The SaniSecure System: Product Service Design for Improved Sanitation in the Imvepi refugee Settlement, Uganda

Master Thesis | MSc Integrated Product Design |
Faculty of Industrial Design | Delft University of Technology

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Partners

Jan-Carel (JC) Diehl - Chair

Stefan Persaud - Mentor

Peter Scheer - Semilla Sanitation (Client)

Lilian Ateenyi - CRC Consortium

Henry Wasajja - HS Green Energy

Design Without Borders Africa

Waru Justine - Imvepi Buidling Manager

Maria Sofia Clercx Lao

Biogas Solutions Limited

Guus Paardekoper - SkillEd

Taban Asega Kamala - UNHCR

Derrick - Water Mission Imvepi

Stephen Candia - Gulper Group Imvepi

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Abbreviations

DALY – Disability Adjusted Life Year

DRC – Democratic Republic of the Congo

HDPE – High Density Polyethylene

OPM – Office of the Prime Minister

PSS – Product Service System

ReHoPE – The Uganda Refugee and Host Population Empowerment

SDG – United Nations Sustainable Development Goal

UGX – Ugandan Shillings

UNHCR – United Nations High Commissioner for Refugees

UTI – Urinary Tract Infection

WASH – Water, Sanitation and Hygiene

WTCAP – Waste to Clean Air Project

Glossary

Exchange rate between Euro : Ugandan Shillings – €1,00 : UGX 3.875,00

Fecal sludge – the combination of excrement and urine, often found in the pit of latrines

High quality fecal sludge – in the context of the project, 'high quality' fecal sludge refers to fecal sludge with high biogas producing potential

Home (pit) latrines – the current unlined pit latrines found in the Imvepi inhabitants' home setting

Host community – Ugandan nationals living in the Imvepi area
Imvepi – the Imvepi settlement area

Public (pit) latrines – the current lined pit latrines found in Imvepi at public facilities such as schools or community centres

SaniSecure Service – The service that empties and maintains the SaniSecure Toilet, consisting of people, transport vehicles, sludge pumps and health and safety equipment

SaniSecure System – the designed SaniSecure Toilet together with the SaniSecure Service

SaniSecure Toilet – the product designed for this project, consisting of pre-existing parts and specifically designed parts

Executive Summary

In low-resource settings such as refugee camps, **inadequate sanitation and poor hygiene contribute to the spread of infectious diseases**. 'Adequate access to safe drinking water, sanitation and hygiene (WASH) could have prevented at least **1.4 million deaths** in 2019' (World Health Organization: WHO, 2023). Without improved sanitation, hygiene education, and clean water access, these preventable diseases will continue to threaten public health in these areas.

The SaniSecure project was developed to address critical **sanitation challenges** in the **Imvepi refugee settlement** (Fig. 0.1), where unlined pit latrines contribute to **groundwater contamination, disease transmission, and environmental degradation.**

The research for this project was conducted using a **human-centered approach**, incorporating field visits, in-depth interviews, and direct engagement with settlement inhabitants, latrine emptying groups, and sanitation experts. Through which, **key challenges** were identified. Most latrines were poorly maintained, often **structurally compromised due to flooding** and material degradation. The lack of handwashing facilities and cleaning agents further increased disease risks. Additionally, **latrines were not designed for elderly or disabled individuals**, creating barriers to safe and dignified sanitation. These challenges, however, presented **opportunities for a new Product-Service System (PSS) that integrates a safe toilet design with an effective emptying service**.

Fig. 0.1 | Challenges with unlined pit latrines

By proposing the SaniSecure System, **multiple levels of complexity were tackled on product, system, & human interaction, while taking into account environmental, financial, cultural and human factors**, such as renewable cooking fuel, a self-sustaining business model, and inhabitant latrine habits.

The SaniSecure Toilet (Fig. 0.2) was developed to directly address these issues. It features a sealed sludge container that prevents groundwater contamination, a robust and flood-resistant structure, and an inclusive design that accommodates users with mobility challenges. **The introduction of the toilet resolves multiple health and environmental problems by ensuring safe containment and hygiene maintenance, while also improving user experience through better privacy, cleanliness, and security.**

