7 hours per device ➔ 45.7x1.2 = 54.8hours per patient ➔ 0.5 patient per day ➔ 1 patient per day with 2 printers.
  Maximum 4 printings in 1 week, maintenance on Fridays by 1 P&O.

[45] https://africaopendata.org/dataset/size-of-uganda-districts-in-square-kilometers

- **1st Fitting**: Time median: 18 minutes per devices ➔ 18x1.2 = 21.6 minutes per patient. Increased to develop the communication and overcome some data collection challenges ➔ 30minutes per patients. ➔ Including of the transport time : 6 patients per day per P&O.
- **Assembly and modification**: Time median: 69.5 minutes per device ➔ 69.5x1.2 = 83.4 min per patient ➔ 3.5 patients per day per P&O.
- **2nd Fitting and delivery**: Time median: 30 minutes per device ➔ 30x1.2 = 36 minutes per patient. Time increased to ensure advise, rehab exercises are shared, schedule for the physiotherapy is organised and to respect a good communication. ➔ 1h30 per patient. ➔ 3 patient per day per P&O and PT.

1.3 In ARRH workshop: number of patients per phase and per day

- **Identification and general assessment**: 1h per patient ➔6 patients per day, per P&O.
- **Clinical assessment, scanning:** Identical time median done by the mobile team. Subtraction of the travel time ➔ 5 patients per day, 1 P&O and 1 PT.
  After this step half of the patient (2.5) will chose traditional services, and the other half will stay in the 3D services. This information was included in the chronogram.
- **Designing and printing time:** Same time median and patient per P&O as the mobile team.
- **1st Fitting and assemblage**: 2Hours per patient ➔ 3patients per day per P&O
- **2nd Fitting and delivery:** 60 minutes per orthoses ➔ 60x1.2= 72 minutes per patient ➔ 4 patients per day per P&O and PT.

2. Costs calculation per finance categories – Additional information

2.1 Running costs

Maintenance of technical services:

The maintenance costs are based on HI budget for every programme. When this budget was determined, there were 4 programmes running in Arua. Therefore, the total has been divided by 4 ➔ Budget of 6,000,000 divided by 4 programmes = 1,500,000 UGX per year for the maintenance of the office.

The costs for the maintenance of the AC is the same as HI's.

The lifespan of the drill machine has been reduced to compensate the fact that the battery will not be changed ➔ Drill machine – vertical: 13 years lifespan; Cordless drill machine: 8 years

Transport utilities:

Costs are different if the service uses a rental car or if they buy a car. Based on PETRA, HI programmes in 2021 and 2022, costs to rent a car, including insurance and maintenance is 15,517.21€ per year. If the 3D printing service buys a car, the costs of maintenance for a car are approximately 209.48€ per year and the insurance is 1,862.06€ per year. These costs can variate according to the state of the car, the use and the reparation needed. HI bought for other programme a Toyota double cabin Hilux which cost 3,669.11€ when they bought it. However, for 3D activities, it is recommended to use a car with more seating places.

According to the context and the information shared during the workshop with ARRH staff members, the hospital can and should buy a car for the 3D printing service. Furthermore, it would be less expensive on a long term.

The total cost for fuel over 4 years for this 3D service is 17883.67€

Fuel – Distance covered:

Calculation of the fuel needed for the service, based on the cost of fuel per L, and the average distance the mobile team will have to travel.

The distance the team will travel would be 2h hour including the return per day. The distance to cover is maximum 2hours drive from Arua. There is no minimum because a beneficiary might live next to the hospital but would be unable to move to the hospital. That is why the average traveling time done by the mobile team is 2H including the return.

Calculation for the needs of fuel:

Travel done by the mobile team = 1h for one way in average
In 1 hour, from ARRH, the team can travel in average 0.83 km/min, driving at an average of 50km/h (based on the distance, the time and the average speed drove by HI team).
The average consumption of fuel by HI driver (from year 2021, and January to April 2022, by 3D programme), is 0.1732L/Km.
Cost of 1L of fuel on May 2022: 1L= 4150 UGX

- ➔ For 1hour: 0.1732*50 = 8.67 L/hour
- ➔ Including return: 8.67*2 = 17.35 L/day
- ➔ Litre per month: 17.35*20= 347.14 L/month
- ➔ Cost per month: 347.14*4150 = **1440632.31 UGX / month for the fuel**

Electricity and Water:

- Fuel for generator: Monthly costs = 810480 UGX = 209.61€
- Repair generator, replacement of oil pressure ➔ 881400 UGX = 227.95 € to carry out every quarter
- Repair generator, general repair, overhaul of the engine ➔ 770000UGX = 199.14€ every year.

The total amount water bills for the full office in Arua, divided by 4 (number of programmes run by HI in Arua) ➔ 150,000/4 = 37.500 UGX per month.

