MASTER

Technology transfer challenges

Attempting Assimilation of Affordable 3D Printed Below-Knee Prostheses on Lombok

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TECHNOLOGY TRANSFER CHALLENGES

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ABSTRACT

Sustainable Development projects have always been difficult to execute, and since every project and implementation context is different, there is no one correct way to successfully execute such a project. There are however challenges that most projects will face. This thesis builds upon existing know-how by exploring a technological sustainable development project from ideation to execution, in order to conclude on good practices and potential pitfalls for future cases. The focus is on 3D printed prostheses, introduced and carried over on Lombok, Indonesia. This topic is studied using existing theories of assimilation and North-South technology transfer, combined with an action research and grounded theory methodology. The findings are both project specific, and broader good practices for other development projects. Its main findings include, among others, the need to carefully assess the Global South context, understanding sociocultural structures and including motivated stakeholders and facilitators.

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Executive Summary

Globally only 5 to 15% of amputees have access to proper medical care, this deficit is concentrated in the Global South, where despite efforts of the ICRC, prosthetic services remain unaffordable for many. New developments in 3D printing technologies could provide an alternative product, which is less costly and time consuming to realize. However, translating these technologies to global contexts where 3D printing has not been introduced can be challenging. Through an exploration of a new prototype to create 3D printed lower leg prostheses, consisting of a 3D printer prototype, prosthesis prototype and production method, this thesis attempts to improve upon existing projects of 3D printed prostheses in Global South settings. These technologies were introduced on Lombok, where the current prices of prostheses exceed the average annual income. The added value of this project is the aim to achieve technology assimilation in order to ensure lasting impacts in this specific setting, something that has rarely occurred in similar projects of this kind. By taking the learnings from this project, this thesis then presents lessons for other projects of similar nature, in order to answer the following research question:

What challenges occur when implementing 3D printed lower leg prostheses on Lombok, and what wider lessons can be drawn from this case for future assimilations of technological innovations in Global South settings?

Technology assimilation is a goal that follows the introduction of a novel technology, as it ensures that the new product or process will be utilized in the long term by the end user in the Global South setting. This is relevant to this thesis as it overcomes the challenge of previous attempts of 3D printed prostheses, as these often were not created to fit the specific context in which they were introduced. This thesis explores this topic, as well as North-South technology transfer, to draw lessons on the existing knowledge base of technology driven challenges in the Global South, and the challenges that arise in attempting a translation of a novel technology from the Global North to the Global South. Understanding what this entails, and the limitations to this approach, allows this thesis to present broader learnings that could apply to other technologies and Global South contexts. The thesis also focuses on existing literature about challenges in development projects, as well as sociocultural studies, as this was used to steer the implementation of this project in a local hospital on Lombok in the right direction. The 3D printer was introduced in this hospital in the island's capital Mataram, where local doctors were trained to understand the technology and the production methods, in order to fit the printer within the existing methods and capabilities. Through using action research, the implementation of this project was mindful of the need for reflections and dynamic adjustments, and grounded theory was used to frame the findings in order to gain a deeper understanding of the encountered behaviors and challenges.

The project of 3D printed prostheses is presented in great detail to provide a comprehensive insight into the technology itself, its medical background and the devised production method. This is done in great detail to ensure that the reader understands the decision-making process and challenges that had to be overcome. Focus is on the implementation of the project on Lombok, as here the majority of the assimilation challenges occurred. Finally, the project is evaluated to uncover why these challenges occurred during this specific project, to provide learning outcomes for other projects, expanding upon this case with lessons for different technologies and Global South contexts.

Many challenges occurred, which directly impacted the outcome of the project. These are presented by breaking the project down into its core components: The 3D printing technology, the prosthesis design, the production method, the constructed training program, the implementation phase and the online interactions that followed. During the research at the start of the project, it became clear how challenging it can be to create a functional and reliable 3D printer that conforms to specific requirements. Exploring the design of prostheses, specifically the ICRC design, allowed for a deeper understanding of the prosthesis deficit and the methods and capabilities present on Lombok. During

the implementation phase the challenges consisted of technical failures and legislative obstacles, trust building and collaboration with local stakeholders, and conflict of ownership with the facilitator. This thesis presents these challenges, as well as learnings about training individuals from different global contexts, time management, and desired contextual settings, in an attempt to translate to the reader how challenging a project of this sort can be, and provide learnings that are applicable to other scenarios as well.

Working in a Global South context proved to be unpredictable and requires an open-minded and flexible approach, using dynamic adjustments as the context is better understood. Sociocultural factors directly impact the way in which a novel technology can be translated between two substantially different contexts, and the understanding thereof only truly occurs during the implementation process itself. Despite many preparations the outcome remains unpredictable, yet utilizing existing lessons allows for easier adjustments, and ultimately allows the project to find a more suitable fit within the existing sociotechnical system. These lessons, amongst the others presented in this thesis, apply to broader technology assimilation challenges in Global South settings. Through the scope of North-South technology transfer and assimilation, it becomes clear that such challenges occur no matter the technologies, methodologies, and contexts. It is therefore important to gain a better understanding of challenges that will continue to occur in attempting to share technical knowledge on a global scale, as these knowledge exchanges impact many stakeholders in their respective global settings.

By exploring this topic, the thesis provides lessons, and also reflects upon the used literature to explain its relevance, as well as its limitations. Besides the learnings about technology assimilation, the thesis also provides recommendations for future research, and addresses the limitations of the used approach.

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1. Introduction

1.1 Justification & Objective

Currently, only 5 to 15% of global amputees have access to proper medical care. A vast majority of these people live in developing countries. Their limited income, in combination with little to no medical expertise in their local area, prevents them from obtaining a fitting medical device (WHO, 2015). In 1979 the International Committee of the Red Cross announced the ICRC design for prosthetic limbs. “The ICRC’s Physical Rehabilitation Program has promoted the use of technology that is appropriate to the specific contexts in which the organization operates, i.e., countries affected by war and low-income or developing countries” (ICRC, 2013, p.2). The aim of this program was to create a local infrastructure of prosthesis fitting and production, by providing a relatively simple method with clear guidance, to tackle the lack of prostheses on a global level. The ICRC design for prosthetic limbs has been widely implemented in developing nations around the world, as it provides an affordable yet comfortable form of medical care (ICRC, 2013).

Figure 1: ICRC prosthetic leg in production (ICRC, 2020)

Yet, the prosthesis shortage continues, as the ICRC method is very time consuming, and the costs continue to be a constraint that leaves many amputees in the Global South unserved. Developments in 3D printing could provide a solution for the continued high unmet demand for prostheses in the Global South, as this technology is becoming more accessible and reliable, and could automate stages in production processes, lowering time and costs (Mohr & Khan, 2015). In recent years there have been successful conceptualizations of 3D printed prostheses (van der Stelt, 2021), which are of equal comfort as the ICRC prostheses (Ratto, et al., 2021) yet very few cases have created long-lasting prosthesis manufacturing facilities in the Global South which utilize this technology. According to Abbady et al. (2021) there have not been enough scientific experiments of 3D printed prosthesis in this context, particularly for lower-limbs, and the projects that were executed were rarely led by local stakeholders, nor accounted for socio-cultural desires and needs of communities.

There is therefore a need for a new approach to introduce 3D printed prostheses, where we look beyond the technical proof of concept and focus on socio-technical embedding of the product and process, to create lasting changes in the Global South. This master thesis is concerned with the process through which western technological innovations can be assimilated in a specific Global South setting. This process is explored hands on through the creation of a production method for affordable 3D printed below-knee prostheses, and its implementation in a representative Global South setting.

To create durable robust embedding in the community, the product needs to be fit-for-purpose in the local environment, and the production method needs to be comprehensive, and adapted to local know-how, to be compatible with existing ways of producing and fitting prostheses. This thesis explores this topic through a 3D printer and prosthesis prototype, which have been introduced in a hospital on Lombok with the purpose to achieve local assimilation through a process of societal embedding. The challenges that occurred in the translation and implementation of 3D printed prosthetics in this specific Global South setting are explored, and are used to reflect upon the reasons why it has been difficult to promote enduring changes in existing sociotechnical systems in the Global South. This finally contributes to broader good-practice lessons as well as opportunities and key takeaways for North-South technology transfer.

1.2 Background

Lombok is an Indonesian island where the issue of unavailability of affordable good-quality prostheses is pressing. In the year 2004 the national social and economic survey revealed that there are approximately 1.7 million physically handicapped Indonesians, of which 1.5 million are in need of prosthetic or orthotic services (Central Bureau of Statistics (BPS) of Indonesia, 2004). Additionally, it is estimated that 19.5 million people in Indonesia suffered from diabetes in 2021 (International Diabetes Federation, 2021), a condition that causes very high amputation risk (Marshall & Stansby, 2008). There is no specific data available about amputees on Lombok, but as the island accounts for 0,9% of the total Indonesian inhabitants (Central Bureau of Statistics (BPS) of Indonesia, 2020), it is assumed that well over 13.000 people are in need of prosthetic services.

Figure 2: Geographical location of Lombok

Bergsma (2011, p.2) states the following about the medical device shortage in Indonesia: "Currently, there are only a few domestic manufacturers who provide quality prosthetics and orthotics equipment at affordable prices, mainly due to a lack of infrastructure, facilities and skills" The ICRC prosthesis is the most common leg-prosthesis in Indonesia and on Lombok. A large part of this product is imported as only the socket can be locally manufactured. The parts are imported from China and for a lower leg prosthesis would cost around 800 Euros, partly due to high import taxes. This results in a final price per below-knee prosthesis of approximately 1000 Euros, and 1500 Euros for an above-knee prosthesis[1]. The national average net monthly income in Indonesia is 187 Euros (Central Bureau of Statistics (BPS) of Indonesia, 2022), and on Lombok it is approximately 134 Euros[2] (Central Bureau of Statistics (BPS) of Indonesia, 2021). At the current price point, lower limb prostheses are therefore not realistically affordable for the majority of the population, as prostheses are also not covered by standard health insurance (Bergsma, 2011).

Producing a traditional prosthesis requires a lot of time and manual labor. Generally speaking, it would take well over one week to manufacture a below-knee ICRC prosthesis and two weeks to manufacture an above-knee prosthesis[3], not including fitting, rehabilitation, and patient education. Could the benefits of 3D printing technologies fill the demand for affordable leg prostheses in Global South settings such as Lombok? This thesis explores a below-knee prosthesis prototype based on the ICRC design, which utilizes 3D printing to lower the costs and production time, whilst aiming to maintain the necessary durability and comfort.

[1] Source: Informal interview with Suci Anatasia, Prosthetics and Orthotics expert from the Ministry of Health of Indonesia, Jakarta (October 2020)

[2] There is no direct data available for this figure, but the income gap between Lombok's province West Nusa Tenggara and the rest of Indonesia is approximately 28% (Central Bureau of Statistics (BPS) of Indonesia, 2021), this is used to derive the monthly income

[3] Source: Informal interview with Suci Anatasia and Arbi Ibrahim, Prosthetics and Orthotics doctor from the Unram hospital, Mataram (October 2020).

1.3 Timeline

Although the main focus of this thesis lies on project implementation on Lombok, it is crucial to also consider to some extent early stages of the project that preceded the actual implementation of the 3D printed prosthesis in the Global South setting because they impacted the subsequent implementation to some degree. This section therefore describes the 29-month time period taken by the entire project, from ideation to implementation. It is summarized in the following figure:

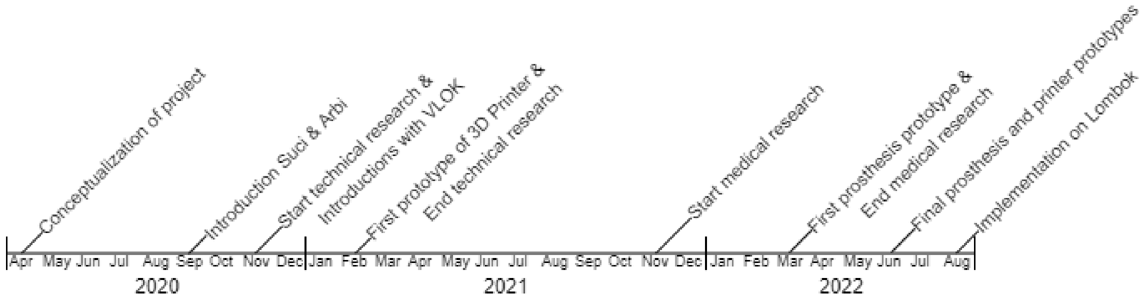

Figure 3: Timeline of the 3D printed prostheses project

The project commenced at the start of 2020, when the author finished his Bachelor End Project about the leapfrogging potential of 3D printing technologies in developing countries. In that work he explored the opportunities for development projects utilizing 3D printing technologies, through a wide-reaching literature study. One of the key takeaways was that the technology can create affordable tailor-made products with ease and of sufficient strength. This sparked an inspiration, as the author had been experimenting with 3D printing for quite some time and had become quite skilled at using and adjusting 3D printers.

In April 2020 further exploration of 3D printing technologies led to the definition of a thesis topic focused on: 3D printed (and also, at the time, circular) leg prostheses. The management of the master program Innovation Sciences kindly gave special permission to spend the greater part of the author's master's track on this project. The project comprised several distinct phases, as follows:

1. Preparation

The first activity was a search for a suitable internship to create the first design of the 3D printer, for which the author reached out to plastics and 3D printing companies. This unfortunately did not materialize, but in the process the author was brought into contact with both Suci Anatasia, a prosthetics and orthotics expert from Jakarta, and Arbi Ibrahim, a P&O doctor on Lombok, with whom the project was eventually implemented. Having these contacts early on really helped to adjust the 3D printer and the prosthesis design to the local context.

Having been in contact with the Indonesian medical experts, in November of 2020 the author was introduced to Harry Peters, founder and head of the Geldrop-based 'Vrienden van Lombok' Foundation, which executes development projects on Lombok. He provided information about the local conditions and offered to help with the project implementation process on Lombok.

2. Adjusting the printer design

In November 2020, the first research project component commenced at the Eindhoven University of Technology, under supervision of Henny Romijn from the Innovation Sciences department and Edwin van den Einden from the Innovation Space. This phase comprised the exploration and technical design of an adapted 3D printer that would be capable of printing lower leg protheses for adults at low cost, which was required as there are no affordable 3D printers on the market capable of printing large objects expeditiously. The author also attempted to create a way for the printer to work in a circular way by adding a pellet extruder in order to (partially) print from shredded plastic waste. Finding affordable solution to this problem however proved to be too costly and time-consuming, but proof of concept for this idea was found. The exploration of circularity of the materials falls outside of the scope of the project that is reported on in this thesis, but could be valuable for future advancements. Within a month, the first version of the adapted 3D printer was finished, though a lot of issues arose in the first stages. By January 2021 it was working reliably and in February the first research project component was completed (Vernooij, 2021). Thereafter new issues occurred with the 3D printer but through testing and trial and error these were also resolved. Multiple iterations were made to improve the printer in the months that followed.

3. Designing prostheses that meet medical requirements

In the meantime, the author was planning to create the first prototype of the prosthesis. Some information was already received from Suci Anatasia and the ICRC about the design of leg prostheses and it had become apparent that 3D scanning would be vital in order to be able to use the 3D printing technology. In November 2021, the medical research project commenced, consisting of education provided by Suci Anatasia and Gijs van Lent from the Fontys Hogeschool in Eindhoven, and self-study. The result was the first prototype for the prosthesis, the 3D-scanning and -modeling method, the first prosthesis fit with a test patient, and preliminary strength tests. This research component was completed in February of 2022 (Vernooij, 2022).

4. Implementation

The 3D printer and prosthesis prototypes were finished in March 2021, when the plan to visit a hospital on Lombok hospital was conceived. The connections with Arbi Ibrahim's hospital, Rumah Sakit Unram Mataram (Unram for short), were made. Introductions were made with the local hospital staff to arrange the shipment of the printer to Lombok, and to arrange the scheduling of the training program. The visit by the author to the hospital was scheduled at the end of August 2022. In the period before the visit the author improved the modeling method, wrote the printer user manual and training program, and finalized the adapted design of the 3D printer.