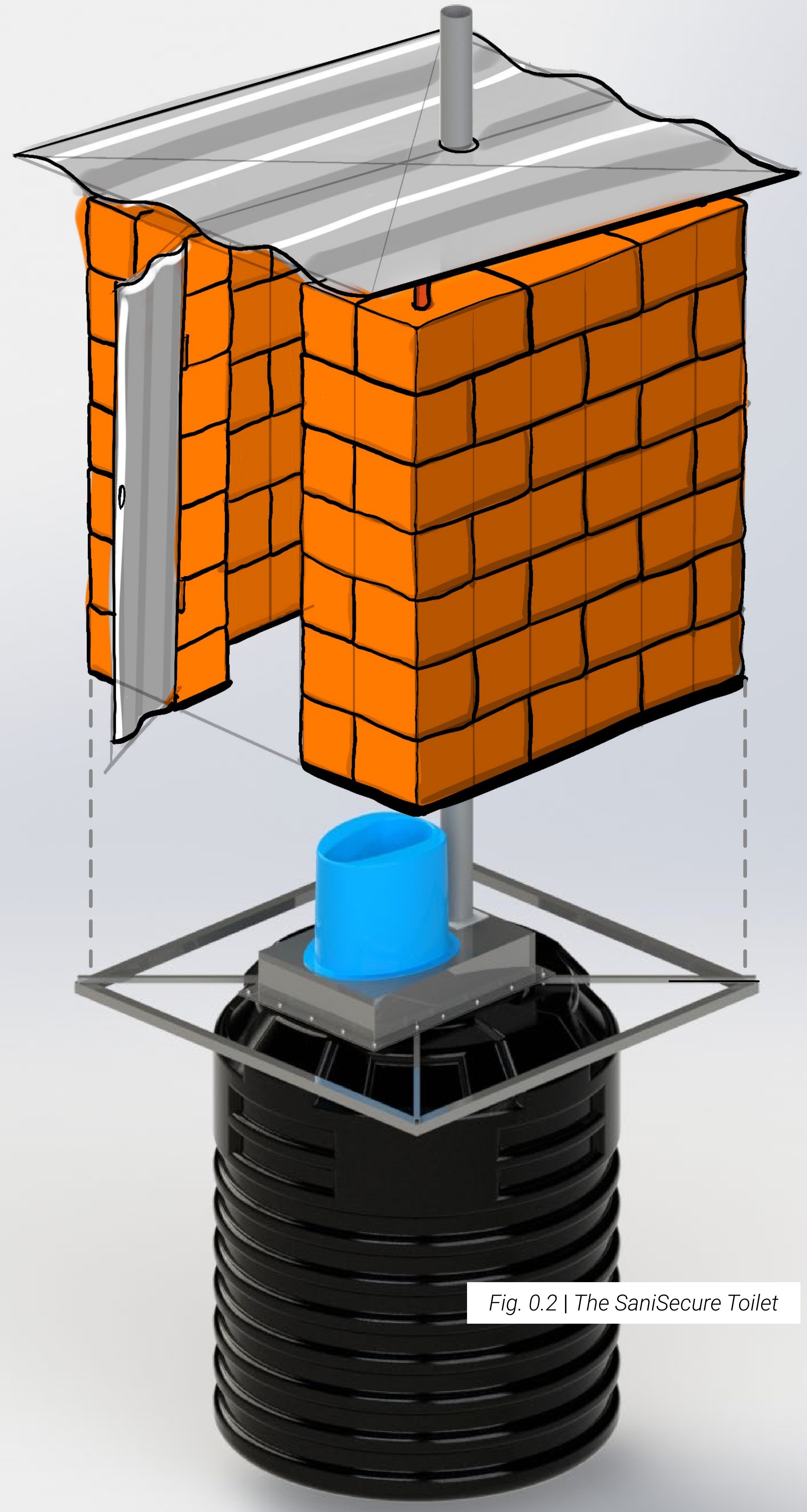

Fig. 0.2 | The SaniSecure Toilet

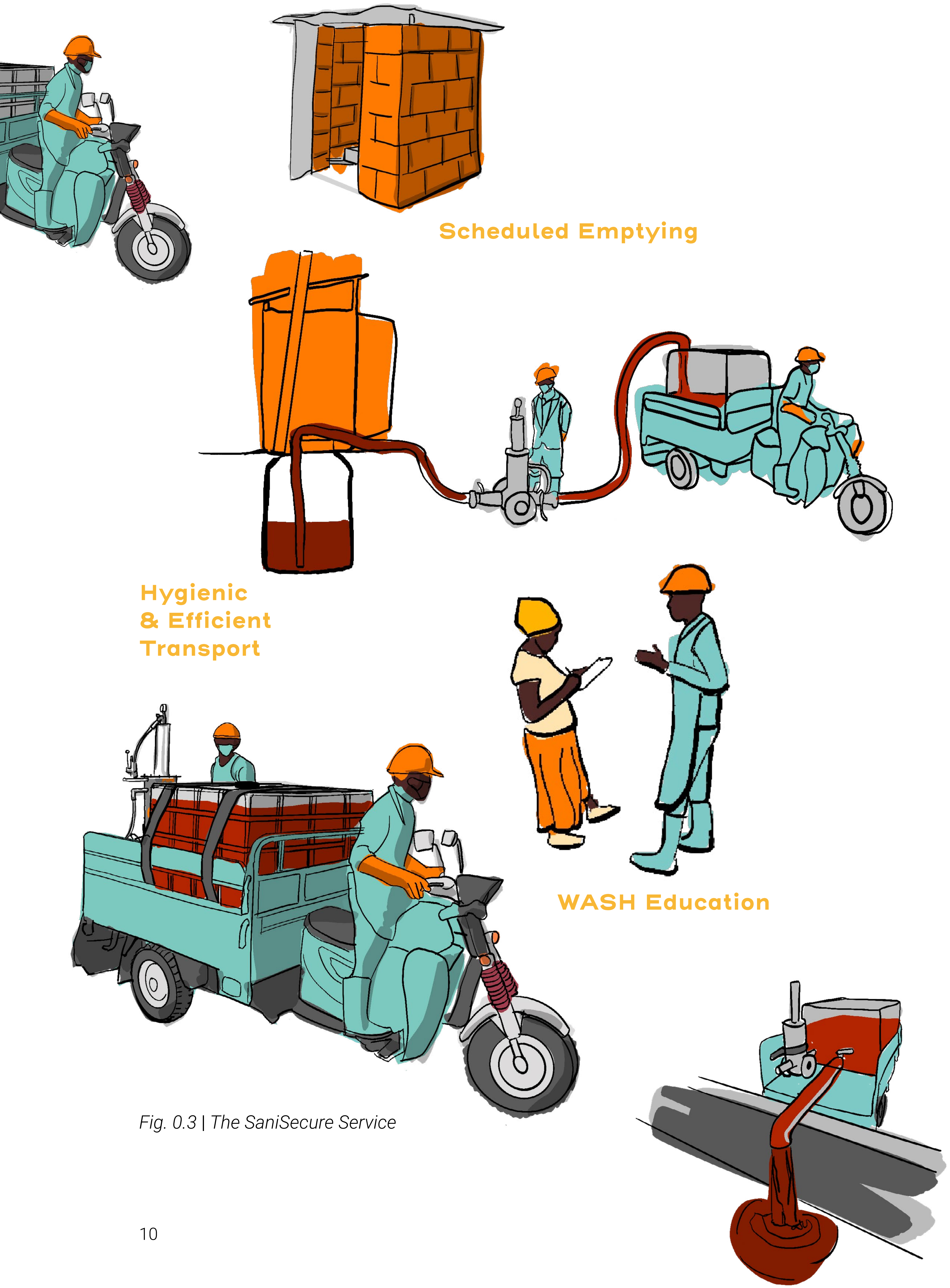

Fig. 0.3 | The SaniSecure Service

The SaniSecure Service (Fig 0.3) complements the toilet by providing scheduled **emptying, maintenance, and user education**. This service, run by a trained Service Group, utilizes the Pupu Pump and motorized tricycles to ensure hygienic and efficient sludge transport. Beyond emptying, **the Service Group plays a key role in educating users about WASH practices and providing access to cleaning supplies.** The integration of this service ensures the long-term functionality and sustainability of the sanitation system.

To validate the SaniSecure System's impact, **a phased implementation strategy has been designed.** A pilot test involving 40 toilets will be conducted, allowing for real-world evaluation of system effectiveness. The testing phase will gather data on user behavior, sludge quality, and system efficiency to refine the design before full-scale deployment. **Financial sustainability is achieved through a dual revenue model: biogas sales from treated sludge and fees for public latrine emptying.**

In conclusion, the SaniSecure project presents a **scalable, community-driven solution** that addresses sanitation challenges through an integrated design approach. By combining improved toilet infrastructure with a reliable service, **the system enhances public health, environmental protection, and economic resilience within the Imvepi settlement**. The pilot phase will serve as a foundation for future expansion, demonstrating the viability of the SaniSecure model in low-resource settings.

Table of Contents

Project Introduction

01.

This chapter elaborates on the need for clean sanitation in low resource settings to stop prevetable death.
It introduces the context, problem, involved stakeholders, project, aim and approach.

1.1 The Need for Clean Sanitation

In 2022, **3.5 billion people lacked safely managed sanitation.** (Goal 6 | Department Of Economic And Social Affairs, n.d.) (Fig. 1.1)

"Access to safe drinking water, sanitation and hygiene (WASH) could have prevented at least **1.4 million deaths** in 2019." (World Health Organization: WHO, 2023).