2.2 Administrative costs

Stationery and office supplies:

The list of office supplies, small equipment and stationery are based on a monthly list given by HI - Arua, and adapted to represent the needs of a 3D printing service only. The quantity of items and costs were listed for a period of 1 month.

Exceptional travel costs:

Two persons from the 3D team go every quarter to Kampala for a technical meeting.

- 3 nights in Kampala, for 2 people, 20€ per person per night ➔ Total of 120€ per travel
- Per diem: Per diem in Arua per day : 55000UGX/day , per diem in Kampala : 65000UGX/day If 2 people go to Kampala for 4 days, per diem for Kampala = 65000UGX*4= 260000UGX= 67.24€ per person for 4 days ; 132.48€ for the two people.
- Usually needs two car for a kiss and drive, double the gasoil price = 300€ per travel.
- Salary of two daily drivers = 51.72€ per travel.

Cleaning materials and kitchen provision:

For every item: list of materials ordered every 3 months. Divided by 3 to have the costs and order per month, and then divided by 4 (the number of HI programme in Arua), divided by 2, because it was the list for Omugo and Arua office. Multiply per 12 to have the total for 1 year.

Banking fees:

The average banking fees, regardless the transaction range and type of receiver is 4.15%. This percentage has been applied for every line.

2.3 Devices materials, components

Materials for 192 orthoses per year, meaning 160 beneficiaries.

Filaments:

Spool of 2 kg, according to the information from HI report. 924 m per spool of 2 kg.

Mass = m = 2kg = 2000g
Density = ρ = 0.9g/cm^3
Diameter = D =0.175cm
Radius = r = D/2 = 0.0875cm
Length filament = L = ?

$$Volume\ of\ filament: V_{filament} = \pi \times r^2 \times L$$

$$\rightarrow L_{filament} = \frac{V}{\pi \times r^2} \quad (1)$$

$$Density: \rho = \frac{m}{V}$$

$$\rightarrow V = \frac{m}{\rho} \quad (2)$$

$$\rightarrow (2) \text{ into } (1): L_{filament} = \frac{\frac{m}{\rho}}{\pi \times r^2}$$

$$L_{filament} = \frac{\frac{2000}{0.9}}{\pi \times 0.0875^2} = 92389\text{cm} = 924\text{m}$$

16 devices per month, average need: 129.35 m per device ➔ 2070 m per month ➔ 2.23 spool per month ➔ 27 per year

Table 6– Quantity of materials required for 192 devices

Item	Explanation and calculation
Woods	Bought directly to carpenter after the seating brace has been printed and fitted. Costs in phase 1: 2020 and 2021: 910000 UGX for 7 seats; 520000 UGX for 4 seats ; 6500000 UGX for 50 seats. ➔ Average price for 1 seat = 130 000 UGX = 33.62€
Webbing	Average 1m per seating brace.
Velcro, hook and loop 300x25mm Brown	Back-up for seat, 10 per year
Velcro(spec: Type : Astrakan (Female), Width : 40mm, Length : 50m, Colour : blue)	With one Velcro can do approximately 10 seats ➔ 3 for 30 seats for 2 years.
Proteor - 10 Cotton strap, rigid	10 for 50 seating braces ➔ 3 for 15, combined with the other straps, parts.
Tibular Rivet - 8,5mm Ø Head, 4mm Ø Tube, 11mm Height	12 per KAFO, for children. 70% of KAFO for children ➔ 41 KAFO for children ➔ 41*12=492/year
Tibular Rivet - 10,5mm Ø Head, 4mm Ø Tube, 15,6mm Height	12 per KAFO, for adults 30% of KAFO for adults ➔ 17 KAFO for adults ➔ 17*12=204 /year
Steel locks KAFO 14mm	2 per KAFO ➔ 58*2 ==> 116
Side bars, Adult CRE 721.1	2 per KAFO ➔ 17 KAFO for adults ➔ 34 side bars for adults
Side bars, Child CRE 722.1	2 per KAFO ➔ 41 KAFO for children ➔ 82 side bars for children
Tamarak Joint, Adult (Becker Orthopaedic - 742-L-75 ; Ankle flexure joint + dummy pairs(1 kit = 5 pairs))	2 per dynamic KAFO. 58 KAFO produced per year ➔ 34% of these 58 KAFO will be dynamic KAFO ➔ 20 dynamic KAFO per year ➔ 30% for adults ➔ 6 dynamic KAFO for adults. Needs of 12 Tamarack joint adult size. Kit of 5 pairs ➔ 3 kits (for a total of 15 pairs / 30 tamarack joint) every 2 years.
Tamarack Joint, Child (Becker Orthopaedic - 742-M-75 ; Ankle	2 per dynamic KAFO. 58 KAFO produced per year ➔ 34% of these 58 KAFO will be dynamic KAFO ➔ 20 dynamic KAFO per year ➔ 70% for