Initially, the plan was to replicate the first adapted printer design in Eindhoven, and ship it to Lombok. Unfortunately, this proved impossible, as it could not be arranged with the local customs. For this reason, a new printer was purchased on Lombok and directly delivered to the hospital, and the author brought all the components in his luggage to complete the adaptations to the printer on the first day of his visit to the Unram hospital. The actual implementation of the project was finally executed from 22 to 31 August in the Unram hospital, where the author presented the project to the hospital staff and personally trained them, in the scanning, modeling, and printing processes. In the months that followed the author and the hospital staff finalized the 3D printer and the prosthesis design through online interactions.

1.4 Research Questions & Thesis Outline

This chapter serves to elaborate on the topic, set out the research questions and lay out the structure of the thesis. As mentioned, attempts have been made to tackle the prosthesis deficit in the Global South through 3D printing technologies. Abbady (2021) described how such attempts proved the merit in this solution but lacked in the implementation methods, leading to project failures. For this reason, among others, the prosthesis deficit has not been resolved to date. The lack of focus on an appropriate implementation method can be described as a socio-technical assimilation challenge, where the challenge is to not only introduce the novel technology, but also ensure it is adopted and deployed by local stakeholders through a process of collaborative assimilation, in which the users gradually achieve true ownership of the innovation. The following figure describes these relations.

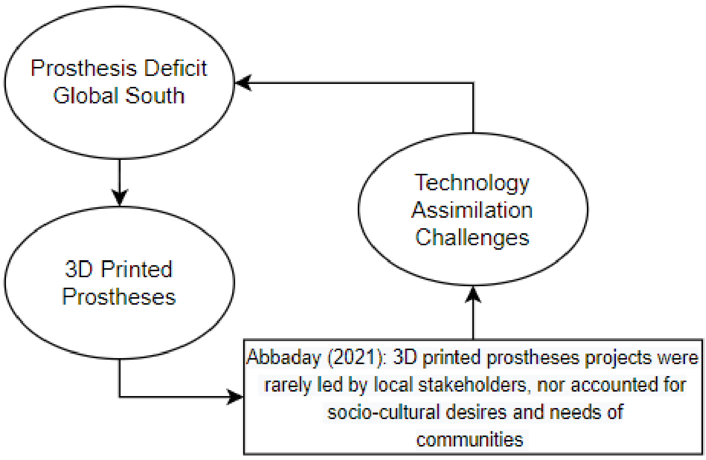

Figure 4: Abstracted visualization of the problem statement

The introduction of the specific 3D printed prostheses project in this thesis has taken the learnings from Abbady (2021) into consideration, and supported by additional North-South technology transfer and culture-oriented literature, and implementation methodologies has aimed to tackle the problem in a different manner from the start, so as to try to avoid these challenges as much as possible from occurring. The project however still faced many obstacles and assimilation challenges. By evaluating the attempts to overcome or work around these, new lessons can be drawn, not only for 3D printed prosthesis, but also for generic take-aways for technological assimilation challenges in other projects executed in the Global South. The main research questions therefore is:
What challenges occur when implementing 3D printed lower leg prostheses on Lombok, and what wider lessons can be drawn from this case for future assimilations of technological innovations in Global South settings?

This research question is explored further in subsequent chapters, through the following sub-questions:

1. *What assimilation challenges have frequently occurred in development projects involving the introduction of new technologies in the Global South, and what methodologies have been applied in this project? (Chapter 2)*

2. *What steps were taken to realize the prototype and assimilation of 3D printed prostheses on Lombok (chapter 3)*

3. *What assimilation challenges occurred in the implementation of this specific project? (Chapter 4)*

4. *What lessons can be taken away from these challenges for future projects? (Chapter 5)*

The following figure presents an outline of the thesis, structuring the problem overview and research questions (RQs).

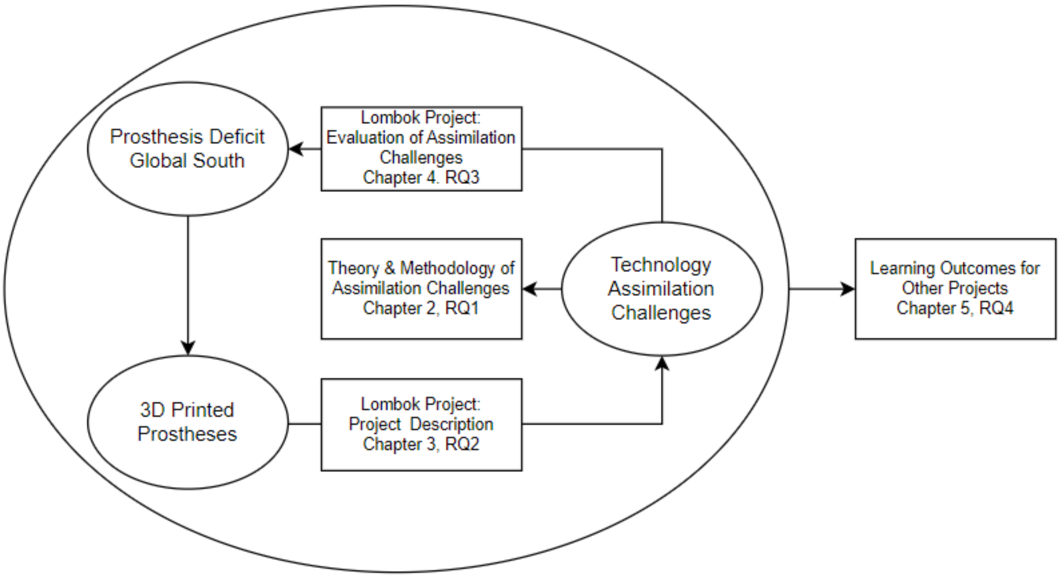

Figure 5: Thesis outline, describing the relations between the topics and their associated chapters

2. Theory and Methodology

The author developed the technology of 3D printed prostheses in the Netherlands with the purpose of being introduced in Indonesia, as such, this thesis studies a North-South technology transfer process. This has proven to be a challenging feat, as such projects face obstacles that are difficult to foresee. Many attempts of North-South technology transfers have occurred in the past, and lessons have been captured in literature focusing on specific challenges of such endeavors.

International Technology Transfer (ITT) is so challenging that it has been a relevant topic in academic literature for over 50 years. This is the case because it is not only a transfer of physical goods, but is also accompanied by communications of information, skills, and managerial know-how (Stewart, 1981). The technology in question has to be appropriate for the specific context in which it is introduced, in line with its resources and characteristics, for this transfer process to be feasible. Executing a successful project is very demanding as it not only requires a lot of effort, but also requires the innovator to envision the technology within the local context, and transform it to fit within the locally defined social needs (Hartley, Mcleod, Clifford, Jewitt, & Ray, 2019).

During the 1980s however, the focus in literature shifted from cross-national transfers to domestic transfers (Bozeman, 2000), focusing on value-added supply chains, organizational learning and knowledge spill-overs (Noh & Lee, 2019) (Daghfous, 2004). As a result, the literature used to describe and assess ITT in this thesis often predates the 2000s, as academic focus has changed course ever since. This is deemed more appropriate in this case as the technology was initially developed in a Global North setting, and the design was purposedly introduced to selected recipients in the Global South. Understanding how such transfers occur has been studied in great detail in this period, whilst more recent literature has a more prominent focus on indirect and regional effects of technology transfer and is therefore rarely oriented towards projects such as these.

Additionally, the success of the project depends heavily on the collaboration with the end-user, as their personal motivation, culture and knowledge influence the use of the product or process, and the extent to which it is assimilated in the existing socio-technical system (Douthwaite, Keatinge, & Park, 2002). Through capacity building the innovator increases the odds that the technology and knowledge are absorbed in the Global South (Baser & Morgan, 2008).

Different literature studies regarding these topics are explored in this chapter, supported by existing lessons of the North-South technology transfer process, and cultural understandings, as this has impacted the design and implementation processes and will later be used to evaluate the project as a whole. Additionally, the reflection method, action research and grounded theory methodologies applied in this project are explored, to explain how the research was executed and the research questions were answered.

2.1 Defining Technology Assimilation & Capacity Building

The thesis is oriented towards North-South Technology transfer with the end goal of technological assimilation, but what does this entail? Assimilation is a goal that follows the introduction of an innovation, as it ensures that the innovation will be utilized in the long term by the end user in the Global South setting (Kim, 1998). This is not always the case, as the user is for example not interested in the technology, does not know how to use it properly or is not motivated to change current methods (Lackey, 1993). Assimilation is the step where the user learns to adapt the innovation and fit it into the current methods, and thus results in the successful integration of the innovation in the local context.

In this case, technology assimilation is therefore referred to as; *the absorption and integration of novel technologies in a socio-technical system*. This is achieved through *learning by doing, knowledge conversion, knowledge socialization and adaptation* (Kim, 1998). Adaptation is a very important factor of technology assimilation, as even though a technology is created for the specific context, it will rarely be a perfect fit. Not only is the context hard to assess, but the outcome is also influenced by the lack of data and local knowledge (Lackey, 1993). Through assimilation the end user makes the innovation their own, combining the knowledge of the innovator with the local capacities (Kim, 1998).

This relates closely to the broader concept of technological capacity building, where the user is enabled to adapt the technology and build upon the innovation (Baser & Morgan, 2008), and ultimately gains the ability to drive industry-wide technological innovations (Oti-Sarpong & Leiringer, 2021). This is an outcome that would provide even more agency to the end user and will ultimately lead to a further improved product or process, but in this case is not the goal of the prosthesis project. The project in this case is deemed a success when the end user utilizes the technology to create more affordable prostheses, in an attempt to tackle the global prosthesis deficit. Therefore, technology assimilation is the main focus, where opportunities for capacity building/development are perceived as additional benefits. It is important to state that before the introduction of the 3D printed prosthesis project, there were already capacities present to create suitable prostheses, as it was discovered early that there was sufficient medical and technical know-how. Rather, this project enabled a more rapid leap in technological development by introducing novel technologies in a new setting, and would therefore be better suited under the definition of capacity development instead (UNDP, 2008), as it aimed to build upon the existing knowledge within the hospital.

2.2 Theories of Technological Assimilation

The introduction of novel technologies is often referred to as innovation, as this describes the development and creation of a new product or service, and is defined as *something new or a change made to an existing product, idea, or field* (Merriam-Webster, n.d.). This definition however is insubstantial, as the act of innovating entails a more complex and dynamic operation of development. This development process is influenced by many different factors such as demand, industry, technological advancements and geographical and social context. Some argue that innovations only occur when the novel technology has the capability to add value (Rogers, 1998), which can only be determined in hindsight. Nevertheless, framing the technology in this thesis as an innovation creates opportunities to explore relevant innovation-oriented literature, and its innovative nature remains open for discussion.

In this specific process case the innovation process was undertaken by a single person, who was the original creator of the solution, but as will become apparent, was not the only one contributing to the innovation. Through dynamic interactions with other parties and the end user, co-innovation occurs to create an innovation that is suitable for the final use context. An attempt was made to facilitate this process both through the inclusion of experts, as well as the end-user in the Global South context. The inclusion of multiple actors influenced the decision-making process, and consequently influenced the final result.

The implemented solution comes forth out of a perceived need in the Global South, in this case the deficit of (affordable) below-knee prostheses. The possible solution is conceived, yet the final form of the solution is initially not well defined and evolves over time. During the innovation process the subject matter is explored, and as a result different important aspects come to light. By encountering challenges and failures the technology is improved upon through iterations. This iterative process continues when the innovation is introduced in the Global South, as the final form and use of the technology are influenced by the dynamic context of the international project setting (Oti-Sarpong & Leiringer, 2021).

Douthwaite et al. (2002) argues that the success of the project is dependent on the user, as the use process leads to the final design over time through gradual learning, rather than it being a fit for purpose solution upon introduction. Douthwaite et al. (2002) argues that there is an innovator within the Global North setting, whose interactions with the recipient of the technology, the user, are key throughout the project as local knowledge and technologies are embedded in the innovation through co-innovation. This introduces two key concepts. The first, learning by using, is defined as the lessons learned by both parties during the design and manufacturing process, whilst learning by doing is the process of finding improvements during the use process. Both influence the final innovation, and the experimental learning processes and cooperative improvements will lead to a higher quality product that is more locally appropriate.

Key learnings for successful assimilation projects according to Douthwaite et al. (2002) therefore are:

1. Start with an obtainable outcome (plausible promise) that convinces the end user of the usefulness of the innovation
2. Keep the plausible promise simple, flexible for revision, robust to work even when unoptimized, and match with the needs and knowledge level of the end user
3. Cooperatively nurture the innovation with a motivated end user to find the final innovation by providing learning opportunities, creating revisions, and experimenting
4. Work in a context where the need for innovation is great and will lead to great benefits and local community feedback
5. Work with innovative and motivated partners: possess abilities to make improvements, introduce first users as co-developers

6. *Don't release the innovation too widely too soon*: do not miss out on adaptation phase, keep motivated users close and ensure a user does not get frustrated and stays motivated to adapt
7. Let market selection take over after once the innovation has been adapted by motivated users

Combining these lessons means that the project will only be successful if there are consistent and frequent interactions with a user located within the local context. The focus should not solely be on the technology itself but also on the way it will be used and by whom. The design will then change, or evolve, over time as it is adapted to the local context. This evolution of innovation relates closely to adaptive innovation systems. Clark et al. (2003) provides a heuristic framework to create adaptive innovation systems where improvements in longevity of impact become apparent. This provides learning opportunities for how to prepare projects to become self-sustaining through assimilation, considering the need for active participation, and process iterations based on the local context.

The theory that Clark et al. (2003) introduces is focused on the long-term sustainability of a project. How does one engage with an end user in such a way that he or she stays motivated, so the innovation is not abandoned. This is introduced as a Research-action program. The goal is to create an innovation system that is able to adapt to changes of circumstances, contexts and needs. The attempt is successful if the local stakeholders are encouraged sufficiently so the project remains in use after the donor or innovator has withdrawn. Ideally, the innovation even keeps evolving further, and local technological capacity keeps growing. This would result in the creation of new local dynamics with regards to the innovation, expanding local agency as a result.

Key learnings for successful assimilation projects according to Clark et al. (2003) therefore are:

1. Connect the innovation to the local context and as such account for the complex system; look at the relationship between technology and diffusion, beyond the supply chain.
2. Build trust and confidence for the local stakeholders, whilst working on team-building in each stage through involvement in the process.
3. Understand what motivates the local stakeholders and provide conditions in which these motivations can be realized.
4. Establish a project through parties that are locally involved to build up trust.
5. Learn from past projects and use this knowledge, to improve and to make mid-course corrections when necessary, in order to evolve the system.
6. Establish clear links with donors, and align your goals and approaches in advance.
7. Develop personal and professional networks, and select partners with the same motivation whilst avoiding those who aim to change the agenda.
8. Recognize the different roles of different organizations and individuals, and their relations, and assess when they should be included in the process.

Both Douthwaite et al. (2002) and Clark et al. (2003) have given clear learnings that are relevant for North-South technology transfer projects, based on realistic experiences from development projects. The learnings are useful beyond their specific scope of research, but are limited by their framing of the described processes.

By aiming towards finding the right user or stakeholder in the Global South to implement the technology from the Global North, the structure of the project will remain top-down. Instead, finding ways to understand the local context in order to promote agency and local innovation, and viewing these technological development as equal, allows the technology transfer to become a two-way process, where innovation is promoted within the Global South setting, but technologies and habits from within the Global South could also promote development in the Global North setting as a result. The technology transfer is therefore not a one-way event, but leads to positive change in both settings as knowledge is exchanged amongst all stakeholders. The way in which both authors frame this transfer misses out on this process as it would mean that advanced knowledge is only available in the Global North setting, which frames the Global South as a minority.