In summary, adequate WASH facilities are crucial to **public health and quality of life.**

Fecal matter can contain a range of pathogens, including bacteria, viruses, and parasites that can cause waterborne illnesses such as **diarrhea, cholera, and typhoid fever** (World Health Organization & Lee, 2004).

Most cases of diarrhea result from **water contaminated by fecal material** (Dickson-Gomez et al., 2023).

In Uganda, the context of this project (Chapter 1.2), diarrhea ranks among the top five causes of mortality in children under five, contributing to over **140,000 deaths annually** and accounting for 7.1% of all under-five mortalities (Nantege et al., 2022).

People in low resource settings, such as refugee camps, are particularly exposed to inadequate WASH, due to reasons including insufficient **materials,** inadequate **infrastructure,** limited **education**, and **natural disasters**. Additionally, other **financial, societal and environmental** factors play an important role in the implementation of sanitation interventions, which are explored in this thesis.

THE SUSTAINABLE DEVELOPMENT GOALS REPORT 2023: SPECIAL EDITION- UNSTATS.UN.ORG/SDGS/REPORT/2023/

Fig. 1.1 | Infographic of SDG 6 (Goal 6 | Department Of Economic And Social Affairs, n.d.)

1.2 Project Context

The project takes place in Northwestern Uganda, in a region called West Nile. Uganda is home to over 1.8 million refugees (Country - Uganda, 2025), with more than 950,000 residing in the West Nile region (RISE, 2023). Increasing numbers of refugees migrating to the area is putting pressure on community resources (RISE, 2023).

Specifically, research was conducted in the **Imvepi refugee settlement**, located in Terego District, Odupi Sub-county (Fig. 1.2). This region borders **South Sudan** and the **Democratic Republic of the Congo (DRC)**, from which the majority of the refugees originate.

Imvepi is relatively small compared to its neighboring settlements, housing approximately **67,000 refugees** of which, 65% are South Sudanese and 27% are from DRC, as of July 2019 (Reach_uga_factsheet_hlp_imvepi_15july2019_0, 2019).

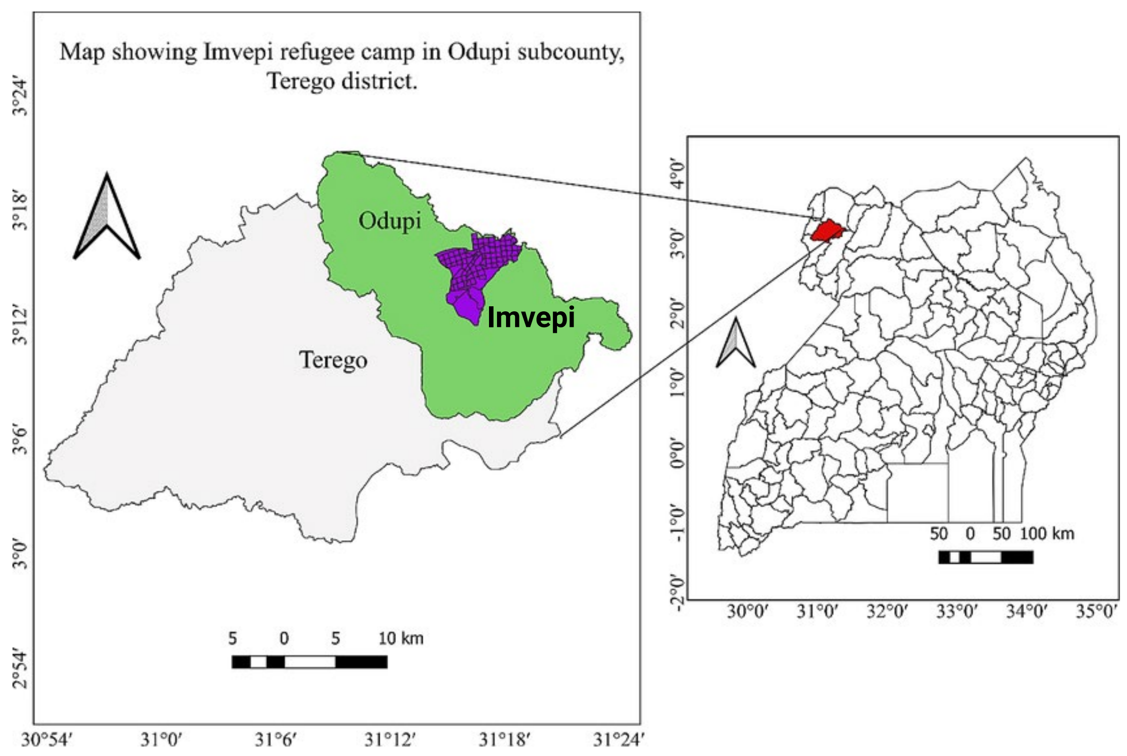

Fig. 1.2 | Map showing Imvepi refugee settlement (ResearchGate, 2025)

Refugees from South Sudan are fleeing the country due to its political instability that persists despite multiple peace agreements (South Sudan and Uganda Refugee Crisis, n.d.).