flexture joint + dummy pairs (1 kit =5pairs))	children ➔ 14 dynamic KAFO for children. Needs of 28 Tamarack joints children size. Kit of 5 pairs ➔ 3 kits (for a total of 15 pairs /30 tamarack joints) every year.
Press Rivets	For every devices: in average 4 per AFO, 8 for KAFO, 10 for seats, depends on the number of straps ➔ AFO : 4 * 115 = 460 ➔ KAFO : 8* 58 = 464 ➔ Seating brace : 10*15 = 115 ➔ Total = 1039 Box of 1000 ➔ 5 boxes every 4 year
Velcro Straps with buckles (Ready made), Small	per devices, AFO in average 2 max , KAFO : 4 in average, seating braces: 0 ➔ 115 AFO per year, 70 % small for children ➔ 81 AFO for children X 2 ➔ 162 Small Velcro straps with buckles 58 KAFO per year , 70 % small for children ➔ 41 KAFO for children ==> 82 Large Velcro straps with buckles ➔ Total = 244 / year
Velcro Straps with buckles (Ready made), Large	Per devices, AFO 2 max , KAFO : 4 in average, seating braces: 0 ➔ 115 AFO per year, 30 % large for adults ➔ 35 AFO for adults X 2 ➔ 70 Large Velcro straps with buckles 58 KAFO per year , 30 % large for adults ➔ 17 KAFO for adults ➔ 34 Large Velcro straps with buckles ➔ Total = 104 / year
Nuts HT metric 4mm	Temporary before putting on the Tibular rivet + total of tibular rivet needed ➔ 492+204 = 696 per year
Foam EVA, 3mm blue	40 m2, Average needs for 200 devices, according to PM based on experience and phase 1
Foam EVA, 6mm blue	15 m2, Average needs for 200 devices, according to PM based on experience and phase 1
Buckles	Use the already made 50 per year
Leather for device assembly	1 for 50 devices➔ need of 4 for 1 year
Leather sheet	50m for 200 devices per year
Sheet of micro cellular rubber	1 for 50 devices ➔ 4 per year
Bolts HT metric 4x60MM	Total tibular rivet = +/- 700 per year

Nylon stockings and Shoes for beneficiaries:

In this context, the majority of people cannot afford to buy stockings nor shoes. For the ideal use of the orthosis, every beneficiaries must receive stockings and shoes.
One pair per beneficiary ➔ 192 devices ➔ 160 beneficiaries and hence 160 pairs of shoes and stockings.

2.4 Imports costs and taxes

3D printers:

The imports and transport costs of 3D printers are based on the costs in phase 1 to import and deliver the 3D printers to Arua, including a truck to transport the printer from Kampala to Arua. The cost total is 5366 €

3D materials:

The **storage** at the airport depends on the number of days and the quantity of materials stored. The cost used in the analysis is based on the average costs from phase 1 and 2 = (46.01+10.90)+603)/2 = 329.96€

The **shipping** costs are based on the costs in phase 1: to import materials for 50 orthoses for a total of 1051.2€ (60+35+397.45+530+28.75) ➔ total multiplied by 3.84 to have the approximate costs of materials for 192 orthoses for 1 year = 4036.6€

The **duty customs clearance** taxes is based on the costs in phase 1 : 128.49+217.90= 346.39€

Bioport documents used in phase 1 have been added up: 20+33+23.64 = 76.64 €

Appendice 2: Templates of questionnaires

Here the list of the shared guides:

- Beneficiaries feedback
- Physios' direct feedback (evaluation of the scanning practice) Physios – Direct feedback
- Data collection – Team instruction on how to collect data on time
- Process 3D printing – Data collection tool (word format, used on Survey CTO
- Travel form – Collected on Survey CTO
- Interview guides (CBWs, typical week, physiotherapists, printer technician, beneficiaries, GRRH, CoRSU)
- Workshop with ARRH - Agenda

1. Beneficiaries feedback

Satisfaction towards beneficiaries of 3D printing orthoses – PETRA programme

Beneficiary ID: Zone:

Date of delivery: Date of the survey:

Type of orthosis: Beneficiary's age:

Questions

1. Did you face any complications? Yes or No

1.a. If yes, what kind (several answer possible):

Orthosis broke Straps broke Skin irritation Judgment amongst the community Too difficult to put the orthosis on Device not comfortable Too heavy

Other, specify:

1.b. If the orthosis broke :

After how many **days or months**:______________________

What did you do? Informed CBW Went to a health facility Waited Nothing Other, specify:

2. Do you still wear your 3D printed orthoses? Yes or No

2.a. If No, why ? Does not fit anymore Broken Painful Do not like it Judgment in the community Take too much time to put it on Too heavy Make me walk slowly Other, specify:

3. Have you received any follow-up after the delivery orthosis? Yes or No

3.a. If no, do you think you would have needed any follow-up after the delivery? Yes or No

2. Physios' direct feedback (evaluation of the scanning practice)

Date:
Name :
Number of staff members present during the scanning:
Number of people from the family or community present during the scanning:

On a scale of 1 to 10... 1 being terrible and 10 being amazing

1. How did you feel while introducing and explaining the 3D programme to the patient? ...... / 10
2. How did you feel while carrying out the assessment of the patient? ...... / 10
3. How did you feel while carrying out the scanning? ...... / 10
4. How would you rate the care you provided to the patient? ...... / 10
5. How was your therapeutic relationship with the patient? ...... / 10
6. How enthusiast did the patient seem regarding the 3D technology? ...... / 10
7. How comfortable do you think the patient was during the assessment? ...... / 10
8. How comfortable do you think the patient was during the scanning? ...... / 10

3. Data collection – Team instruction on how to collect data on time

Table given and printed in landscape orientation and fitting on one page for the data collection team.

How to collect data on time

Legend:

- Green = Instruction on when to start the timer
- Red = Instruction on when to stop the timer
- Blue = Instruction on how to report

Note : all the time entries **must** be written in this format **__h__min** The minutes must **ALWAYS** be specified.		
Steps	**Person in charge**	**Roles in data collection + Explanation**
Travel time	**EVERYONE**	Fill the travel form for **every trip completed**, by car or on foot, **one form per trip** (not one per person). From a place A to a place B, or from a place B to a place C. For example: • From HI office to the camp (1 form per car) • From the first beneficiary's house to the second beneficiary's house (1 form per team)
Identification	CBW	Start the timer when arrived at the beneficiary's place. Includes greetings, explanation of the programme, etc. Stop the timer when you leave the beneficiary's place. Not included at this stage of the research.
Clinical Assessment	Physio	Start the timer when arrived at the beneficiary's place. Stop the timer when you leave the beneficiary's place. Fill the form on Survey CTO directly after the clinical assessment.
Second assessment	PM	Start the timer when arrived at the beneficiary's place. Stop the timer when the second assessment is done. Fill the form on Survey CTO directly after the assessment.
Prescription	PM	• If the prescription **is not** done at the same time as the second assessment: Start the timer when arrived at the beneficiary's place.

		• If the prescription **is** done at the same time as the second assessment: Start the timer when the second assessment is completed and you will start the prescription. For both cases: Stop the timer when the prescription is done. Fill the form on Survey CTO directly after the prescription.
Scanning	PM and Physio	• If the scanning **is not** done at the same time as the second assessment and the prescription: Start the timer when arrived at the beneficiary's place. • If the scanning **is** done as the same time as second assessment and the prescription: Start the timer when the prescription is completed and you will start to explain the scanning and the next steps to the beneficiary or the family. • The scanning duration includes the explanation, positioning of the beneficiary, etc. Stop the timer when you leave the beneficiary's house. Fill the form on Survey CTO directly after the scanning.
Designing	PM	Start the timer when you opened the software to design the orthosis. Stop the timer when you send the design for printing. Fill the form on Survey CTO after the designing.
Printing	Printer Technician	**2 timers:** • Time of operating printer – Total duration of the printing: o Start the timer when the printing is launched and starts. o Stop the timer when the device is printed and removed from the printer. o Fill the form on Survey CTO directly after the printing. • Time of the printer technician: o Start the timer when you entered in the printing room to launch or monitor the printing of a device. o Stop the timer when leave the printing room to work on other tasks. o Addition all the working time spent in the printing room per devices (can be over multiple days; for example: if the technician went to the printing room for more than one day, the timing is taken for the two days and we add them up). o Fill the form on Survey CTO when the devices is printed and ready to be sent for fitting or assembly.

Fitting	PM	Start timer when you arrived at the beneficiary's place. Stop timer when leave beneficiary place, or if you conduct the adjustment on the field, stop the timer when you start the adjustments. Fill the form on Survey CTO after the first fitting.
Adjustment - Modification	PM	Start timer when you started the adjustment for the device. Stop timer when adjustment is completed, or when you leave the beneficiary's house. Fill the form on Survey CTO after the adjustment.
Assembly	PM and ARRH	Start timer when arrived at ARRH workshop to carry out the assembly, for the 1st assembly of the day. If there is more than 1 assembly for one day, start the timer when you started the assembly. Stops timer when the assembly is completed for the device. Fill the form on paper by ARRH and on Survey CTO by the PM after the assembly.
Second fitting (or 3rd)	PM	Same as the 1st fitting.
Delivery	PM or Physio	• If device is delivered at the same time than the fitting, write this information : delivered when carried out the (1st or 2nd or 3rd) fitting. • If delivered later, start the time when you arrived at the beneficiary's house. Stop the timer when you leave the beneficiary's house. Fill the form on Survey CTO after the delivery.