The use of evolution as a grounds to study technological development has been a widespread approach, and it is clear that a technology or innovation will be adapted throughout its development process. This is true in ITT projects but occurs on a global scale as iterations and improvements are made, no matter the context. In viewing this as a different phenomena many learnings from innovation processes as a whole are disregarded. It is undoubtedly important to adjust the technology to the needs, influences, and cultures of the local setting, and preparing to work in a flexible way to overcome dynamic changes is necessary, but it is also important to be mindful of the process that every technology undertakes before it reaches its final form. An example of this is the bathtub curve of technological failure, which is explored in chapter 4.4.

Douthwaite et al. (2002) and Clark et al. (2003) have a similar view on creating successful innovation systems in the Global South. Taking into account the limitations of their respective perspectives, the lessons that are presented in both works remain relevant to this day, and were considered in this project to strive towards the creation of lasting impacts in the Global South setting. The most important factors are dependable collaboration, knowledge adaptation, long term vision and considerations of the local context. Applying this to North-South technology transfer means that a project of this kind will not be successful without including the end user in the design process and providing opportunities for the creation of trust and co-innovation, even before the implementation phase. Additionally, the local context needs to be studied and understood, in order to create value and motivation for the local stakeholders. Yet many projects still fail to create long-term impacts. Learning from existing projects and their reasons for failure could provide additional lessons to avoid known pitfalls and steer the project in the right direction.

2.3 Learnings from Previous Development Projects

Each development project seeks to reach a certain predetermined goal, but Lackey (1993) claims that not a single project works out as planned. This can be due to many factors such as complexity, incomplete information, and miscommunications. As such, Lackey (1993) has created an overview of the most common challenges, and created recommendations for future projects.

From Lackey's (1993) perspective, a development project is created based on the desire to address a perceived need in the Global South. This need is based on assumptions, which are often inaccurate, due to unreliable and incorrect data, as well as a limited understanding of the local context. On the one hand these assumptions are based upon the introduced development itself, and the problems it could resolve. On the other hand, the assumptions are about the target group and their wants and needs. Pitfalls could lie in treating this group as homogenous and as a group that always maximizes its economic benefits. Gathering sufficient local data is therefore vital. The attention to local context is important, as miscommunication often hinders progress. This can be due to misunderstandings of e.g., language, culture, habits, and knowledge. Additionally, the initial assumptions will often change as the environment shifts throughout the process. There can be externalities that affect a project significantly, based on changes in social, economic, natural, and political landscapes. If these are not accounted, misinformation could lead to problematic decision-making.

North-South technology transfer projects are inherently complex, and the complexity of the system makes it difficult for the innovator to determine cause and effect. The assumptions made and the available data will impact how much knowledge the innovator has regarding the variables and relations within the system, and this impacts how much control there is over the outcomes. Due to its complexity it is impossible to understand each single variable and relation, as depicted in *Figure 6*, but with sufficient research and preparation this system becomes less difficult to control and predict. Even with sufficient understanding of the system, there is still a large probability to encounter failures. This is due to the fact that there are a large number of variables that determine the outcome, and even if all of these have a high probability of success, the combination still gives the innovator a slim chance of implementing a successful project. It is up to the innovator to collaborate with the local stakeholders and dynamically adapt, the original plan may not work out, but this allows new opportunities for developments in the Global South context.

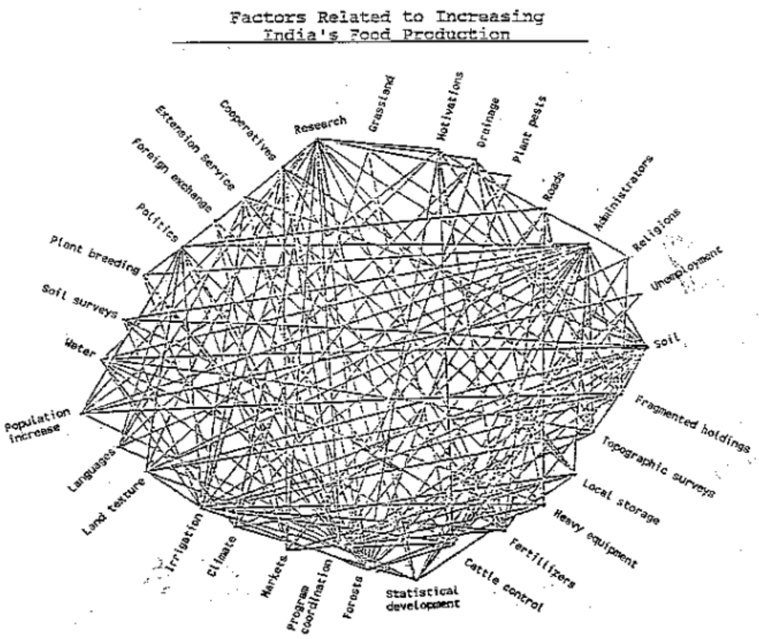

Figure 6: Lackey's visualization of the complexity of variables and relations (Lackey, 1993)

Often a project is created with a certain goal in mind, initially this goal revolves around the perceived development need in the Global South, but if not managed well this goal could be displaced. When external funders are involved it is possible that the innovator tends to aim towards pleasing the funder rather than the beneficiaries, which leads to focus on easily measurable outcomes rather than aiming for the most impactful ones if the funder's priorities and perceptions of "project success" are not sufficiently aligned with those of the beneficiaries. Being mindful about goal displacement and using transparent communication about the changes and their impacts prevents this from negatively affecting the outcome. Innovators should also be wary of corruption, as funds and resources are often knowingly or unknowingly misdirected for personal gain, if mismanagement occurs. This is bound with time and cost estimates, where projects are scheduled within too short timeframes and evaluated shortly after to measure its success for the funder, which provides too little time to truly discover its impacts. If the reflection process is not carried out successfully, the final evaluation is prone to failure and does not create a realistic depiction of the events and their impacts.

Based on the aforementioned challenges, Lackey (1993) provides the following recommendations:

1. Research – When preparing, aim to understand the local situation, involve locals, find cause-effect, perform stakeholder analyses, and create a matrix of problems and timetable.
2. Participation – Involve many diverse stakeholders on both a policy and implementation level.
3. Communication – Use simple and concrete words, not only to lower complexity, but also to reuse words to explain their meanings, pre-test messages and define abstract words clearly.
4. Bureaucratic Organization – prioritize decentralization and manage goal displacement.
5. Learning Process Approach – Work people-centered and create good feedback loops, foster a holistically perceived learning process.
6. Development Philosophy – People cannot be developed, they can only develop themselves, therefore facilitate for the creation of something for the people, by the people.

These lessons, though somewhat generic, were of much relevance to this project. These were studied before the implementation phase and each occurred in some form. The recommendations were used not to prevent pitfalls, but rather to recognize unfavorable developments in time and steer the project in the right direction.

2.4 Culture

There are many factors that influence the success or failure of North-South technology transfer projects. As previously mentioned, one of the most important learnings is to adapt an innovation to the local context. This concept of context however is very broad as it not only describes tangible aspects such as available resources, climate and infrastructure, but also describes a variety of human-centered aspects. For example, it includes the way that local communities behave, drivers of financial markets, as well as perceptions on technology, change and foreign aid. It is virtually impossible to account for every one of these complex issues, and it is therefore logical to focus on the overall collection of distinguishable human behaviors of the specific target group, in other words, the local culture. This section aims to extract lessons from cultural studies that could be of help in technology transfer and capacity building challenges.

To draw coherent conclusions, culture is defined in this thesis as: *"The social behavior, institutions, and norms found in human societies, as well as the knowledge, beliefs, arts, laws, customs, capabilities, and habits of the individuals in these groups."* (Edward, 1871) It is not limited to those aspects however, as it also includes "*language, ideas, codes, tools, techniques, rituals, and ceremonies, among other elements*" (White, 2022).

The aim of development projects is to improve the local conditions, but the openness to change is dependent on the specific culture. Therefore Rhodes (2022, p.12) states: "By strengthening understanding about the influence of cultural values in locations in which change is expected to occur, as well as in the collaborative relationships and conversations which are necessary to bring about change, facilitators of change will be better equipped to make their contribution relevant and thus more likely to succeed." Rhodes (2022) clarifies what roles culture play in this process, and the learnings, relevant to this thesis, are as follows:

Cultural understanding from both sides is necessary for understanding and collaboration. The creation of mutual understanding of each individual's beliefs and morals, and exploration of shared cultural values, creates shared meaning and trust, and encourages cooperation. This means to not only focus on the end-user's culture, but also reflection upon your own. This cultural understanding is relevant throughout the whole process, including in monitoring, evaluation and learning processes, and encourages openness to change. This cycle is depicted in the following figure:

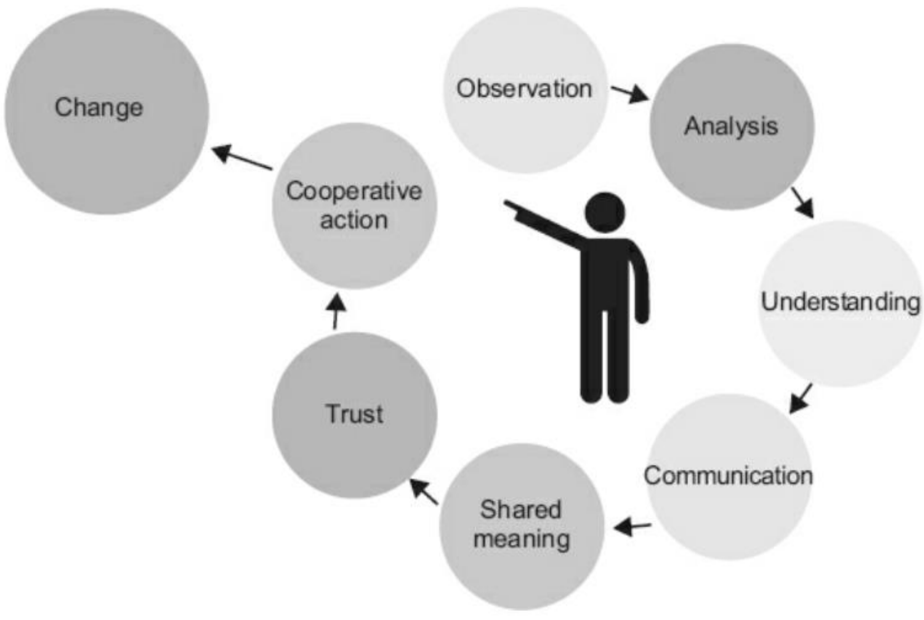

Figure 7: Elements linking cultural values and change (Rhodes, 2022)

There is a clear link between participation and cultural values, one must find the culturally relevant participatory approach (collaboration, partnership, or inclusion), in order to stimulate change. Due to a sense of shared responsibilities and benefits based on the same values, parties will be more motivated to achieve successful results. Understanding of the local culture not only promotes collaboration, but also provides a better understanding of the specific context as a whole. Cultural values influence the aforementioned tangible assets, and enable opportunities for change. Finding these opportunities demands understanding of interactions within communities, as marginalized groups are difficult to detect without understanding the local culture.

Change is essential in development practices, and needs to be carefully managed and translated. It is advised to build strengths-based collaboration between people who seek to bring about change, and manage those who oppose it. Change is perceived differently through different cultures, and especially negative perceptions need to be addressed. Conflict is probably inevitable in cross-cultural contexts, as negative perceptions will arise through cultural differences and challenging communications. By analyzing the context in which change is expected to happen, and also the collaboration context, conflicts could be avoided[4].

Finally, cultural differences will create unpredictable scenarios. The understanding of the cultural and communal values will evolve over time and the perceptions of change and trust will also transform. For this reason, adaptive and flexible ways of working are essential for intercultural collaboration. Rhodes (2022) highlights not only the importance of context and culture, but also relates this to the impacts of the changes that are made, and the level of participation that is involved. Considering these learnings throughout the innovation cycle should result in a product or process that is more suitable for the user, and easier to realize when there is cultural understanding from both sides.

[4] Rhodes suggests using a Cultural Landscape Analysis for this purpose

2.5 Synergies

The previous sections highlighted the challenges and learnings from international technology transfer projects from different perspectives. It became apparent that there is much overlap between the used literature, and in the following figure the most important lessons have been combined to be used in the evaluation of this project.

Learnings	Recommendations	Source(s)
Assimilation is important for the creation of long-lasting impacts	Use a learning by doing methodology Foster knowledge conversion & adaptation	Douthwaite, Clark
Understanding the local context directly impacts the success of the project	Gather sufficient local data Adapt the project to the specific context Understand the culture to understand the context as a whole	Douthwaite, Clark, Lackey
Focus on the (motivated) end user and their connection to the innovation	Promote co-innovation Further develop the innovation within the local context Do not introduce the innovation too widely too soon Understand what motivates the stakeholders and provide conditions in which these motivations can be realized	Douthwaite, Clark
Confidence of the end users is important in materializing the project	Provide an obtainable and translatable product and description Introduce the innovation with the help of local stakeholders Understanding each other’s cultural and moral values creates trust from both sides	Douthwaite, Clark, Rhodes
Work in a context where the need for the innovation is high	Perform thorough analysis of the context early in the project Development will only occur by the locals when it is relevant to their needs	Douthwaite, Lackey
Prepare the innovation for dynamic changes in the context and during the implementation phase	Learn from past projects Have clear and transparent connections with donors Understand each stakeholder, their motivation, and capacities, and manage these accordingly Be wary of goal displacement Prepare for changes in cultural and communal aspects over time	Clark, Rhodes
Development projects are highly complex	Be mindful of the assumptions that are made about the local context It is impossible to understand the whole system and its relations, but sufficient research makes it more predictable and controllable	Lackey
Miscommunications are likely to occur	Use simple and concrete words Understand each other’s cultures and customs	Lackey, Rhodes
Project evaluation is important but often not performed thoroughly	Do not evaluate the project too soon after completion	Lackey
Connect with the user and provide opportunities for bonding and cooperation	Aim to understand each other’s cultural values Find the culturally relevant participatory approach Perceive the first users as co-innovators	Rhodes, Douthwaite
Change and perceptions of change are important factors	Seek out those who embrace change and manage those who oppose it	Rhodes

Table 1: Synergies of relevant background literature

2.6 Methodology: Reflection Loops, Action Research & Grounded Theory

From the foregoing literature review it can be concluded that the creation of a technological innovation is generally not a strict linear path. Developments have consequences which in effect determine the outcome of the product. This occurs not only in the creation of the innovation, but also in the implementation phase. There is a lot of value in understanding these changes and utilizing them. Through reflection it is possible to take these changes into account as forms of feedback and use them beneficially.

But when does one reflect, and how? One approach is to reflect after each stage of the innovation process. Defining these steps however is cumbersome, as the approach to the innovation process would in this case be linear, after one step is completed the next would commence. In reality this is often not the case. This process that this project followed is no different, and is regarded as an innovation in order to understand its development and decision-making process. In this case for example the innovation process could be depicted as follows:

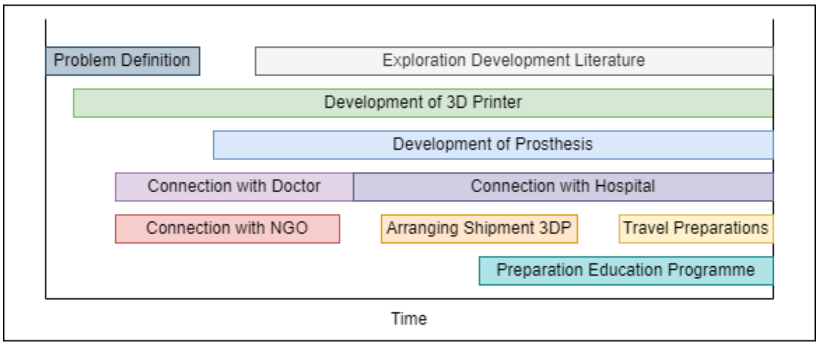

Figure 8: Visualization non-linearity of the innovation process (not to scale)

Instead, the approach to innovation that is proposed in this thesis is an adaptation of the software engineering Feature Driven Development Methodology (Razzaq, Razzaq, Hasan, Ahmed, & Ullah, 2018). After the end goal is sufficiently clarified, the way to reach this goal is broken down into measurable intermediate goals and outcomes, called sprints. These sprints do not necessarily happen linearly, but rather overlap in time. This parallel workflow allows for reflections at the end of each sprint, in order to steer the innovation process in the right direction each time new progress is made. Instead of scheduling the whole innovation process from start to finish, this method allows for dynamic changes resulting from e.g., changes in context, technical failures, or setbacks.