Refugees from the Democratic Republic of Congo have fled the devastating conflict that has been going on since the late 1990's, largely centred in its eastern regions, bordering Uganda (Global Conflict Tracker, n.d.).

Ugandan nationals living in the Imvepi area, referred to as the **host community,** coexist with the local population in the Imvepi Area. This non-refugee population, was estimated at **45,300 individuals**.

Historically, these residents have engaged in tobacco cultivation, a low-yield practice that depletes soil health and prevents them from growing other crops, thereby trapping them in a cycle of poverty.

It is found that refugees and host community members live in close proximity to one another and have **similar living conditions** (Chapter 2.3).

While there have been instances of conflict between these groups, overall, field research (Chapter 2) reported both groups living in a peaceful coexistence, with members of both the refugee and host communities stating that there is "no predisposition for violence in the culture of either group."

This harmonious relationship may be partly attributed to the geographical and cultural interconnectedness of the communities found between the groups, as the land borders in Easern Africa do not serve as strict dividers for tribes. Predominant languages such as Lugbara, Kakwa, and Arabic are spoken across the borders with South Sudan and the Democratic Republic of the Congo, further enhancing the social integration of these groups.

The Uganda Refugee and Host Population Empowerment (ReHoPE) strategy by the Ugandan government states that **30% of all humanitarian refugee aid needs to be directed at the host community**, aiding fair and peaceful co-existence between the groups.

The research done for this project focusses primarily on refugees, but includes some members of the host community as well. The results of the research can be used to benefit both refugees and the host community.

1.3 The Problem

Unlined pit latrines (Fig. 1.3) in Uganda's informal settlements pose health risks to inhabitants due to **water contamination with fecal particles** (Chapter 1.3.1) **and inadequate hygiene practices** (Chapter 1.3.2).

1.3.1 Water Contamination

Unlined pit latrines are the most common form of sanitation found in the Imvepi settlement (Chapter 2.5). While the observed latrines at public facilities such as schools or community centres in Imvepi have a concrete lining preventing the fecal matter from coming into contact with the soil, in home settings, 100% of observed latrines were unlined.

This type of latrine consists of a pit, dug in the soil and a latrine stall. During use, fecal matter and urine are deposited into the pit, and fluids from the waste seep into the surrounding soil.

Research done by Nayebare et al (2022) in low-income urban areas of Uganda found that unlined latrines contribute to groundwater contamination, particularly with E-coli, as shown by high microbial counts in nearby shallow water sources such as rivers or wells. When this water comes into contact with people, it can lead to can lead to waterborne illnesses.

Unlined pit latrines therefore pose a risk for public health in the Imvepi settlement through contamination of water sources with fecal particles.

Despite efforts by the government and non-governmental organizations to address the issue (Chapter 2.5), the problem persists.

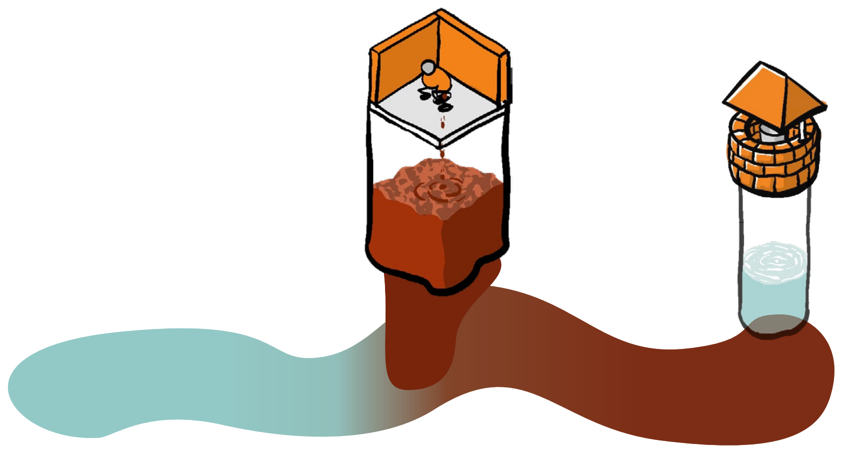

Fig. 1.3 | An unlined pit latrine contaminating the groundwater

1.3.2 Latrine Hygiene

Latrines in the settlement were often found in a poor state (Chapter 2.5) (Fig. 1.4 & 1.5).