4. Process 3D printing – Data collection tool (Word format, used on Survey CTO, with additional questions on Survey CTO)

Beneficiary's HI ID:

Type of orthosis:

Clinical assessment - PT

- Date:
- Duration of the first clinical assessment: ______H______Min________
- Number of staff members present for the assessment:
- Positions of staff members:
- Location of the clinical assessment (HI fixed point, home, ARRH):
- Challenges faced:

2nd Clinical assessment – PM

- Date:
- Duration of the second clinical assessment: ______H______Min________
- Number of staff members present for the assessment:
- Positions of staff members:
- Person who did the 2nd assessment:
- Location of the clinical assessment (HI fixed point, home, ARRH):

Prescription

- Date:
- Person who prescribed:
- If no prescription, reasons why:
- If no prescription, is the beneficiary is referred? Where to?
- Duration of the prescription:

Scanning

- Date:
- Duration 3D scanning: ______H______Min________
- Number of staff members present for the scanning:
- Positions of staff members:
- Position of the person who did the scanning:
- Location of scanning:
- Beneficiary alone for the scanning?
- If no, how many people and who are accompanying the beneficiary:
- Challenges faced:

Designing

- Date:
- Time taken for the designing: ______H______Min________
- Person involved in the design (profession : OM, consultant, etc.):
- Challenges faced:

Printing

- Date:
- Time taken to print: ______H______Min________
- Position of HI staff member present (Printer technician, PM, etc.):
- How long was the person present for? ______H______Min________
- Issue during the printing (Yes - and details of the issue - or no) :

- Reaction (restart from beginning, ...):
- Quantity of filament used:
- Printer used (small or big):

Assembly

- Date:
- Time taken to complete the assembly: ______H______Min________
- Number of staff members present for the assembly:
- Positions of staff members:
- Number of HI staff members present for the assembly:
- Positions of HI staff members:
- Location of the assembly:
- Challenges faced:

First fitting

- Date:
- Time taken for the 1st fitting: ______H______Min________
- Number of HI staff members present for the 1st fitting:
- Positions of HI staff members:
- Location of the 1st fitting:
- Does it fit ? If no, why?
- Next step taken (Adjustment, rescanning, redesigning, reprinting, discharge?):
- Time taken for the adjustment: ______H______Min________
- Number of HI staff members present for the adjustment:
- Positions of HI staff members:

Second fitting

- Date:
- Time taken for the 2nd fitting: ______H______Min________
- Number of HI staff members present for the 2nd fitting:
- Positions of HI staff members:
- Location of the 2nd fitting:
- Does it fit? If no, why?
- Next step taken (Adjustment, rescanning, redesigning, reprinting, discharge?):
- Time taken for the adjustment: ______H______Min________
- Number of HI staff members present for the adjustment:
- Positions of HI staff members:

Delivery

- Date:
- Time taken for delivery: ______H______Min________
- Number of HI staff members present for the delivery:
- Positions of HI staff members:
- Walking test done? If yes duration of the test : ______H______Min________
- Test passed?
- If no, action taken (referral to PT session, reassessment, referral to health facilities, rescanning, etc.):

5. Travel form – Collected on Survey CTO

Travel Follow-Up

Date (dd/mm/yyyy):

From (HI office, camp XX):

To (HI office, ARRH, camp XX):

Departure time (...h...):

Arrival time (...h...):

Traveling time (...h...min):

Travel by car or on foot:

If by car...

- **Number of people in the car:**
- **Number of people in the car traveling for the 3D printing programme:**
- **Profession / Position of passengers working on the 3D printing programme:**

Reason of travel (Clinical Assessment, fitting and delivery , etc.):

Problem faced on the way (accident, no gasoil, flat tyre, etc.):

Number of beneficiaries met:

6. Interview guides

Similar base for every interview guides:

Introduction - Welcoming

Thank you for joining us today and for participating to this evaluation. We truly appreciate your participation; your feedback is crucial and so important.

Objectives

We are conducting a cost analysis on the 3D printings services in Uganda, PETRA project. This discussion will allow us to better understand the costs, challenges, added value, and impact of the programme and 3D orthoses.

Organisation

The discussion will not be more than 1 hour. You are free to stop the interview or leave whenever you want. The participation in this analysis is your choice, and your participation is voluntary. If you do not wish to answer a question, you may decline to do so and we will move onto a next question. However, we encourage you to share your feedback and to try to participate. The information you will share will be crucial for us and to help other people in future programme.

Addition, when this is an interview with beneficiary or stakeholders: If you have any questions about us or the work we do, you can ask us any time.