This methodology requires reflection throughout the process, with clear evaluations of progress after each sprint, as well as clear documentation of the steps that were taken, as these will be relevant further along the innovation process. In hindsight it is therefore possible to establish what steps in the sprints shaped the final outcome, and in what order the events occurred. The previous figure shows the different topics with starting and finishing points, but the sprints were defined as more precise milestones. This way the reflection steps do not only occur for example when the 3D printer is finished, but rather when the first iteration is completed. A practical example of the benefits of this technique in the 3D printed prosthesis project was the co-development of the prosthesis and the 3D printer to determine the required size of the printer.

The reflection steps followed a very simple principle, to flexibly adjust the planning of future sprints based on the learnings from earlier sprints. This is depicted in the following figure:

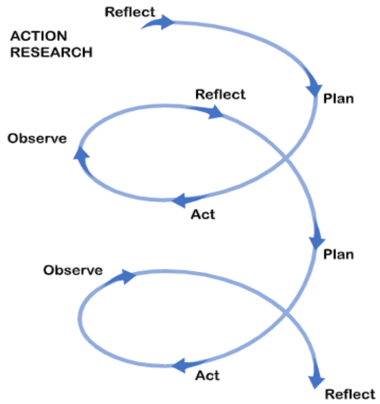

Figure 9: Reflection Loops (Williams, Wiles, Smith, & Ward, 2022)

This figure by Williams et al. (2022) describes the cyclical nature of the action research methodology, defined as executing a problem-based investigation to provide insights by means of first-hand experiences of the implementation process, resulting in opportunities for improvements and reflection whilst researching (Kindon, Pain, & Kesby, 2007). The reflective properties of this theory were intuitively applied by the author in the prototyping phase, whilst the general method was purposively used to structure the implementation phase. This method is advised to be used in practical development studies both by Lackey (1993) and Douthwaite (2002), where its purpose is to help identify possible improvements in time and resolve them.

An action research methodology is focused on resolving practical problems using reflection, whilst being centered around participation. Similar methods are therefore often referred to as participatory action research. This method is a way to create and share knowledge that is meaningful to the people and context in which it is executed by empowering local stakeholders through participation (Johnson & Guzmán, 2013). An idea is linked to a practical execution where co-research, or in this case co-innovation is used to solve relevant problems in an iterative manner and create positive change (Reason & Bradbury, 2008). As the researcher is situated within the execution of the innovation, he or she is able to directly steer and adjust the outcomes through collaborations with local stakeholders, and as such looks at the problem from a unique viewpoint. It is for this reason that the conclusions are often of qualitative nature, as detailed insights provide additional learning opportunities, and unforeseen challenges become apparent (MacDonald, 2012). The lessons that follow are therefore often personal and case-specific, but the methodology recommends detailed and periodic documentation of events and decisions that occur. This documentation is where a large portion of the lessons will be situated, and it is up to the researcher to abstract these and attach constructive meaning to them beyond the project as a whole (Williams, Wiles, Smith, & Ward, 2022).

Action research is broadly defined, and challenging to pinpoint as its usage depends on the context and capacities in which it is introduced (Reason & Bradbury, 2008), yet there are a number of characteristics that emerge in the various examples of action research methodologies put to practice. Achieving action research requires responsiveness, to the location, the stakeholders and the increased understanding thereof, and it is very likely that the early stages of the process will be fuzzy, as better understanding is formed during the collaboration period (Dick, 1995). Continual engagement through experimentations with the stakeholders can be challenging, but the practical nature of this methodology has the potential to have direct positive impacts on local communities (Reason & Bradbury, 2008). For these reasons action research is regarded as an essential approach to hands-on and people-centered development projects such as these.

Willams et al. (2022) proposes to use a combination of action research and grounded theory specifically in health research. Their reasoning is that using multiple qualitative research methods mitigates the limitations of each approach, and harnesses their respective strengths. There is methodological overlap between action research and grounded theory that has the potential to strengthen each other for a more comprehensive approach to practical research and experience-based learning.

Grounded theory is characterized by the way in which a researcher works in an inductive manner, observing issues of importance to people's lives to try to understand what is happening without the influence of preconceived ideas or opinions (Mills, Bonner, & Francis, 2006). The researcher inquires qualitative data for a general explanation of actions, interactions, and social processes. In brief this translates into the following practice (Creswell, 2007); The researcher is in a situation that is difficult to understand or explain, and collects data to form a general idea. In stages, the data is broken down into key occurrences (or phenomena), and explores what causes them to occur and in which context. Through iterations and reflections this data becomes increasingly comprehensive. The outcome is a collection of ideas about the occurrences, and possible explanations thereof, which can be used to create a general theory to explain why a certain social group acts the way it does.

This is beneficial since the researcher is introduced to a complex social system driven by different cultures and contextual factors, and making sense of this system is very challenging (Rhodes, 2022). Preconceived ideas about the way in which a project or occurrence will take place will rarely be correct and the influence of existing stereotypes often hinders the transfer of technologies (Allen, 1990). Grounded Theory helps to look beyond this through open-mindedness, by aiming to qualify social behaviors in a systematic way.

There are some key differences between the two methodologies. Examples of this are focus on generating change (action research) versus developing theory (grounded theory), and the conscious use of theory (action research) versus the inductive approach (grounded theory). Yet combining the two methodologies and understanding their benefits allows for the researcher to understand what is happening and learn through practice and collaboration in a setting with many unknowns (Williams, Wiles, Smith, & Ward, 2022). Similar to action research, grounded theory works in a cyclic and iterative manner, where reflection is a central topic as the researcher gains more understanding of the events and repeatedly gathers additional data and analyses it (Mills, Bonner, & Francis, 2006).

It is therefore a suitable addition to the action research methodology. In this thesis grounded theory was not consciously applied during the implementation process, but it is utilized to frame the findings that occurred, as the author attempted to experience the implementation phase with an open mind in order to steer the project in the right direction. It is combined with the action research methodology in order to understand what influence the sociocultural aspects of the Lombok setting had on the execution and outcome of the project, and how the iterations and reflections during the implementation process tailored the design and training program to the involved stakeholders.

Coupling this with the research questions, the use of reflection loops, through of action research, resulted in an understanding of the events that occurred during the implementation of this project. Framing these events through the lens of grounded theory allowed for a qualitative representation of the influences of the relevant sociocultural factors. These combined with the underlying properties of the project were used to evaluate this project and draw wider lessons for future assimilations of technological innovations in Global South settings.

3. Project Description

This thesis revolves around the project of 3D printed prostheses for the Global South, which consisted of a medical and technical background research and implementation on Lombok. To provide a better understanding of the decisions that were made and steps that were taken, the individual facets of the research project are broken down in this chapter. This is done to provide a comprehensive overview of the events that occurred to realize the prototype and technological assimilation of 3D printed prostheses on Lombok. This will then be used in the following chapter to reflect upon the case study as a whole.

3.1 Design of the 3D Printer

3D printing is a technology where layers of a specific material are consecutively fused on top of each other to create a product. There are many different technologies which utilize different materials, but the focus of this project is on Fused Deposition Modeling (FDM) 3D printing. This type is chosen as it is affordable yet has the ability to create strong and durable objects with relative ease.

FDM 3D printers print with different polymers. The most common types are PLA, ABS and PETG. These all have different strengths and weaknesses, and the user is able to experiment with all these materials depending on the requirements of the products. The benefit of a FDM 3D printer is the fact that it is easy to modify. There are hundreds of printers to choose from, but for this particular project there were a few demands that had to be met, namely:

1. Affordability

The project was intended such that after proof of concept it would be possible to duplicate the printer within a Global South setting. This means that the costs should be as low as possible whilst achieving the desired quality

2. Size

The printer needs to be able to print a full-size lower leg, up until the knee. The desired size was determined by looking at the knee-height of the 95th percentile of the Indonesian population, namely 62 centimeters (Chuan, Hartono, & Kumar, 2010), so the vast majority of patients could be treated with this one machine. As there were no affordable printers available with this size, I instead looked at printers of which the size would be easy to increase. At the start of the project, it was still unknown what the shape of the final product would be, and as such the printer was created so the size could fit the whole prosthesis as one part, this requirement changed as the project developed.

3. Speed

Speed is an important factor as well, and one of the biggest limitations of FDM 3D printing technology. The other requirements were simpler to realize, but the print speed was challenging throughout the entire project. To print a lower leg prosthesis on a standard 3D printer would take multiple days to complete. To limit the complexity of the project, only one printer would be provided to the hospital, and the goal was to provide a printer that could produce one prosthesis per day, which meant a lot of adjustments needed to be made to the original design.

4. Maintenance

Finally, the printer needs to be relatively easy to maintain. The technology was envisioned to be introduced to people without prior knowledge of 3D printing, and this can be quite overwhelming. By having a printer that is easier to understand and maintain this problem can be minimized. This influenced some of the design decisions throughout the process, where ease of use and ease of maintenance needed to be balanced.

The printer was introduced to local hospital staff, where the normal P&O work is quite labor intensive and technical, so it was assumed that the staff possessed basic technical skills. Yet, the end user had never worked with 3D printing or similar technologies. This was challenging, and the complexity of it could very well scare the user and hinder the implementation process. Therefore, the printer was introduced during the development stages, accompanied with photos and videos. This way the hospital staff knew what to expect, and gained prior knowledge in the early stages of the project.

The design was kept as straight forward as possible. There are many tricks in using 3D printers that will make the process less labor intensive or change its functionality, but these are more complex to understand and should only be considered for advanced users. For example, the first design of the 3D printer used a BL-Touch sensor. This sensor takes care of the normal bed leveling procedure, by automating it. This seems great, but it adds to the price of the printer, and introduces new settings and calibration steps that are very important. The manual process is very easy to explain and understand, so despite the benefits of the sensor it was decided that this would not be included in the final design. This sensor and other complex components could always be added in the future, once the user has a better understanding of the technology.

3.2 Patient Treatment & 3D Scanning

The scope of this project is limited to transtibial (below-knee) prostheses. These occur when an amputation has taken place where there is a residual limb, or stump, below the knee of the patient. This is the most common form of amputation (Marshall & Stansby, 2008) (Andhika & Ismiarto, 2020), and hinders the patient from walking and performing daily tasks without help from a medical device. Even though it is possible to 3D print multiple types of prostheses, the scope is limited to this kind as it can make a vital difference to the user's life, whilst it requires fewer (complex) parts compared to above-knee or transfemoral prostheses.

On Lombok the predominant method for creating prostheses is the previously presented ICRC method[5]. The procedure is therefore widely known. First the patient's stump is measured, before a plaster mold is made around the stump. This is then cast to create a physical replica of the stump. On this physical replica the doctor will make adjustments to make the prosthesis fit well, whilst protecting the sensitive areas. The result is what is known as the rectification, or corrected model.

This model is the basis for the prosthesis. Combined with the previously taken measurements the doctor will build the prosthesis around this model. For the ICRC method this means shaping a combination of plastic components and sheets, made such that the doctor is able to adjust it according to the needs of the patient. The prosthesis is made by hand, melting the plastics together to form the general shape of the prosthesis based upon measurements of the patient. The patient will then fit this prosthesis to allow the doctor to adjust the positions of the foot and the area around the stump, called the socket, to fit with the walking pattern of the patient. This is known as the alignment process, making the prosthesis comfortable and easy to use. The alignment position is locked in place and finally an aesthetic cover is made from plastic sheets.

Instead of building the prosthesis around the corrected model, the purpose of creating 3D printed prostheses is to minimize labor and material use, which corresponds to a lower cost per patient. 3D printing technologies use digital files to create dimensionally accurate physical objects. It therefore needs a way to transform the physical information about the patient's stump into a usable digital copy. To do this, 3D scanning is introduced. 3D scanning is the use of a specific camera to create digital copies of the physical world. There are many types of 3D scanners, but most of these are very expensive. As an alternative, the Xbox360 Kinect is used as a 3D scanner in this project. This device is originally created for the purpose of video games, but the software Skanect has been created to use it as a 3D scanner instead, and the results are adequate when compared to other scanners. As these have been mass produced on a global scale, they are readily available at an affordable price point.

The doctor can use this scanner, in combination with the Skanect software on a computer, to create the required digital copy of the corrected model. This process takes around ten to fifteen minutes and is

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[5] Information about this method is based on the transtibial prosthesis manufacturing guidelines of the International Committee of the Red Cross (ICRC, 2006), and the Jakarta School of Prosthetics & Orthotics transtibial course manual (JSPO, 2009)

relatively simple. Combining this with the patient measurements provides an opportunity for the doctor to create the 3D printed alternative.

3.3 Design of the Prosthesis

To provide a better understanding of the design of the 3D printed prosthesis, first the ICRC design is explained in more detail. The ICRC design, like most other transtibial prosthesis, consists of the area around the stump called the socket, the prosthetic foot and a connecting rod called the shank. The purpose of this design is that there are two locations in which the aforementioned alignment can take place. The doctor can adjust the angle of the socket and the shank, as well as the angle of the shank and the foot, to perfect the configuration of the prosthesis for the patient (ICRC, 2006).

Figure 10: Examples of the ICRC transtibial prosthesis (Geographical Imaginations, 2015)

The most common method for the alignment is to use the pyramid connection from Ottobock (Zepeda, 2022). This metal connector however is generally too expensive to be used in a Global South setting, which is why the ICRC has created a plastic alternative. This plastic connector can be set in different positions as it consists of a concave disk with gridlines. By tightening the locknuts, the position can be securely set.

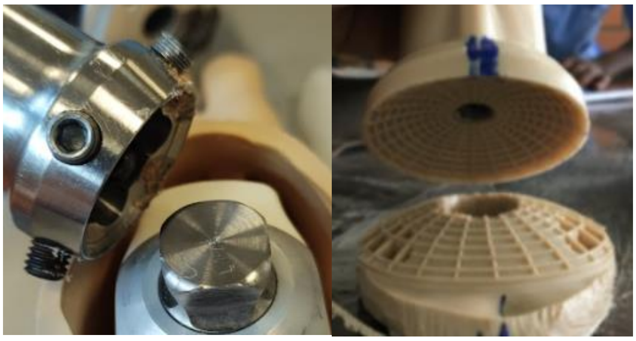

Figure 11: Ottobock Pyramid connector (left) and ICRC connector (right)

The same design principles are applied in the 3D printed design. Here however one of the limitations of 3D printing influences the design. As the material used for 3D printing is plastics, the material properties are to be considered. The plastic has good load-bearing properties, and is easily adjusted to fit the needs of the patient, but the problem arises when torsion arises in the connection between the components. These forces are most likely to damage the prosthesis, and have been the reasons of failure for all of the prostheses tests that occurred.

Based on this limitation, the decision was made to change the design of the 3D printed prosthesis, where it does not consist of a socket, shank, and foot. Instead, the socket and shank are made out of one solid piece. The upside is that it decreases the number of connections, increasing its strength and removing the need for an aesthetic cover, but the downside is that it removes one of the alignment positions. This was discussed in detail with medical professionals, as it is a direct trade-off between durability and patient comfort. The decision was made based on the fact that fewer alignment steps generally occur in this position, and lack thereof should not cause medical issues for most patients, and would only influence their comfort. In the event that the patient is experiencing significant discomfort the whole print needs to be produced again. In the future it would be interesting to see if the other alignment position could also be integrated, but this falls outside of the scope of this project.

The benefit of using a 3D printer is that it simplifies the steps the doctor needs to take. The same corrected stump is created, but instead of building the prosthesis by hand, the doctor will use the 3D scanner to digitally capture the prosthesis, and using software will convert this into the final prosthesis design. This lowers the production time from multiple days to a few hours, and the 3D printed part includes the aesthetic shape right away. As a result, the patient will be able to use the prosthesis immediately after the alignment steps have taken place.