Badly cleaned and maintained latrines pose the risk to infection through direct contact with fecal matter.

Fig. 1.4 | Poorly kept latrine in Imvepi

Fig. 1.5 | Poorly kept latrine inside

Hand washing stations were found in bad condition or incomplete, with soap missing for 50% of research participants (Chapter 2.4), and reports of broken jerrycans that were not replaced, completely disabling hand washing stations.

Poorly constructed, structurally compromised or unfinished latrines pose safety issues.

While financial, material and infrastructure issues are part of the problem, a lack of perceived latrine value, knowledge and responsibility observed (Chapter 2.5) reveal the complexity this problem faces on social, environmental and educational levels.

Campaign efforts observed in the settlement (Fig. 1.6) attempt to increase WASH knowledge and motivate hygienic latrine practices with infographics stating the importance and presenting the steps to hygienic latrine practices. However, the state of latrines suggests the problem persists.

Fig. 1.6 | WASH campaign in Imvepi

1.4 Stakeholders

The inhabitants of the settlement are part of the focus of this project The client of this project, Semilla Sanitation, as well as other stakeholders are involved in the project organisation, waste management, product development, transportation and education. A subset of stakeholders have set up the Waste to Clean Air project in Imvepi, to which the solution presented in this thesis (Chapter 3 & 4) is an addition.

1.4.1 Project Client

Semilla Sanitation (Semilla Sanitation, n.d.), the client for this project, is a start-up focused on providing Water, Sanitation, and Hygiene (WASH) services, encompassing the supply of drinking water units, sanitary facilities, and mobile wastewater treatment systems. Their services result in outputs such as clean water, improved sanitation, and the production of compost and fertilizers (Semilla Sanitation Hubs, n.d.).

1.4.2 Settlement Organisation

The settlement is overseen by the governmental organ: **Office of the Prime Minister** (OPM).Intergovernmental organisations and NGO's with a humanitarian objectives are present, the ones relevant for this project are the **United Nations High Commissioner for Refugees** (UNHCR) and **WaterMission**. Details on these organisations are found in appendix C.

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1.4.3 Waste Management

HS Green Energy is a Ugandan company specializing in waste-to-energy systems, product development and logistics (HS ENERGY GREEN ENERGY, 2025).

Biogas Solutions Uganda Limited is a Ugandan firm focused on biogas production (Biogas Solutions Uganda, n.d.)

1.4.4 Awareness & Education

SkillEd is a Dutch company specializing in educational tools for low resource settings (SkillEd, n.d.).

1.4.5 Community Lead Latrine Emptying

Within the settlement, a community lead latrine emptying service was found called the **Gulper Group** (Chapter 2.7), utilizing locally available vehicles and materials to empty full pit latrines.

1.4.6 The Waste to Clean Air Project

Established in Imvepi, the Waste to Clean Air project (WTCAP), utilizes a biodigester (Chapter 1.5) (Fig. 1.7) to process several organic waste streams and produce biogas, compost and irrigation water. The project precedes this thesis, which serves as an addition to the WTCAP.

The WTCAP proposes a decentralized human waste management system tailored for low-resource and emergency settings, such as refugee camps and informal settlements in Uganda.
The WTCAP is being implemented as a pilot study with the goal of assessing whether biodigesters can support the development of viable and sustainable human fecal waste management systems in low-resource settings (e.g. slums and refugee camps) in Uganda. If the WTCAP demonstrates success, expansion withing Uganda and other countries in East Africa (Chapter 5.3) will be considered.

The biodigester is being built in collaboration with several stakeholders, consisting of:

- **Semilla Sanitation**, focused on the operation and maintenance of the biodigester.
- **HS Green Energy** and **Biogas Solutions Uganda Limited**, providing technical expertise on the biodigester, as well as logistics.
- **SkillEd**, creates awareness and understanding of the project among inhabitants.
- **CRC Consortium** is responsible for coordination and networking
- **Muni and Wageningen Universities** are conducting research on the quality of biogas produced by fecal matter.