Procedure

Please note that there is no good or bad response to our questions, and no good or bad opinion. We are sincerely interested in learning about your feedback of 3D printing services and to have more information on the programme.
Addition, when this is an interview with beneficiary:

Unfortunately, apart from our sincere appreciation, we cannot promise you anything in exchange for your participation in this analysis. The participation in this analysis does not guarantee your selection in future HI activities nor should it have a negative effect on your involvement in ongoing activities.

Confidentiality

Your name will not appear in our evaluation and no one will be able to identify what you shared with us. Everything that you will share will stay anonymous. Your identity will not be shared and you will not be negatively impacted by this evaluation.

I will be taking note, to ensure I will not miss any information you share and to ensure a good analysis of this information. So do not be surprise to see me writing.

Seek verbal informed consent

Do you have any questions? Do you agree to participate to this evaluation?

Questions

See the questions bellow, according to the profile of the person interviewed.

Conclusion

Thank you for your time.

This discussion was really interesting and helpful. All the information you gave to us was important for us to understand the context and the challenges of the 3D printing programme. I hope you also found this discussion interesting. We would like to remind you that this discussion will stay anonymous.

Have a good day.

Community Based Workers (HI)

Topics	Questions	Sub-questions
1. Patient's pathway	*Review of the patient's pathway – steps of 3D printings service*	*Correction – Additional information* *Time, challenges*
2. Impact of 3D printing on the practice (in person)	When did you start to work with HI? Can you tell me challenges that you faced while conducting your work/ identifying patients for 3D programme?	How do you conduct the assessment? How long does it take?
	How do you feel when carrying out the identification of beneficiaries?	Are you confident in identifying beneficiaries? Why? How long do you think it took you to feel confident and quick in your work?
	Have you received any training on the identification of a beneficiary for the 3D printing programme? For the assessment?	How long was the training? How many days? What did you think of the training? How has your practice evolved since you have received a training?
	How was the identification of patients for phase 2? Can you go through the whole process with me please.	How long does it take to identify 1 patient? How do you process?

		How was the organisation for phase 1 different?
	Are you involve in any other steps of the programme, other than the patient identification?	Are you involved in awareness sessions on rehabilitation needs and services with the community? Are the community willing to receive 3D printed orthoses? Would that be different if it would be traditional orthoses?
	How is the reaction of the community when you talked to them about 3D printed orthoses?	Have their perceptions and reactions changed since the beginning of HI's programme?
	What could be better in the organisation?	What could we improve?

Typical day/week – Physiotherapists, Printer technician and PM

Questions	Sub-questions	Comments
When do you start your workday? (time) What do you do first?	What are you doing after that? Etc. When? How long does it take?	**Use of the 24h activity chart**
Would the second day be the same? What would be different? Why? How does a workday differ from another?	Is there any specific tasks you have to do every day? What is the most time-consuming task?	**Use of the 24h activity chart**
What is a typical week? Can you please describe a typical week, the tasks you have to do day by day. Are your weeks similar one to another? If no, 'how would it be different? Why?	What is the most challenging part of your week?	
What do you wish to be different in your week?	What do you wish to be different, more generally, in your work?	
Do you think you could be more efficient in your work? How?		
Could you tell me the main challenges you are facing with the printer? Could you tell me a story of a moment, your experience when there was an issue with the printer, what happened and what you did? It can be a small or big story.		

24h activity chart

Time	Activity	Duration	Change from one week to another

Printer technician

Topics	Questions	Sub-questions
1.Patient's pathway	*Review of the patient's pathway – steps of 3D printings service*	*Correction – Additional information*
2.Typical workday/week	*Interview guide – Typical day/week*	
3.Maintenanace	Have you received any specific trainings? How was the training you received?	
	You said you were doing the cleaning of the 3D printers after every printing, is that right? Who asked you to do this? How long does it take?	Have you received any clear instructions from WASP? *Or do you only use the general manual instruction of the printers?* Have you read any instruction or guidelines on the maintenance of 3D printers?
	What other types of maintenance have you been doing in the last year? How long does it take?	
	What are the most frequent challenges with the printers? Have you ever had any issue with the printer?	Ask the following questions for every problem mentioned: What happened? How many times has this problem happened in the last month? Last year? What did you do to fix this problem? How did you seek for help? Who did you contact? What did they do? What did you do while waiting for the printer to be fixed? How long did it take to find a solution and fix it?
	What is your reaction when there is an issue with the printer while printing an orthosis?	**Situation/Example**: The generator stops working while

		there was a printing ongoing, what do you do? Or opposite situation, the generator works but the printer stops working while printing. What do you do? What is the frequency of this problem? How many times has it happened in the previous month? In a year?
	Has there been any issue with the printer due to the climate condition? For example, formation of rust on some parts of the printer? Or overheating and burning of some parts of the printer? Is there any issues with the printer due to the dust? Due to the humidity? Is there any specific rules you have to follow regarding the climate condition?	How frequently? What type of materials? Do you have any in stock? What do you do in the meantime? What are the parts of the printer that are more likely to break or face an issue? How often has this problem occurred? What did you do?