3.4 3D Modelling and Printing Steps

To create the prosthesis, the doctor will use the 3D scanning data from the Skanect software and upload it into Fusion360. This is one of the most-used 3D modeling softwares and provides the user countless ways to manipulate a 3D object. This program is used to derive the 3D printed part from the 3D scan and the patient measurements, by using parametric design methods. This method is feasible since although it takes some time to learn, it will be the same procedure for each patient. With practice this should therefore take around one hour per patient. This was a very time-consuming part of the project to prepare as there are many different ways to reach the final outcome, but the chosen method would have to be easy to understand for first time users. Additionally, the size of the scanned 3D model directly impacts the speed of the software calculations, so the 3D scan had to be adjusted to be as detailed as necessary, but not so detailed that the hospital would need a very powerful computer to be able to create the prosthesis.

There are software packages available that reduce the amount of work for the user even further, by automatically creating the socket from the scanning data, yet these software packages are very costly and are typically used with other 3D printing technologies. Exploring the 3D modeling steps in the preparation phase led to a design that was most suitable, and it allows for easy adjustments to improve upon the strength, visuals and comfort for the patients if needed, as well as an opportunity for the end user on Lombok to make adjustments to the design, specific to the local needs and methods.

Once the final model is created it can be 3D printed. To do so, the 3D model first needs to be converted into a set of instructions for the printer. This is done in the program Cura, where the user can manipulate the design in such a way where material use, weight and strength and time consumption (among others) can be changed to optimize the final 3D print. The final instructions can be inserted into the 3D printer, and the production process can start. If the printer is set up correctly this is as simple as loading the file onto an SD card, turning on the printer and starting the print. The printer will then start the production process without needing involvement of the user. As the printer is prone to errors however it is advised to monitor the device throughout the day as not to waste materials and time on faulty prints. This is why the maintenance part is critical, as the printing process itself is fully automatic, the user is instead spending the most time to ensure that the printer works consistently.

3.5 The Training Program

As mentioned, the doctor not only needs to learn how to operate and maintain the 3D printer, but also needs to be able to create the prosthesis using 3D scanning and 3D modeling software. The figure below shows the aforementioned software's and the orders of use:

Figure 12: Different Softwares Used to Create the Prostheses

All of these softwares are free to download and use, and have a lot of support features from the creators and user communities. This means that there is plenty of available information online for a new user to learn about each program. Fusion360 is normally a paid program but is free for students, so it was possible to arrange an account through the Unram University on Lombok.

Initially it was decided that the most effective way to teach these steps would be through a combination of different mediums, as this would surpass the language barrier. However, as the design of the 3D printer and the prosthesis were still being improved in the last weeks before the scheduled visit to Lombok, there was no time to also create videos. The final manual therefore consisted of a physical and digital booklet with English instructions, where almost all instructions were accompanied by clear images.

Before implementation some of the materials, including existing instructional videos, were shared with the hospital on Lombok, but the majority of the training program was executed during the visit. Mindful of the fact that the doctor also had other daily obligations. The end result was a streamlined program which explored each part of the production method in detail, whilst in theory providing enough time for the training program to be completed without disrupting the workflow of the hospital staff.

3.6 Implementation on Lombok

This section provides a subjective overview of the implementation phase as perceived by the author.

I arrived on Lombok on the 21st of August, together with my partner Nine. We had purposefully scheduled the training program to start on the 23rd to have some time to rest and prepare for the first day. The Unram hospital is located in the busy city of Mataram, and stands out as it is one of the few high-rises in the area. Upon arriving at the lobby, it became apparent that a considerable number of patients visit the hospital each day, and we stood out as the only westerners in the hospital. Being such a large organization, the scheduling was well arranged, and the hospital staff was prepared well for our arrival. It is a university hospital, and especially the educational staff was much involved in the project, this department was in charge of arranging the rooms, presentation, and scheduling, and were very accommodating. The medical staff was very knowledgeable about the creation of prosthetics, and showed promise of technical capabilities as well.

Figure 13: The Unram hospital in Mataram

The equipment that was made available was adequate, only the laptop that was used was very slow. Luckily, this was anticipated in the training program and because the software was optimized this did not cause any significant issues. To speed up the process the program was executed on my personal laptop, and only converted to the slower alternative at the end of the program. The tools for the prosthetics department are still very limited, such that the doctor takes the patients' casts home in order to do the rectification process. This brings about the risk of damaging the cast during transportation, and also hinders the efficiency of the process. The hospital therefore has the capabilities to consult with patients, take their measurements and create prostheses accordingly, but is not able to do this efficiently within a reasonable timeframe. The introduction of the 3D printer could help in decreasing the production time, but should also serve as a tool to grow the prosthetics department to attract more staff and allow for all procedures to occur within the hospital itself.

The 3D printer that was assembled on Lombok was a direct replica of the printer in the Netherlands. It was initially planned to ship this printer to the hospital, but this was not possible as there were issues in arranging this shipment through customs. It was brought to my attention that there could be many issues if the package would not be registered beforehand, but this was not possible as it was denied continuously for various reasons. In the end the original printer was purchased on Lombok, and the components necessary to adapt the printer were brought in my luggage, luckily without any issues at the airport customs. I also brought all of the tools that would be required for the printer and prosthesis assembly, and donated them to the hospital staff, as such I was not dependent on the hospital to supply these.

On the 23rd of August, my partner and I arrived at the hospital in the morning to assemble the 3D printing and run some tests. It was initially intended to give the opening presentation this day to meet all the staff, but this was not possible due to inspections at the hospital. Despite the fact that we had to get used to the climate conditions, we managed to build the original 3D printer, and implement the adaptations, before lunchtime. During this time we met with a great number of hospital staff who stayed to watch us work. We were welcomed with open arms and the doctors were present to follow our progress. During this time I decided to include them in some of the steps to explain the functionality and the different components of the 3D printer. I also gave them the manual to study beforehand, so they had time to study the information before the training program commenced. Here it already became apparent that the language barrier would be an issue, as they took a very long time reading the introductions. They tackled this by studying together whilst using Google translate.

The printer was finished at lunch but apart from a small demonstration to the staff we could not test it yet, because the software of the 3D printer, called the firmware, could not be loaded onto the motherboard. We were aware of this issue, so we brought the right component, called a bootloader, to solve this. However, doing the same procedure as we did at home did not seem to work, and we were not able to load the firmware onto the 3D printer on the first day. Part of the issue was the fact that we were in the radiology room, where there was no Wi-Fi access. This meant that we had to walk to the hallway and back every time we tried to find a solution. In the end we decided that it was best to look up the problems and solutions in the hotel, so we could find the solution more efficiently and think of multiple options.

The next day this paid off, as we were able to solve the issue in the early morning. This meant we were able to demonstrate the printer during the presentation. I presented the project to a large audience of medical staff, the director of the hospital and the VLOK foundation. In the end it was a good way to answer their questions and explain in more detail what I would teach the doctors and how it would fit in the current system of the hospital. It turned out that the hospital already owned a 3D printer, and one of the doctors was learning how to use it to be implemented in the hospital. I was never informed of this, partially because I never asked as I assumed they would have told me this beforehand, but this was great news nonetheless. This means that the information I would present in the following days was not new to everyone in the hospital, and they could use it to their advantage. This also means that if a 3D printed part of the printer breaks it can be resolved more easily. For the printer already in use at the hospital, there was a back-up power source, which is something I had considered to be too expensive to include, a wrong assumption from my part.

Figure 14: Presentation of the project in the Unram hospital

After the presentation, the training program commenced, which continued for 5 more days. During this time I taught Doctor Arbi everything he needed to know, from the patient measurements to printing the prosthesis. He is the only prosthetist at the hospital, and therefore treats all amputees at the Unram hospital. The training program consisted of 3D scanning, 3D modeling and 3D printing. The latter however was very difficult, as more issues arose with the printer throughout this period. In the end the motherboard of the printer was not working when the training program finished. We had discussed this, and I would send a replacement from home. This meant that the majority of the training program on site consisted of the preparatory steps. Arbi was accompanied by doctor Sabda most days, he was in charge of repairing the hospital electronics, so this was a good match. In the end doctor Sabda had gained as much knowledge as Doctor Arbi. However, the language barrier was a big problem. I had arranged for a translator for the training program but when no one came after the first days I had to make new arrangements, luckily a translator was able to accompany us on the last two days, who also agreed to translate the manual to Bahasa Indonesia, which should help for future issues.

Arbi and Sabda were quick learners. They were able to master the 3D scanning process within one morning, and enjoyed this part a lot. The 3D Modeling steps, in Autodesk Fusion360, were the most difficult steps of the program. I knew this beforehand as there were a lot of steps that would be very difficult for someone with no 3D modeling experience. In the end Arbi was able to walk through all of the steps on the final morning, without needing assistance. This was achieved by doing small portions together, and letting him repeat it himself. This independence proved to be quite difficult, but it helped him as he grew used to first looking in the manual, then trying it, and only asking for my help when necessary. This learning by doing method is the reason that we were able to achieve so much in only a few days.

When the program was finished, I was given the opportunity to say goodbye to everyone involved in the project, and despite the technical issues with the printer it felt like the implementation of the project had been successful. The medical staff was excited and was already motivated to help the first patients. Very shortly after my departure I was informed that doctor Sabda had resolved the issues with the motherboard, but as they started doing more tests there were still some issues with the printer. These issues would remain for the first months after my departure, but through online interactions new solutions could be implemented to repair the 3D printer.

3.7 Online Aftercare

After the implementation phase the printer was not yet ready to be used to create prostheses for patients. As a matter of fact, it took around three and a half months until all of the technical issues were resolved, and the printer was fully functional. This can be broken down into two different types of problems. First were the printing quality issues. These consisted of molten and shifted prints, and the printhead colliding with the printed object. A combination of hardware tweaks and revised printing software eventually solved these issues, but the printing quality was still not sufficient. Second was the filament issue, which became apparent in the final stage. Due to the high moisture levels in the air the filament degraded at a much higher rate in the local climate than in the Global North setting. The same prints executed on the same printer in the Netherlands and Lombok would therefore result in different outcomes, which made it very difficult to deal with the aforementioned printing quality issues. Once the cause of the issue was discovered it was possible to improve the filament storage method, and use the same files to achieve similar printing results, of sufficient quality.

Figure 15: Examples of failed prints shared by the hospital staff

The project ended when in December of 2022 the hospital staff was able to independently print a successful 3D printed prosthesis prototype. A cast of a former patient was used, where the newly acquired 3D scanning and 3D modeling skills were applied to create the prosthesis, and the printing process was carried out within the hospital, without any outside help.

Figure 16: The first complete prototype printed by the hospital staff

4. Project Evaluation

The aim of the project description was to provide an overview of the events that occurred to the reader. However, these events alone are not sufficient to draw conclusions about the success or failure of the project, and its resulting learnings for future projects. The stages of the project are evaluated and coupled with relevant theory to determine what decisions and methods influenced the final outcome, and what learning opportunities these findings provide.

4.1 Evaluation of the Intended Outcome

Initially the project was envisioned as a leapfrogging tool, utilizing 3D printing technologies to create a variety of circular leg prosthesis types for the Global South. There is however a large deviation between the intended outcome and the actual outcome. There was not enough time to develop the recycling aspect nor the above-knee prosthesis design, as the author had to manage the time and funds in such a way that the prototype that would be introduced would be as feasible as possible. The result is a minimum viable product, a presentable product that meets the base requirements for its purpose (Kleczewski, n.d.). This is a prosthesis design and 3D printer prototype that created a proof of concept to create affordable 3D printed below-knee prostheses, based upon a novel production process fitting for the setting of Lombok, including a training program adapted to the intended user.

Focus was not just on the design itself, but also on the way in which it would be introduced in the Global South setting. This is a vital part, as the technology and methods have to be adapted to the local context and introduced in the most suitable way to promote assimilation. Here the question was, should the project fit within the current system, or change the current production methods and departmental structures in the hospital? This is a decision that is made by an innovator throughout the process, whether conscious or subconscious, as he or she assesses the available knowledge of the current system and finds a way to fit the project within it. This however raises the question to what extent the system itself needs to be changed for the project to become successful.

More systemic change can steer the target group in better directions (organization oriented, economically, environmentally) but it could also lower the chances of the project's success as there could be more resistance to substantial change, or more difficulty in implementation (Hirschman, 1967). For this project it was envisaged that the best approach was to fit the technology and methods within the existing system. This seemed most suited for the Unram hospital as the P&O department was already functioning as its own entity within the hospital, and the 3D printer would serve to increase efficiency and reduce costs. As such the doctor would simply be able to help more patients than before at a more reasonable price-point. As the P&O department of this hospital consists of only one staff member the only additional considerations were considered to be with the department of finance as the required materials for the patients would change. If these changes would be adapted and implemented successfully it is expected that more reforms to the system would be necessary to account for different patient experiences and return rates as the new prostheses reached their end of life. This however was not implemented as these results would still be uncertain in the early stages and the hospital would be better suited to account for these changes in the future.

The intended outcome was therefore to promote 3D printing technologies as a tool for the Unram hospital. The P&O doctor would need to be trained in the use of the 3D printer and the accompanied 3D modeling and scanning methods, building on his experience as a trained medical professional to stimulate the availability of affordable below-knee prostheses on Lombok. Through learning by doing he should become increasingly capable in using the technology and build upon the initial prototype to truly make it his own, assimilating it within the existing system and production methodology.

During implementation it became clear that the supporting structures in the hospital, especially the technician and education staff, would play a large role in this process. Where the training program was envisioned to be the largest challenge, technical issues proved to have the biggest influence on the results of the project. The first prosthesis prototype was successfully printed in the Global South context, but it is not yet possible to determine its impact on the local amputees. Where the phrase ‘no project works out as planned’ (Lackey, 1993) applied seamlessly to this development project, it was also clear that understanding the structure at the hospital, knowing the capabilities of the users and adjusting to their culture and methodology played vital roles. This will be explored further in the following sections.

4.2 Evaluation of the Innovation

The innovation consists of three parts, namely the design of the 3D printer, the design of the prosthesis and the production method. These were all created within a relatively short timeframe and were therefore not optimized. There was (and still is) room for improvement for each, but each also had beneficial properties that could be of use for other projects. For this reason, they are broken down into their strengths and weaknesses.

3D Printer	
Strengths – Affordable – Easy to assemble and maintain – Made from readily available components – Large print volume – Relatively fast print speed	Weaknesses – Unreliable at times – Difficult to transport through customs – Filament not optimal in humid climates – Dependency on reliable electricity network
Prosthesis	
Strengths – Affordability goal reached (<$50) – Requires less manual labor compared to conventional manufacturing technique – Customizable to fit patient’s wishes – Reusable foot and bolts – Lower lifetime carbon footprint than conventional manufacturing technique – Quick production and assembly	Weaknesses – Fewer alignment possibilities – Has not yet been sufficiently tested – Predicted to be weaker than traditional, lower lifespan as a result – Predicted to only suit patients up to 70 kg – Not suitable for high intensity purposes (e.g. sports) – Dependency on functionality of 3D printer
Production Method	
Strengths – Shorter production time – Fitting with existing ICRC methods – Free software’s and affordable 3D scanner – Digital archives of stump, prostheses and scanning procedure, allowing for easy adjustments – Worldwide access through cloud services – Flexibility for methodology to be adjusted by user	Weaknesses – Requires invested practice time to be quick and reliable – Dependency on functionality of 3D printer – Production time depends on power of used computer

Table 2: Strengths and Weaknesses of the 3D printer prototype, prosthesis prototype and production method

Evaluation of the 3D printer

It became apparent that the 3D printer caused the biggest hurdle in the implementation phase, as many unforeseen problems arose that were only resolved after several months. The author aimed to create an affordable 3D printer with the benefit of having affordable replacement parts and the potential for the hospital to replicate the 3D printer within their own budget if there would come need to increase production. This also allowed for experimentation given the limited budget, and the printer works perfectly in the Global North setting.