Fig. 1.7 | The biodigester set up by the Waste to Clean Air project (under construction)

1.5 Project Background

1.5.1 The Working of a Biodigester

A biodigester (Fig. 1.8) refers to a tank or system designed for the decomposition of organic waste through microbial activity, resulting in the production of biogas (Giles et al., 2023). The process (Fig. 1.8) also yields by-products such as compost and water suitable for irrigation.

1.5.2 The Biodigester System in Imvepi

The biodigester system in Imvepi (Fig. 1.9) is designed to decompose human fecal matter collected from the settlement's latrines, among other organic waste such as food waste and cow dung. The biodigester has the capacity to process up to 10 cubic metres of organic waste per day, of which 4000 L will be human fecal matter and 6000 L other organic material. The biodigester is anticipated to be fully operational by April 2025.

1.5.3 Destination of Products

The biodigester produces biogas, compost and irrigation water. The products of the digester are partly used in other projects to benefit the community, farmers and the environment and partly sold directly to support the operational costs of the biodigester. Additionally, the products contribute to the creation of jobs and income opportunities for settlement residents.

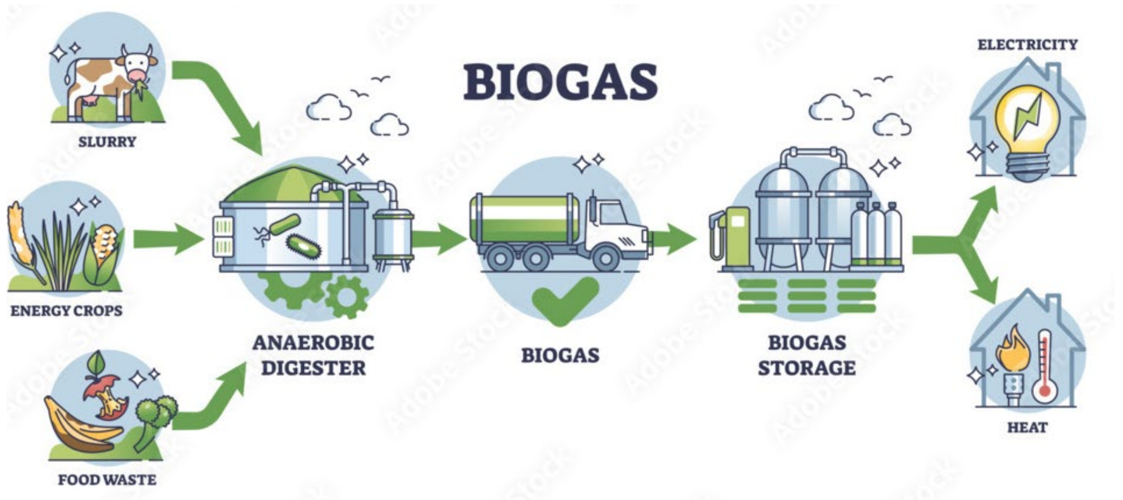


Fig. 1.8 | The workings of a biodigester

Biogas is sold to residents at an affordable price, providing an alternative cooking fuel to open-fire cooking with wood or charcoal. Cooking with (bio) gas is preferred over open fires as it eliminates the risk of carbon monoxide poisoning. Approximately 2.5 million deaths annually are attributed to indoor exposure to particulate matter in rural and urban areas of developing countries World Health Organization et al. (2002). The cookstoves needed for the use of biogas are made by HS Green Energy and are planned to be distributed in the settlement as part of the Waste to Clean Air project, although this has not yet commenced.

Compost is sold to Ugandan farmers, creating a source of income that is vital for funding the operations of the biodigester and supporting sludge transport logistics (Chapter 4.5).

The remaining compost, along with the **irrigation water**, is utilized for establishing a tree nursery. This nursery will cultivate native trees for reforestation and regreening efforts, as well as fruit trees for sale to local farmers. Reforestation plays a crucial role in this project due to the significant deforestation for cooking fuel that has occurred with the expansion of refugee camps in the West Nile region.

By addressing both alternative cooking fuels and reforestation, the project adopts a dual approach in its environmental impact efforts: preventative and regenerative.