Physiotherapists

Topics	Questions	Sub-questions
3. Patient's pathway (remotely)	*Review of the patient's pathway – steps of 3D printings service*	*Correction – Additional information*
4. Typical workday/ week (in person)	*Interview guide – Typical day/week*	
5. Impact of 3D printing on the practice (in person)	Have you received any training on the assessment of a beneficiary for the 3D printing programme? For the scanning?	How long was the training? How many days? What did you think of the training? How has your practice evolved since you have received a training?
	How do you feel when carrying out the assessment of beneficiaries?	Are you confident in assessing beneficiaries? Why?

		Has your practice of assessment has changed since the 3D printing programme?
	How do you feel with the use of the scanner?	Would you like to be more involved in the scanning process?
	What do think of 3D printing?	What is different in your practice since you work with 3D printing?
	How do you think the 3D process has changed your contact with the patient and their care?	Do you think the 3D printing programme improves the patient care? How?
	Do you spend more or less time with the patient since the use of 3D printing? Why? How?	

Beneficiaries

Note

The first task on the first day in the refugees' settlement is to introduce ourselves to the person in charge. We will also explain the objectives of the study, the reasons of our presence, and seek their permission.

Use of visual content, images that explain the steps of the patient's pathway.

Topics	Questions	Sub-questions
Patient's pathway	How did you hear about the programme?	Would you have sought orthopaedic services by yourself without HI's services? If no, why? If yes, where? How would you go there?
Identification	How was your first contact with a CBV?	How long was it? How did you feel? (Comfortable, uncomfortable, did not want this service at first, happy, etc.)
1st Clinical assessment	What happened next? How was your first contact with PTs and PSS?	How long was it? How did you feel? (Comfortable, uncomfortable, happy, etc.)

2nd assessment and Scanning	What happened next? How was your first contact with the technical team who did the scanning?	How long was it? How did you feel? (Comfortable, uncomfortable, happy, etc.)
Fittings	What happened next? How did you feel when you/your child tried the device for the first time?	How long was it? How did you feel? (Comfortable, uncomfortable, happy, etc.)
	How many times did the team come to make you try the device before you could keep it?	What did you think of these fitting steps? (Too many, too long, too many times before getting the device, etc)
Delivery	What happened next? How was delivery?	How long was it? How did you feel? (Comfortable, uncomfortable, happy, etc.)
FU	Did the team come back to see you and to check if there was any problem after the delivery of the device?	If yes, how many times? Who did come? If no, would you have preferred that they would come?
	What would you do if you had a problem with the orthosis?	How would you communicate the problem? What would happen after you communicate the problem? Has this already happened? Can you give an example?
Perception, first feedback	What do you think of your / your child's 3D printed orthosis? What do you think of the 3D printing service?	What could have been better with your 3D printed orthosis? Have you faced any issue with your orthosis? (Broke, lack of cushions or straps, comfortable, pain free?)
Feedback on service How to improve the 3D printing programme	What could have been better in the process of the 3D programme?	What went well? What did you appreciate in the process of the 3D printing service that you would not have had with the traditional service?

		What could be improved? Have you been feeling uncomfortable in the process? When ? Why?
Comparison between traditional orthosis and 3D printed orthosis.	What do you think of the 3D technology?	Does it change anything for you that the service uses 3D printing technology? Why? Would you have preferred a traditional service? Why?
	Have you ever had a traditional orthosis?	What difference did you feel between the two orthoses?

Gulu Regional Referral Hospital

Topics	Questions	Sub-questions
Visit of the orthopaedic workshop and physiotherapy room.		
Thoughts on 3D printing	What do you think of the 3D printing services to provide orthosis in this context? In general?	
Challenges	What are the challenges that you are facing to produce traditional orthoses?	How do you overcome these challenges?
Patient's preferences	Do you think the patients are willing to receive a 3D printed orthosis? Would they prefer traditional orthosis? Why?	
Waiting time	How long is the waiting time between the identification and deliver of orthosis when using the traditional method?	
Identification	How are the patients identified?	Is there a specific team assigned to the identification of patients? Do patients come by themselves? Reputation of their 3D printing services? Do they conduct awareness sessions on orthopaedic needs/ 3D printing services?

Costs	Do you reimburse the patient trip to the hospital? Do they stay the full time at the hospital?	**Organisation and location of the different steps in the patient's pathway**.
Patient's pathway	Review of the patient's pathway for traditional services, and projection for the 3D printing services.	
Materials	How do you provide with your materials for the production of orthosis? printing services? Example: assembly material: straps, leather, etc.	What are the pieces of materials imported? What are the pieces of materials bought locally? How long is the waiting time to receive the materials?
Projection	How would imagine the organisation if you would implement 3D printing in addition to your services?	Would identify beneficiary on the field? Where would you do the assessment and scanning?