This printer was created and improved upon over a long period of time. At the start the biggest challenge was to realize the aforementioned adjustments to the purchased 3D printer. This took a lot of experimentation and was realized with the help of two experts. Implementing the adjustments themselves was not the biggest challenge, the designs were well thought out and discussed in detail with the experts. What happened however was that throughout the project the printer faced malfunctions that had to be corrected. These malfunctions seemed daunting as the printer would not be functional for consecutive weeks, as parts broke and new ones had to be purchased and installed. This was very challenging but at the same time gave the author a lot of opportunities to improve the design, and provided insight into challenges that could, and eventually would, occur in the Global South setting. In the end the printer was working reliably in the Global North setting, but the improved design would still be a challenge during implementation.

As such, the printer was not working reliably on Lombok, and it could be argued that for the perceptions within the Global South setting, it would have been better to raise funding for a more expensive printer to be donated to the hospital. This would have better impact on the local amputees, but would not have provided the agency to the hospital staff to continue improving upon the innovation and truly make it their own. The delays in reliable printing allowed for the hospital staff to experiment further with the printer and through learning by doing, create their own problem-solving methods, which was one of the benefits of having a simpler machine. Relating this to the original goal, to create an innovation that was assimilated within the local context and could therefore be used to fill the gap of affordable prostheses, it becomes apparent that the solution would not have been to use an expensive printer instead. The hospital staff now has access to the complete design of the printer, so they are able to make adjustments using readily available parts as needed, this would not have been possible with a more expensive closed-loop printer, which would impose technological dependence upon the manufacturer.

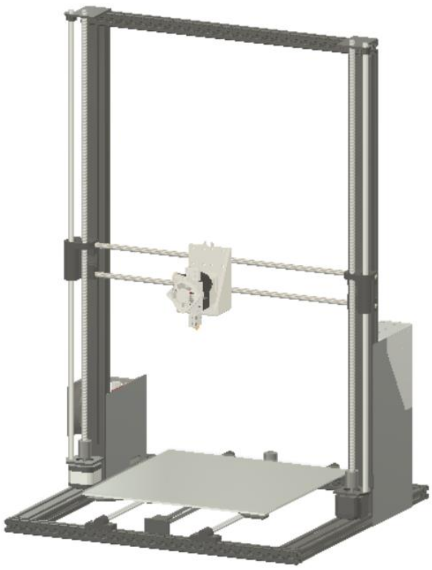

Figure 17: The digital 3D file of the printer, accessible to the end-user

Instead of changing the design of the printer, it would have been beneficial to take more time to test and improve the printer design within the local context before commencing the training program. This would have allowed for the same agency of the end user but would have given them more confidence in the innovation and would have increased the pace at which patients could be helped, as the author would have been present to rapidly solve the biggest issues before departing.

Looking back at the original design it is clear that there are some improvements that could have made the printer significantly more reliable, this could have been achieved in an affordable way. Firstly, the required size of the 3D printer was determined before the final prosthesis design was finished, and for this original requirement only the Anet A8 Plus 3D printer was suitable. In hindsight the size requirements could have been smaller, allowing for a printer of higher quality with a similar price to be bought instead. As the size was determined before the medical research it was assumed that the foot would be part of the printed prosthesis. At this point the printer was therefore chosen to also fit the size of the foot, which in the end would not have been necessary. A smaller printer could have instead been adjusted in height and print speed similarly to the adjustments of the Anet A8 Plus. Not only would the printer be more reliable, as a better alternative could have been utilized, but it would also have been easier to transport. If the project continues in the future this should be considered.

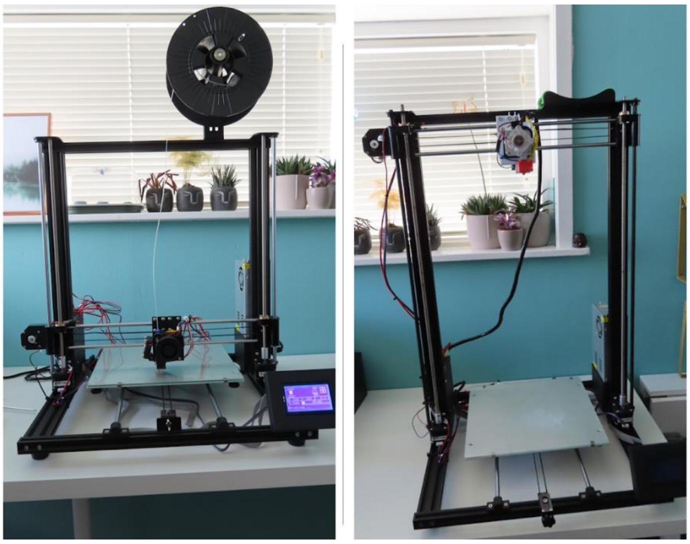

Figure 18: The original Anet A8 Plus (left) and the final adjusted 3D printer prototype (right)

In the end the 3D printer was fast enough to create an adult prosthesis within a ten-to-twelve-hour period, meaning that each day one prosthesis could be created. This aligns with the envisioned goal, but is still not ideal. As the speed of the printer is increased, so is the risk of failure. This contradicts the fact that if the print occurs during a working day, that the user could correct any failures that come up, whereas a longer print would continue during the evening when there is nobody present. In this case this means that the speed of the printer will never be ideal, but can be finetuned to reach the most reliable results. For now, the settings have been calibrated on slower speeds, as such the prints are more likely to succeed without needing corrections from the user. Once the user gains more experience the speed of the print could be increased as is best suitable.

Finally, electricity plays an important role in the use of the 3D printer. This was known beforehand and played a role in selecting the hospital for implementation, as unreliable electricity supply severely hinders the printing process. If the power runs out for a short moment it is highly likely that the whole print fails and has to start over, meaning that the material is wasted, and the hospital has to wait another day to create a new prosthesis. During the training program the hospital provided a back-up power supply that would keep the printer running for approximately one hour if there would be an outage, so luckily this will not cause many issues within the Lombok setting, but should be considered for other locations.

Evaluation of the prosthesis

In the Netherlands, the production method for prostheses is quite similar when compared to the Indonesian (ICRC) method. The patient is measured in the same way, the stump is cast in plaster and is corrected. The JSPO manual (2009) describes the casting procedure in a different order of operations than the Dutch method, but the outcome is almost identical[6]. The next steps however are very different. The aforementioned Ottobock connector is the standard here and as such the prosthesis is made from a more advanced prosthetic foot, metal shank, and light weight socket. This socket is usually made from different types of synthetic resin, hardened with carbon fiber (Movao, n.d.). Finally, the aesthetic cover, which is usually removable, is optional. The prosthesis usually looks very high tech, and the user can opt to make it appear natural as the doctor can form low-weight foam to match the other leg. Comparing this to the Indonesian method shows that the main difference is in the used materials and the amount of labor necessary, yet in principle the methods are very similar.

It was crucial to adapt the design of the 3D printed prosthesis to the Indonesian method however, as this fits better within the current production methods at the Unram hospital. This makes the transition to the new technology easier (Stewart, 1981) and allows the doctor to directly apply his professional skills. Early on in the project the author discovered that the doctor had studied the same JSPO manual, and uses this methodology for each patient on Lombok. The design was therefore adjusted to fit with the JSPO method and terminology. Additionally, considering the available resources within the local context shaped the design of the prosthesis, as the materials need to be readily available for efficient production. Despite its high-tech nature, the design was therefore adapted to existing technologies within the local context, and adapted to the capacities and resources available.

Figure 19: The final prosthesis design, digital (left) and 3D printed (right)

The design of the prosthesis was not thoroughly tested before the implementation phase. The reason for this was both the short timeframe of the project, as well as the difficulty to find test patients. Only one patient was approached through the Fontys Hogeschool, but she was not able to test the prosthesis beyond the fit and size. Finding additional test persons proved troublesome as the Dutch legislation does not allow medical institutions to provide materials to patients that do not conform to human testing regulations (Rijksoverheid Nederland, 2022). Obtaining approval for this would have taken too much time and resources, and as a result the testing phase will need to continue in the Global South setting. This makes it difficult to assess the success of the project within such a short timeframe, but at

[6] This information was gathered when creating the socket for the Dutch test person at the Fontys Hogeschool Eindhoven, where a P&O student followed the JSPO manual to create the rectification

the same time allows the end users to test and improve upon the original design based on the needs of the local patients.

Assumptions have been made about this specific prosthesis design, in collaboration with the aforementioned medical experts and users. Its design is more simplistic than the ICRC alternative, where the reduced alignment possibilities could impact user comfort. This simplicity however benefits the production time, complexity for the hospital staff and durability. It is likely that the prosthesis will support users with an average Indonesian weight of 63kg for males and 53kg for females (Chuan, Hartono, & Kumar, 2010). This is an advantage to this specific context, but as the printed parts are relatively vulnerable it is not likely support the 95th percentile of 89kgs (Chuan, Hartono, & Kumar, 2010) nor suitable to be used for sporting activities. Finally, a traditional prosthesis will be in use for approximately two to three years before it needs to be replaced[7], but to be conservative it is assumed that after one year the printed part of the prosthesis will wear down, and need to be replaced. The foot and metal connectors, which are the most expensive parts, will last much longer.

Evaluation of the production method

The use of 3D modeling to produce the prostheses is inherent in the use of the 3D printer, but there were many different ways to achieve this. Through the use of 3D scanning, after the corrected stump is created, allows for a better fit within the current skills and methods. It would also be possible to perform the corrections within the 3D modeling software but this would require more training without resulting in direct benefits, and making the production method as familiar as possible gives the user more agency and motivation to use the technology (Clark, Hall, Sulaiman, & Naik, 2003).

The software packages were carefully chosen to be affordable and allow for flexibility in the design steps, again to allow the end user to adapt the method to their personal needs. This was very time consuming to prepare, and took many attempts, but in the end was streamlined to be as simple to use as possible. Even still it requires practice and patience from the end user to learn, as it remains a complex endeavor. The chosen method is not automated, which expensive alternatives are, but this ensures that the doctor will look at each patient in great detail to ensure the prosthesis will fit correctly. This is important as only one prosthesis can be printed each day, and errors would be both a waste of materials and time.

It is quite difficult to judge what alternative would have been better, as a more automated way comes with many benefits and risks. If it would be possible it would be advised to adjust the production method to be as obtainable as possible, based on the knowledge of the end context and user (Douthwaite, Keatinge, & Park, 2002). If there are no existing P&O experts available in the location of implementation then leaning on automation might be the only viable option, but in this case the local experts were sufficiently knowledgeable about producing prostheses, as such the design was adjusted to the current methods as much as possible. This was done in order to create an environment where the end user would be encouraged to co-innovate.

[7] There is little information available about these figures, as ICRC has not published these. This assumption is based on available data and comparisons to western prosthetics

4.3 Evaluation of the Training Program

The training program was prepared to ensure a successful implementation phase. This required the aforementioned 3D printer, prosthesis, and production method to be completed, and was therefore created shortly before implementation. On the one hand this was beneficial, as it meant that introductions to the hospital staff had already been made and the planning was created simultaneously. On the other hand, this limited the time available to perfect it and add additional mediums to present the information as comprehensively as possible.

The biggest challenge here was the lack of prior information available about the skills and know-how of the hospital staff. Attempts were made to uncover these beforehand, but most became apparent during the implementation phase. The author therefore had to make adjustment as each day of the program proceeded. The action research methodology played a very large role here as learning by doing, observing, documenting and reflecting each day provided insights in beneficial changes that could be made. The involved staff members acted differently than initially imagined, and by involving more people in the process it was possible to collectively discover challenges in the program and written manual, and improve these on a daily basis.

The manual was created based on the knowledge level of the user and explained every step in detail, accompanied by sufficient visual aids in the form of diagrams screenshots of the modeling programs. Yet the biggest mistake that was made here was the extensive use of text. A significant knowledge gap had been anticipated but by adding too much text in the manual even the simple instructions were not read at the beginning. The text would only be read if the users were instructed to do so. This also occurred when providing instructions in emails and during videocalls. Including a translator during the training program was the most effective solution, but despite efforts to arrange this with the hospital on the first days, the translator was only present at the very end of the program. Her presence increased the productivity of the daily activities dramatically and she was also able to create a version of the manual in Bahasa Indonesia.

Trying to understand these occurrences through the lens of grounded theory, it could be argued that this could have been related to having a short attention span. It was therefore necessary to filter out the most essential information whenever necessary. It is also possible that the staff thought it would be too difficult or too much effort to read the text, or lost confidence, but it could also be related to other aspects of the local culture. Instead of addressing this issue it was more productive to overcome this, not only with the translator, but also through repetition, often referring to the manual to answer questions rather than giving the answer, and asking for explanations when certain steps were taken. It is important to understand what the reasoning is for certain behaviors in different cultural groups, but within such a short timeframe it was prioritized to advance the training program each day, so through action research (testing, documenting and reflecting) the productivity of each day of the training program gradually increased as the methodology was adjusted to the needs and preferences of the local stakeholders.

The lack of understanding of the manual relates directly to another mayor hurdle in the training program. This was the fact that the hospital staff was not able or willing to learn individually, during the moments when the author was not present at the hospital or was working on the 3D printer. This was not anticipated beforehand, as it was expected that the doctors would be able to repeat the steps by themselves under guidance of the manual. Initially the program was designed so after the first days the hospital staff would have two days to experiment without presence of the author, to experiment with the subject matter and discover any unclarities or flaws, this however was removed from the program after discovering that this would not be effective. The author had received multiple warnings about these challenges from within the Global North, as this is one of the common observations about Indonesia within this setting. It is challenging however to cope with these issues without experiencing it firsthand, as it treads the line between culture and stereotypes, as such the training program was not prepared with this in mind, and needed to be dynamically adjusted to keep the productivity level as high as possible.

The use of grounded theory helps to understand this on a higher level. The author attempted to proceed with the program without any preconceived ideas, as such the warnings and stereotypes had not been accounted for from the start. In learning to understand this behavior through reflection, it could be explained through the hierarchical structures present in this Global South context. There are clear differences in this aspect when comparing Indonesia to the Netherlands. Where the author is used to learn to take initiative, as this is often rewarded, this appeared not to be the case on Lombok. Initiative is often linked with accountability, and it was observed that employees prefer to have someone in a managerial level in this position. This was most apparent when doctor Sabda, who later became in charge of the 3D printer, said he was ashamed that the printer was still malfunctioning. This could explain the passive response to the project in the first instances, as the consequences of accountability were avoided.

Despite these challenges, the scheduling of the training program proved to be very effective. There was sufficient time to complete the whole program, as there was a good mix of explanation and supervised self-study. In the end the manual was more often addressed, and the staff started to experiment and ask questions about the software and the printer. In the last few days, it became apparent that the attention and commitment of the staff started to decrease and if the program would have been longer this could have created tension or conflict.

The implementation phase was truly a new experience for the author, and this created a variety of individual learning experiences. To translate these into broader lessons it is important to understand both cultures accordingly. Utilizing Rhodes' (2022) advice to aim to understand cultures and morals from both sides proved to work, as this improved trust and confidence from both sides. In the Netherlands it is often customary to work efficiently and punctually. This works well within the local setting as this is something that is already introduced in primary and secondary education, as such everyone is familiar with this. In Indonesia however this is not often the case. The scheduling of the presentation was well organized, but the timeslots that were agreed upon for educating Doctor Arbi and doctor Sabda could not be followed as it often occurred that one of them came in late or had scheduled other meetings simultaneously. Adjusting to the changes in scheduling were vital as there was limited time available to complete the whole training program. The doctors learned throughout the program that arriving late or scheduling overlapping meetings influenced the pace of the program and their time to learn from the experience, and this was noticeable in the last days, where the author ensured to extend the program as much as possible to account for the hours that were missed.

It became apparent that there are distinct differences in work ethics between genders in this specific Global South setting, as the female employees would work more productively and punctually, where it seemed most of the male staff would work in a more easy-going manner. This was an important observation that was perhaps discovered too late in the process, as the preparations had been very slow up until the introduction of two women who were extremely important in the final arrangements before arrival. Having been introduced to them earlier on in the process would have made a lot of impact on the final results. Finding the most suitable and motivated stakeholders early on in the program (Douthwaite, Keatinge, & Park, 2002) therefore proved to be crucial, and it should have been prioritized to find such stakeholders earlier on whilst preparing the program. Selection however should be based on the individual as a whole, and identifying and accounting for gender roles within a culture is challenging and very complex, and should only be done with caution as it is morally involuted, case specific and should not always play a role.