CoRSU

Person	Questions	Sub-questions
Visit of the hospital, orthopaedic workshop and physiotherapy room.		
Director	When did you start working at CoRSU?	Have you participated in the development of 3D printing services?
	What was the main goal of developing 3D printing to produce prostheses? Why have you decided to use the 3D printing technology?	What was the motivation of developing 3D printing?
	How big is the team involved in the 3D printing services? What type of training have you provided to your team working on the 3D printing services?	Big ? Small? How many people? Type/Topics of training, duration of the training
	How are the patients for 3D printing services identified?	Is there a specific team assigned to the identification of patients? Do patients come by themselves? Reputation of their 3D printing services? Do they conduct awareness sessions on orthopaedic needs/ 3D printing services?
	Do you reimburse the patient trip to the hospital? Are you doing the scanning at the beneficiaries' houses? At your hospital?	Organisation and location of the different steps in the patient's pathway.
Director and Printer technician	What are the challenges that you are facing to produce 3D printed orthoses?	What are the main challenges of the 3D printing services? How do you overcome these challenges?
	Are the patients willing to have a 3D printed orthosis? Do they prefer traditional orthosis? Why?	

	How do you provide your materials (example filaments) for the 3D printing services?	What are the pieces of materials imported? What are the pieces of materials bought locally? How long is the waiting time to receive the materials?
Printer technician	Have you received any specific trainings? How was the training you received?	
	Could you tell me the main challenges you are facing with the printer? What types of maintenance are you doing on the printers? How long does it take?	
	What are the most frequent challenges with the printers? Have you ever had any issue with the printer?	What happened? How many times has this problem happened in the last month? Last year? What did you do to fix this problem? How did you seek for help? Who did you contact? What did they do? How long did it take to find a solution and fix it? What do you do when there is an issue with the printer while printing an orthosis?
	Has there been any issue with the printer due to the climate condition? For example, formation of rust on some parts of the printer? Or overheating and burning of some parts of the printer? Is there any issues with the printer due to the dust? Due to the humidity?	How frequently? What type of materials? What are the parts of the printer that are more likely to break or face an issue? How often has this problem occurred? What did you do?
	What materials do you have in stock?	Why these materials?

Physio, involved in 3D printing services	What trainings have you received on 3D printing services?	
	Do you only work on the 3D printing services?	If no, would you like to be more involved in the 3D printing programme?
	How do you think the 3D process has changed your contact with the patient and their care?	
	How has your working time changed since the use of 3D printing?	What do you think about that?
	What are the challenges that you are facing to with your work within the 3D printing services?	What are the main challenges of the 3D printing services? How do you overcome these challenges?
	Are the patients willing to have a 3D printed orthosis? Do they prefer traditional orthosis? Why?	

Workshop with ARRH: Production of orthoses:

- Agenda
- Powerpoint

Appendice 3: Profiles of people interviewed

1. Beneficiaries

Orthoses Type	Age	Gender	Zone	Phase
AFO + Seating brace	7	M	Imvepi - Zone 2	1
AFO	8	F	Imvepi - Zone 3	1
KAFO (left + right)	3	F	Imvepi - Zone 3	2
AFO	10	M	Imvepi - Zone 3	2
AFO	7	M	Imvepi - Zone 3	2
KAFO	25	F	Omugo	1
KAFO (left + right)	30	F	Omugo	1
AFO	8	M	Arua	1
KAFO (left + right)	12	F	Arua	2

2. Partners

Arua Regional Referral Hospital (ARRH), A 2-day workshop: 2 P&Os and 1 senior P&O on the 09 and 10 of May 2022.

3. Others

Momentum wheels for humanity: technical advisor and finance manager, on the 22/04/2022

CoRSU: Medical director, head of rehabilitation services, and 4 orthopaedic technicians, on the 22/04/2022

Gulu Regional Referral Hospital (GRRH): 3 Prosthetist and Orthopaedist (P&O), 1 Senior P&Os , introduction to the hospital director, on the 29/04/2022

AVSI: 1 physiotherapist, programme manager and technical advisor, on the 29/04/2022

Cost analysis of 3D printing services implementation into public services to produce orthoses: An Ugandan case-study

This study aims to calculate implementation and running costs of 3D printing services to produce orthoses in a public service, in addition to traditional services, in a developing context. A patient pathway has been developed to represent the hypothetical implementation of 3D printing services in the chosen hospital. The cost analysis results are presented by costs per category, per patient and per orthosis, along with their spread over time (4 years – estimated lifespan of the 3D printers).

This cost analysis is based on the Ugandan case-study, but its principles and lessons learned can be replicated to other contexts and/or countries.

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