Another difference in culture between the Netherlands and Lombok is the use of phones. Everyone involved in the project had access to one, but where in the Netherlands it is considered appropriate to put away your phone during meetings and not take calls without consulting one another, the hospital staff would often have their phones within arm’s reach, which could be distracting at times. Email is rarely used as all communications, also with superiors, happens through WhatsApp. This is very effective but was a big adjustment in the beginning.

It was difficult to pinpoint where this behavior originated from, but as the training program proceeded it became clear that this not only applies to the hospital, but to the wider population on Lombok. Phones have a lot more presence in all aspects of daily life, and the use of apps and mobile communication occurs more frequently as well. The use of mobile technologies has been so widely assimilated that it has become a central point of everyday life, independent of occupation. Understanding these different forms of communication creates increased understanding of the culture in this context, and improved the level of communication as a whole. The use of translation apps allowed for more complex discussions through phone than in person, and the hospital staff also took more initiative through these forms of communication than in person.

It would have been beneficially if there was a facilitator present that would have given insights into these cultural traits and habits, and this information cannot be found online. The lack thereof was the reason that the program had to be shifted drastically each day as new habits came to light. There is very little data available about Lombok in general, and especially cultural values (apart from communal and religious habits) cannot be discovered without experience within the local context. Having a suitable facilitator would not only help to make connections and discover suitable locations for implementation, but also drastically impacts the successfulness of the implementation process itself.

4.4 Evaluation of the Implementation

Technological failure

One of the biggest issues during the implementation process was the fact that the printer faced many technical issues. These issues hindered the education process and disappointed the hospital staff. This issue is not uncommon in technical projects, and it is for good reason. The 3D printer is a very complex system and only functions accordingly when all components are working. If there is one component that is malfunctioning or installed incorrectly then the printer will not work. If it is not possible for the operator to procure the necessary replacement parts or remedy the installation error locally, then the system as a whole will remain dysfunctional for long.

Having a system with this many components that all have to function can be compared to a large chain. The odds of one shackle breaking, could be low, but the odds of the printer not working can still be very high. This is known as the principle of the weakest link, which directly determines the performance of the whole system. Roughly estimated, the printer consists of a total of forty functional parts, depicted with the green dots in the image below. This excludes the twenty-two motherboard connectors and forty-six wires which also caused some of the issues. Even a probability of failure of 1% per component would lead to the printer malfunctioning twice out of every five prints. This relates directly to Lackey (1993) who explored the complexity of development projects, and concluded that the culmination of probabilities is likely to influence the success of any project.

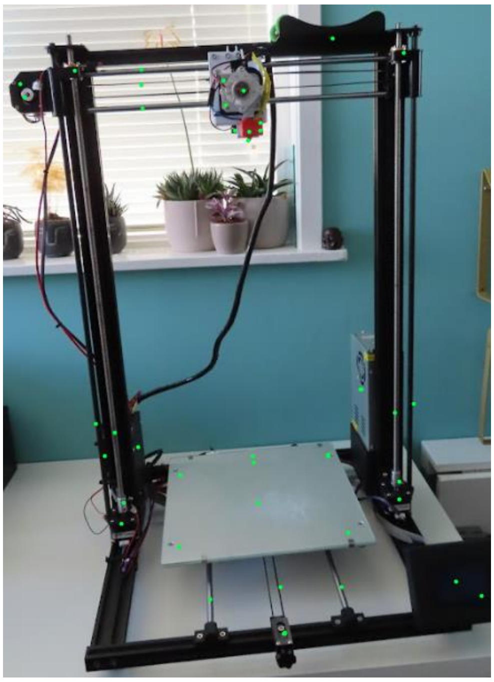

Figure 20: Critical components of the custom 3D printer, marked with green dots

These probabilities however are not linear. Instead, most issues would arise in the first stages, and would decrease over time once the issues are resolved and the printer is optimized. This is known as infant mortality, the technical equivalent of teething problems (Evenson & Westphal, 1995). Once these issues are resolved the probabilities of new issues are relatively low, and manageable, and these would only go up if the printer sustains a lot of damage or the components reach their end of life. This results in what is known as the bathtub curve, as depicted in *Figure 21*. The latter, known as wear out failures, should not be problematic in this case as by the time this occurs the user should be sufficiently knowledgeable about the technology to resolve these issues without external help. Even if the original components are no longer available and the spare parts have been depleted, an experienced user should be capable of finding replacements and adjust the printer accordingly.

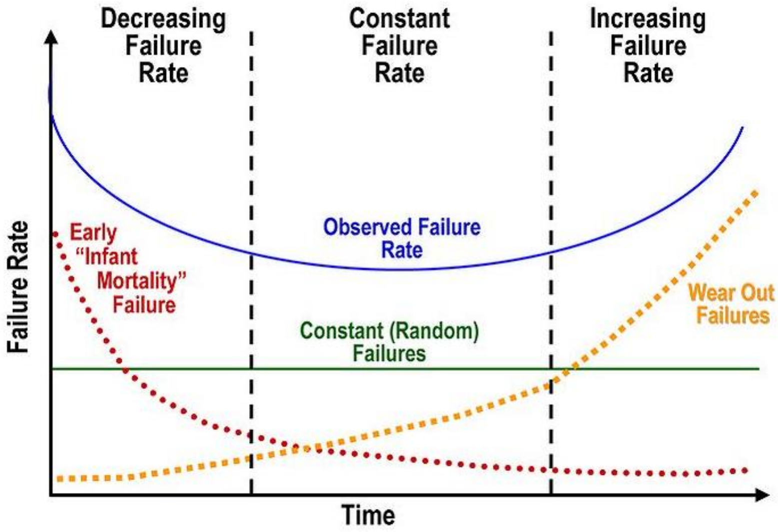

Figure 21: The Bathtub Curve Hazard Function (Smith, 2022)

Every time the printer has any issues in delivering a successful print this is considered a moment of failure, as such this does not directly relate to project failure as a whole. The infant mortality rate of failure is important though, as it directly influences the confidence of stakeholders, particularly the end user. Even though the printer prototype had reached a stage where the failure rate was more or less constant, and thus beyond the early infant mortality stage, the problems occurred again during the implementation phase. Reason being that the printer in Lombok partially consisted of newly purchased components, which were the cause of almost all failures that occurred during the implementation phase. This newly introduced set of failures is described in the following graph:

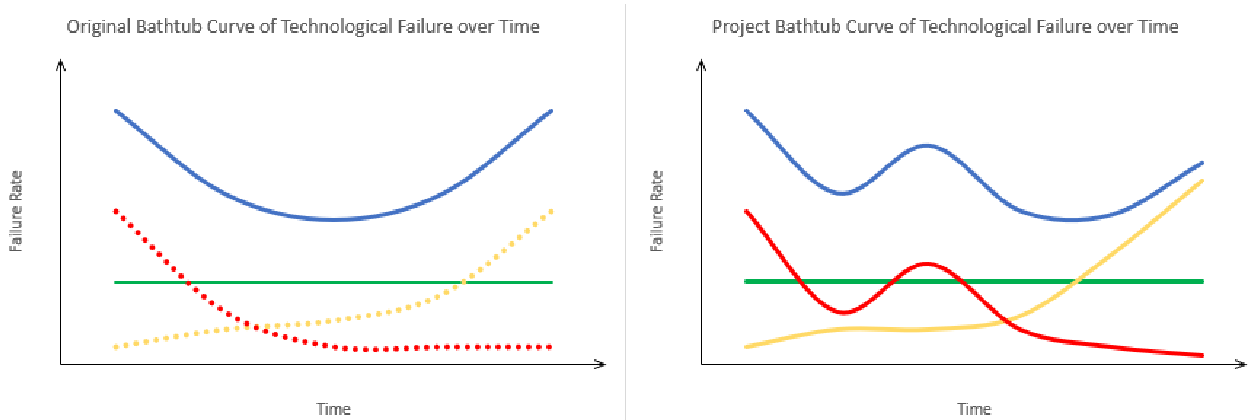

Figure 22: Original and Adjusted Bathtub Curve of Technological Failure (not to scale)

The new peak of teething problems, or infant mortality failures, arose upon re-assembly within the Global South context. Most failures occurred from the newly introduced components, but part of the increased printing failures also relates to the influence of the new users. As new users get their hands on a novel technology, mistakes will be made. This is part of the learning process, but these mistakes will also influence the reliability of the printer as the user adapts it to his own needs. In this case the context itself was also of influence, as introduction within a new climate negatively impacted both the electronics and the printing materials.

Understanding that this effect occurs, and anticipating for it in the development stages, is important as it also happens in a similar way during the prototyping phase. Whenever a collection of new components is introduced, it is expected that some errors will occur, which have to be resolved in order for the printer to work correctly again. Greater understanding also allows for more trust from stakeholders as explaining these effects to the end users will provide understanding of faults in the early stages. The user should not be scared to make mistakes in the use of the technology and their impacts, as this is part of the process, and provides new learning opportunities. Taking these effects into consideration is therefore important, also when scheduling the implementation phase. In this case the training program was scheduled within the right timeframe due to sufficient preparations, yet there was no time scheduled to resolve the technical issues.

One final note is that components that are transferred from one prototype to the next, and ultimately to the implementation design, will have been in use for a longer period of time, and these presumably also reach their end of life sooner. Keeping track of these components will make it easier for the user to predict where problems may occur in these later stages.

Legislation & NGO involvement

One of the main causes of the technological challenges that were mentioned in the previous section was the fact that there were so many issues in arranging the shipment of the 3D printer. It was originally planned to send the 3D printer through parcel services to the hospital so it would have arrived there in time. This was however challenging, every time new materials were delivered to customs to clear the package from delays and import fees, new requirements were made by the officials. This ranged from official letters to invoices, product and project descriptions, HS codes and finally a request for forgery of false information. At this point it was decided that this was not worth the risk, and as an alternative a new printer was purchased on Lombok and the materials to adapt the printer were transported in the personal luggage. This resulted in more causes for technological failures, as mentioned in the previous section.

Another hurdle in this months-long attempt to send the package was the involvement of the NGO Vrienden van Lombok. This NGO had been very kind in providing information about the island in the early stages of the project, and had provided funding for the 3D printer and its shipment. An employee also delivered the introductory letter to the hospital after which the arrangements were made with the author through email. However, without communicating this with the author, the employee started to get involved with the customs arrangements, and provided incorrect information to the hospital staff which hindered the customs applications. Instead of arranging the shipment to the island of Lombok the employee convinced the hospital to arrange shipments to Bali for unknown reasons, without consulting the author in any step of the process. After weeks of arranging the package, this had become apparent, and at this point there was simply not enough time to re-apply at the Lombok customs.

Upon discovering this, the author started to lose trust in the NGO's ability to facilitate the local implementation process adequately, but still invited them to the initial presentation at the hospital. It had already been planned that the NGO would fund the materials for the first patients, but this had not been arranged yet, so it was thought that this presentation event would be a good opportunity to iron out possible misunderstandings by means of a bilateral personal conversation, to continue possible beneficial collaborations. The NGO had also agreed to bring students from the technical school to help with the project, but in the end, it did not follow through with this, nor with the funding. After the visitors from the NGO arrived 45 minutes late to the presentation, and left again without an opportunity for discussion, the author decided it was best not to include them in the rest of the process, due to risk of unreliability issues.

This caused many issues for the project shortly after the implementation phase had ended, as when the printer was not yet functional in the early stages, the NGO decided to involve themselves in the project once again of their own accord by scheduling a meeting at the hospital without the author's consent. Here they tried to convince the hospital to remove the 3D printer and take the project into their own hands, conveying the impression to the author and the hospital that it had been a failure, evaluating it only one week later. The author decided to intervene by contacting the director of the hospital, and it became clear that the hospital was not convinced by the NGO's arguments, which seemed to be mainly geared to appropriating the project for their own PR benefit. The hospital director affirmed the local staff's appreciation of the author's efforts and their trust in an eventual positive outcome of the collaboration with him, and agreed with the author to continue the project without the involvement of the NGO. Yet, not only did this episode cause stress and delays within the project, it also created an unfavorable pressure on the relationship between the author and the hospital, which could have led to the termination of the project. It became clear that the NGO did not aim to function as a facilitator, but rather seemed to want to take visible control over the project for their own benefit.

The previous passage is a short rendition of the conflict that occurred in the months after the implementation, but it may serve as a warning to be cautious with whom one cooperates, and ensure that the goals, ownership, and implementation steps are agreed upon beforehand to the extent possible to avoid any conflicts. The relationship with the facilitator is built on trust, and this is a very personal and case-specific asset, but aligning the essential expectations and commitments and documenting these is advised to prevent the aforementioned issues.

The inclusion of a fitting facilitator is so very important, as this person bridges the gap between the parties in the Global North and South, through knowledge sharing of the local context and culture (Rhodes, 2022). As mentioned, there is little to no available data about Lombok, and many assumptions had to be made. The chosen facilitator in this case was of service in providing meaningful information and general advice, but did not support in laying the foundation for the project and making connections with local stakeholders. This was challenging, as the biggest issues arose in the final stages of the project, where there was no possibility of making arrangement with other parties, and the author did not confront the NGO in time. Choosing a fitting facilitator therefore is advised for all development projects, as it can provide so many benefits, but could also bring many unforeseen challenges.

4.5 Evaluation of the Assimilation

For this project, assimilation had been the goal upon investigating the lack of available prostheses in Global South settings. It had become clear that many attempts had been made to utilize 3D printing technologies to create affordable prostheses, but these projects seemed to fail as a result of limited long-term vision in creating lasting projects in these settings (Abbady, et al., 2021). An attempt was made to improve upon the existing attempts by focusing on assimilating the 3D printing methods. With this in mind the printer, prosthesis, production method and training program were created, but this still proved to be challenging.

Currently, the hospital staff knows how to use the printer and the software's. The staff has started to make their own adjustments to the printer and has taken the time to experiment with it in ways beyond the training program. The printer faced a large variety of errors, and the staff was gradually becoming able to cope with these errors as time went by. In 3D printing this is a step that many users face as it takes time to get the printer to function correctly and improve the results, as the results are dependent on a lot of variables, and it takes time to understand what faults are caused by which components.

This is all promising, but as the technical errors took a long time to resolve the printer has not yet been used to create prostheses for actual patients at the time of publishing this text. This is unfortunate, and makes it challenging to judge the final impacts of the project within this relatively short timeframe. Without a doubt the end users are capable of using the machine and the production method, but it is yet to see if they are capable of tackling any new challenges that could occur without outside help, and it is yet to be seen if this way of creating prostheses is feasible in this setting.

Luckily, the hospital had already discussed a variety of other purposes for the 3D printer for different medical fields, using the 3D scanning technology that was taught. This way the hospital will be able to adapt the innovation to a different end-goal, and even though this was not the aim of the project, the introduction of the printer will then have empowered the hospital to build upon their technical capabilities. It is therefore concluded that as long as the staff manages to keep the printer functional, the project will have served a purpose within the Unram hospital.

Upon implementing such a project it is very important that there are basic technological capabilities present in the development context, as this allows for a more in depth development process, where the end user has the absorptive capability to appropriate the technology for contextually fit usage (Stewart, 1981). One of the learnings from the assimilation process in this case is that the implementation in a university hospital was beneficial for the success of the project. Introducing an innovation in an existing setting is challenging, as it brings about change in existing socio-technical systems. The risk of investing in a research and development track within the hospital was well received and the director of the hospital dared to invest time and funds in the technological development as a result of the existing capabilities within the hospital to take on such a challenge. This openness to change allowed for experimentation and the project was welcomed by all of those involved. This proves that the openness to change, combined with the technological knowledge level of the end-user, or in this case organization, is of significant importance for the execution and assimilation of a project such as the one discussed in this thesis.

The used literature by Clark (2003), Douthwaite (2002) and Lackey (1993) proved to be relevant to this day, as the broader lessons were helpful. Each of their lessons mentioned in *chapter 2* occurred at some point during implementation. Focus on the end user and its context and belief is clearly very important, despite the way in which it was framed. By understanding what drives the user, how to motivate them and how to pass on knowledge, was required to prepare the project for long-term use.

However, the relationship with these users should not be constructed in a top-down manner. Co-innovation (or co-design) should arise out of motivation from both sides, and there is significant knowledge and technology in the Global South, but projects such as these should enable the use of new technologies, knowledge sharing on both sides, and focus on local agency. Attempts were made to promote co-innovation but sadly this did not work out. The author aimed to include the doctor in the design of the prosthesis and the requirements of the printer and training program but there was mostly a passive response to these ideas and proposals. Only when the author had been in the hospital for a few days and had created a personal connection with the hospital staff, the doctor started to become involved in the prosthesis itself and the procedures. This will relate to culture and motivation, and is something that is difficult to prepare for. Still in the aftercare the passive attitude remained, and this could be better understood or handled if a local facilitator remained who remained present in the hospital (even only periodically) as this hands-on approach was necessary in this case. Whether or not the hospital is able to continue the project in an independent manner is therefore questioned, as this is the only way in which the new technology can be implemented within the hospital's system with lasting impacts.

The project came forth out of an attempt of the author to improve the conditions within the Global South, whereas a more natural approach would be to gain an understanding of the issues the locals are trying to solve and attempting to support this. After speaking to Suci and the ICRC however it becomes clear that this is a pressing issue globally and specifically in Indonesia, but as doctor Arbi is one of the few prosthetists currently on Lombok (I managed to find only two, and the second had arrived there just before me, whom I tried to include in the project), this issue is not currently addressed within this specific setting, as this form of medical aid has only just been introduced.

Knowledge spillovers occurred not just from North to South, but also from South to North. The ICRC methodology is not well known in the Netherlands, and this project might change the path students take at the Fontys Hogeschool in Eindhoven. The P&O department of this education had been involved in the development of the prosthesis prototype of this project, and has since learned more about the ICRC methods. The Hogeschool has received the ICRC prosthesis components used in this project and will introduce this to the students in this Global North setting, who hopefully will learn from this and use it as inspiration in both their work in the Global North, and hopefully inspired to work outside of this context as well.

5. Learning Outcomes

The aim of this chapter is to review the learnings from the 3D printed prosthesis project presented in the previous chapter, and present learnings that would apply to future assimilations of technological innovations in Global South settings. The previous chapter provides a large variety of challenges and lessons in different stages of the project, and this chapter serves to translate these to concise lessons that could be of relevance for projects regarding different technologies in different settings

Firstly, the literature by Clark et al. (2003) Douthwaite et al. (2002) and Lackey (1993) that was studied before the implementation phase each highlighted the importance of understanding the local context. This is relevant to this day and prepares a project to mitigate a variety of challenges. In depth studies of context beforehand increases the understanding of sociocultural aspects as well as local capacities and amenities that could be of use. In this case the understanding of context also applied to an understanding of the current prosthesis production methods and technical capabilities within the hospital, and adjusting the designs of the prototypes to this knowledge accordingly allowed for an end product that was better suited to the local context. Sufficient preparation and understanding with regards to the local context is therefore significant for every single project.

Yet, sufficient preparation is no guarantee for success, as nothing works out exactly as planned. The introduction of a novel technology is highly complex and is reliant on many factors, including social, financial, technical and emotional facets. Sufficient preparation helps to mitigate part of the potential challenges that could arise, yet there is no such thing as complete and exhaustive understanding of local context. That is never possible, no matter how well one tries to prepare. Adapting to changes and differences between perceived and actual outcomes is perhaps even more important, as new developments occur throughout the development and implementation phases so frequently that adjustment is vital. This project was planned and thought out for two and a half years before implementation, and still had to overcome unforeseen challenges until the very end.

This relates closely to the management of expectations, not just for the actor(s) developing and introducing the technology, but also for the recipients. Technological failures will likely occur, even if it appears that the prototype is finalized. Maintaining motivation to account for such failures even during implementation is important for all stakeholders, as risking loss in trust and motivation harms the continuation of the project as a whole. Managing expectations for external funders can have a large impact as well, as there is often little to no room to make adaptations due to strict requirements of donors.

The relevance of a capable and reliable facilitator was underestimated in this project, and insufficient management of this relationship and its benefits led to a lack of contextually important information, funding and resulted in an impact on the trust of the hospital staff. No matter what the cause was for the conflict that occurred, it is important to be wary of the expectations of each stakeholder, and find a facilitator that is likeminded. This also applies to the relevant stakeholders for the implementation of the project. The facilitator could help finding the key persons to successfully finalize the project, and their personal motivation and initiative-taking behavior is difficult to assess, but crucial. A facilitator that is locally active and trusted can achieve much in providing opportunities for knowledge creation and sharing, and should be sought out in every project, their task depending on the specific needs and capabilities.

Finding the right location to implement the project is also important. In this case it was beneficial that the project was executed within a university hospital, where the director was willing to invest time and effort in this unproven concept, and was willing to embrace changes in the existing methods. It is advised to seek out institutions with similar interests.

Time management will be very project specific, but one take-away is to consider that due to the many uncertainties and challenges this project was scheduled in a too short timeframe despite many preparations. There was sufficient time to complete the training program as it was well prepared and based on the knowledge of the existing capabilities in the hospital. After facing many infant mortalities in the design of the prototypes it should have been expected that technical failures were likely to occur, yet there was no time scheduled to resolve any technical failures. As a result, the training program had to be shortened to make time to work on the 3D printer, and the printer was not yet functional upon departure. This not only impacted the trust in the project, but also is the reason that the first patient has not yet been helped as the focus of the months that followed the implementation were oriented towards repairing the 3D printer. It would be advised for any project to schedule sufficient time to test the technical products before introducing it to the local stakeholders, as this ensures that technical failures are mitigated, and trust is not lost in the reliability and capabilities of the final product or service.

In this case, the arrangements with customs were a significant challenge. It is advised to ensure that this process is commenced as soon as possible. In countries with corruption or mismanaged procedures this will take much time and effort to arrange, if it is at all possible. Having as many prepared and tested materials as possible available mitigates the risk of more infant mortality issues upon implementation. Ideally custom arrangements would be executed by a facilitator who knows where to apply (as finding the right government body to address can be a challenge of its own), and has experienced this process before and knows what impacts the speed and success of these arrangements.

Finally, it is important to be mindful that there is a potential for two-way technology spillovers. There is much embedded (technical) knowledge and capabilities present in Global South settings, and being mindful of their existence allows a project to add much more value. By sharing the gained knowledge amongst all stakeholders, it is possible for unanticipated knowledge sharing to occur.

Conclusion

This thesis studied the global prosthesis deficit, which is concentrated in the Global South. Through an exploration of a new prototype to create 3D printed lower leg prostheses, consisting of a 3D printer prototype, prosthesis prototype and production method, n attempt was made to improve upon existing projects of 3D printed prostheses in Global South settings. The added value of this project is the aim to achieve technology assimilation in order to ensure lasting impacts in this specific setting, something that has rarely occurred in similar projects of this kind. By taking the learnings from this project, lessons were constructed for other projects of similar nature, in order to answer the following research question:

What challenges occur when implementing 3D printed lower leg prostheses on Lombok, and what wider lessons can be drawn from this case for future assimilations of technological innovations in Global South settings?

The challenges that occurred were studied based on literature about technology assimilation and North-South technology transfer, and lessons were drawn from learnings of previous development projects and sociocultural studies. Through using action research, the implementation of this project was mindful of the need for reflections and dynamic adjustments, and grounded theory was used to frame the findings in order to gain a deeper understanding of the encountered behaviors and challenges.

To be able to draw lessons from this specific case, the project was described and presented in light of its most important developments and events. This was done in great detail to ensure that the reader understood how decisions were conceived and how the findings were constructed. The project was then evaluated to uncover what assimilation challenges occurred in the implementation of this specific project, to provide learning outcomes for future projects, expanding upon this case with lessons for different technologies and Global South contexts.

Many challenges occurred, which directly impacted the outcome of the project. During the research at the start of the project, it became clear how challenging it can be to create a functional and reliable 3D printer that conforms to specific requirements. Exploring the design of prostheses, specifically the ICRC design, allowed for a deeper understanding of the prosthesis deficit and the methods and capabilities present on Lombok. During the implementation phase the challenges consisted of technical failures and legislative obstacles, trust building and collaboration with local stakeholders, and conflict of ownership with the facilitator. Learnings about training individuals from different global contexts, time management, and desired contextual settings were presented.

Working in a Global South context proved to be unpredictable and requires an open-minded and flexible approach, using dynamic adjustments as the context is better understood. Sociocultural factors directly impact the way in which a novel technology can be translated between two substantially different contexts, and the understanding thereof only truly occurs during the implementation process itself. Despite many preparations the outcome remains unpredictable, yet utilizing existing lessons allows for easier adjustments, and ultimately allows the project to find a more suitable fit within the existing sociotechnical system.

These lessons, amongst the others presented in this thesis, apply to broader technology assimilation challenges in Global South settings. Through the scope of North-South technology transfer and assimilation, it becomes clear that such challenges occur no matter the technologies, methodologies, and contexts. It is therefore important to gain a better understanding of challenges that will continue to occur in attempting to share technical knowledge on a global scale, as these knowledge exchanges impact many stakeholders in their respective global settings.

Discussion

The motivation behind this thesis was to find a purpose for 3D printing technologies as a tool for sustainable development, which resulted in an exploration of the potentials of 3D printed prostheses, and an improvement on this technology's current limitations. The work of Abbady (2021) was used as reference for the current developments, and challenges, of 3D printed leg prostheses. The result was an exploration of technology assimilation and North-South technology literature to address the challenges presented by Abbady. The theory and methodologies in this paper therefore were directed to understand this predetermined goal of introducing 3D printing technologies in a Global South setting, resulting in insight into the technological factors of the project as well as its academic foundation.

The findings consist of case-specific, and general learning outcomes about the introduction of novel technologies in Global South settings. The goal of the research therefore shifted from sole focus on 3D printed prosthetics to its academic implications, related to technology assimilations. The research added new insights not only in aiming to progress in solving the global prosthesis deficit, but also for broader lessons for development projects. Most, if not all, of the lessons that were presented had been studied in previous literature, but the added value of this study is an additional perspective of these lessons for this specific means, using literature that often predates the 2000s to restate their relevance to this day, and including a new approach to understand technological failure from a revised bathtub curve perspective.

Incorporating assimilation and North-South oriented literature was deliberate, but required a critical approach, as the relevant literature often did not incorporate a more modern and global vision of development projects. Understanding these limitations and looking beyond allowed for a more critical understanding of the relations and challenges that can occur in introducing novel technologies created in the Global North into a respective Global South setting. It is argued that this is remains a relevant approach, as introducing relevant technologies in specific Global South context has the potential to induce environmental leapfrogging, making way for modern technologies to improve living conditions in a more sustainable manner. Projects will not always originate from within the Global South, and there should be a more inclusive and mindful way to approach such challenges when technologies from the Global North are introduced.

Broader literature included topics such as development studies and culture, to avoid potential pitfalls and approach the collaboration with the stakeholders in the Global South effectively. The methodology consisted of action research, where feedback loops and collaboration in the approach were centralized, and grounded theory. Combining the two methodologies proved effective, even though grounded theory was primarily used in hindsight, to be able to better understand the occurrences and attempting to translate these in a more objective manner. Framing the events was challenging as the subject matter is inherently subjective and complex, and an attempt was made to look beyond stereotypes and understand the sociocultural events without prejudice.

A portion of the findings was anticipated, as the aim was to understand the project and its challenges both in creating the technology as well as implementing it in the specific Global South setting. The learnings therefore often follow the studied literature and come forth from the methodology, gaining better insights as a result of reflecting, documenting, and dynamically adjusting the program as a result. Unanticipated findings also occurred. The importance of including a motivated and like-minded facilitator was more important than anticipated, as well as the understanding that the knowledge transfer is not linear, but had the potential to create new learnings in both contexts.

The thesis is fitting within the Innovation Sciences field of study. The global perspective, reviewing technology assimilation and North-South technology transfer literature and attempting to innovate in a Global South setting are key components of this study, and the inclusion of first-hand experiences allowed for a deeper and more meaningful understanding of the challenges this entails. The use of a qualitative research approach and assessment was therefore best suited in order to translate the personal experiences to meaningful lessons.

Due to the scope and time constraints of the research project, there is a desire to build upon this research to gain a better understanding of the phenomena that were described in this thesis. Firstly, the training program was created based on the author’s understanding of the technology and the knowledge about the Global South context, but this was not based upon, existing literature about education and training. It would be interesting to study what makes such a program more successful, and understandable when it is made for someone of a different culture and background. Additionally, the learnings from technology assimilations were relevant for this thesis, but were not linked to more modern approaches of understanding the adaptations of technologies in Global South settings. An improved methodology to promote co-innovation between different sociocultural contexts, utilizing locally embedded facilitators and digital communication, could create more meaningful partnerships between stakeholders in different settings, to ultimately create projects that are better suited to the specific needs and capabilities. Attempting this could be an interesting addition, in trying to maintain the relevance of such literature as well as learnings from previous development projects and translate them to modern practices.

Reflection / Limitations

This section serves to discuss the limitations of the project in terms of the setup and its specific components, to better understand why the conclusions were drawn the way they were, and to show what other factors could be relevant when relating to other development projects. Its contents were deemed not to be fitting in the body of the thesis, as such this section serves as an additional insight into the project and its limitations, written from the perspective of the author.

I created the project out of a personal motivation to learn about the challenges in implementing potential innovations in the Global South. This was done because of my interests in 3D printing and sustainable development, and therefore the project was not just oriented towards realizing the prototypes, but also for personal learning opportunities. I wanted to develop my technical skills and as such executed the whole project on my own, asking advice from experts along the way. This take on the project did influence the final prototype of the 3D printer and prosthesis, as it was time consuming to thoroughly understand each part of the final system, and many technical setbacks took a very long time to resolve.

Having had the ability to work within a university rather than from a private firm changed the time window of the project as it had to be finished within reasonable time to get my degree, but there was no pressure for financial success, as such the printer and materials could be provided to the hospital for free but no business measures were introduced to turn the project into a company. When growing the project this has to be changed and a reasonable fee has to be established to the hospital for it to still be manageable for both sides. This setting also ensured that there was little to no pressure from funders to see positive or measurable results, which drove the project to focus on working out as best as possible, as such there was no risk of goal displacement.

Having said that, the limited funding, especially in the early stages, was both a blessing and a challenge. As I was working with my own money, I tried to make technology as affordable as possible whilst working reliably, but the lack of funding did limit the amount of experimentation that was possible as the raw materials and printer components were picked carefully and not compared to alternatives through practical tests. In a different setting this would be very different, and will directly influence the final result when considering the technology itself.

Doing all of the work myself, from innovation to communication and implementation, was of direct impact to the outcome of the project Considering the overall goal of helping patients on Lombok one could argue that I should have taken on more help in order to present a more complete project. When talking about aligning personal goals with the goals of the case study, this could be argued, but when looking at the overall goal of my master's program I stand by my decision completely. It has taught me so much and put me in positions I would have otherwise avoided, so it gave me personal insight in the entire process. This does not mean that I was stubborn to take on help, I have reached out to dozens of people for help and guidance, and this has contributed directly to the success of the project. Keeping control over the project allowed me to steer it in the desired direction, but as it has come to an end passing over control could provide opportunities for others to take the innovation to another level and expand upon this initial experimentation.

I would like to end on the importance of my partner in the implementation phase. She enabled me to reflect upon the progress in the hospital every day, and could rely on her for support during the implementation process. She brought a new perspective to challenges, and could work on the 3D printer whilst I was teaching the hospital staff. Without her help, there would have not been sufficient time to complete the training program, and having her support was very encouraging for my personal experience.

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