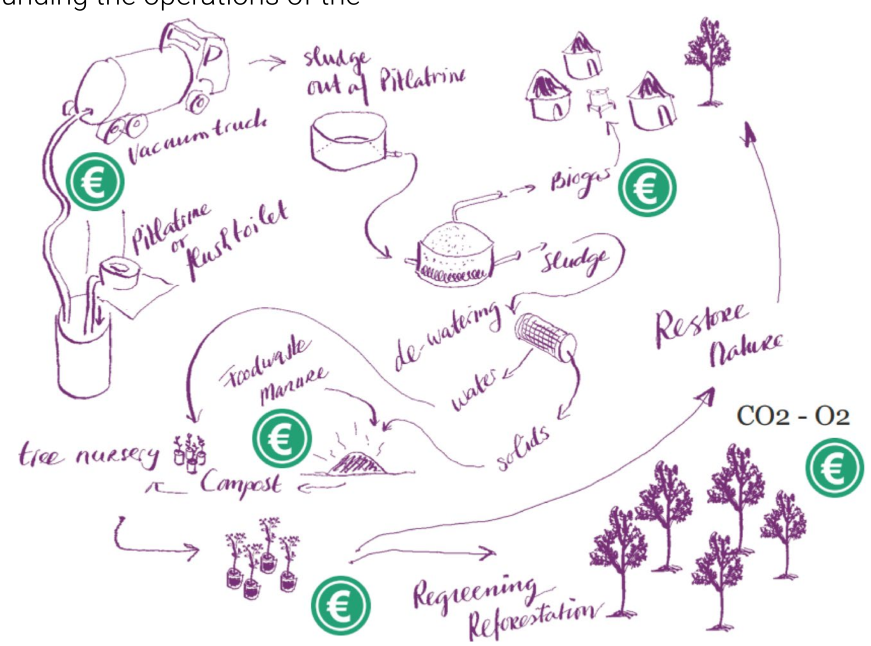


Fig. 1.9 | The Waste to Clean Air Project in Imvepi (Semilla)

1.6 Project Goal, Scope & Impact

1.6.1 Project Goal

The primary goal of this thesis is to design a Product Service System (PSS), consisting of a toilet design for inhabitants' home latrines and an emptying service for this toilet that integrates with the WTCAP's biodigester system. For the original project brief, see Appendix K.

1.6.2 Project Structure

The project takes a human centred approach, in which, the research and design done revolve around the people in that system and their needs, rather than technicalities. The project consisted of three main phases:

1. A **research phase**, which involves field research in the Imvepi settlement, with the goal of creating a holistic overview of project stakeholders and settlement systems (Chapter 2).

2. A **design phase**, consisting of iterative prototyping, testing and validating the toilet concept with users and builders. (Chapter 3), as well as establishing an emptying service to empty the latrines and transport the fecal sludge to the biodigester (Chapter 4).

3. An **implementation phase**, taking into account possible challenges and opportunities found throughout the previous phases (Chapter 5).

1.6.3 Research Questions

Research questions are compiled to guide the research and design phases.

Research Phase

- What is the state of latrines in the settlement and why?
- What are inhabitants' values surrounding latrines?
- What stakeholders are present in the settlement and how could they influence the implementation of the PSS?
- What systems are present in the settlement how could they influence the implementation of the PSS?

Design Phase

- How can the PSS serve the needs of the stakeholders found in the research phase? (Chapter 2.9)

Implementation Phase

- How can the PSS be tested and implemented in the settlement, accounting for challenges it might face? (Chapter 5.1)

Scope

The scope of the project was decided upon in collaboration with Semilla Sanitation's wishes for the project, keeping in mind the human-centred design approach.

In scope:

- Field research to create a holistic overview of project stakeholders and settlement systems
- Literature research to map factors influencing biogas production from human fecal sludge
- The design of a toilet replacing home pit latrines in the settlement
- The design of a service to empty the designed toilet
- The design of a test set-up, scaling strategy and business plan for the toilet and emptying service

Out of scope:

- Latrines for public facilities (these are already lined and emptied, Chapter 1.3)
- The destination of biodigester products: biogas, compost & irrigation water (Semilla takes responsibility for this)
- The business model for the biodigester system in combination with the toilet & emptying system, since this is confidential. However, significant estimations are provided.

Project Impact

With this project, the intended impact could be summarized as: improving sanitation systems in low resource settings, such as refugee camps, to benefit public health by creating a toilet & emptying service. The PSS can be implemented, tested and its results measured for further improvement and eventual scaling of the system for increased impact.

A Deep Dive into the Imvepi Settlement

02.

Over a period of three weeks, field research was done in the Imvepi settlement, using a human-centred approach (Chapter 1.6). The field research is necessary to understand the local culture and identify cultural and human factors that play a role in successful adoption of the design. Interviews with inhabitants provide an overview of the current situation in the settlement. Significant stakeholders that were formerly unaccounted for in the Waste to Clean Air project are identified, engaged and mapped. Through clustering, three main stakeholder groups are found. Challenges and opportunities with relevance to the project are found in different levels of complexity per stakeholder (product, system and human interaction), taking into account environmental, educational and financial factors. From these challenges and opportunities, the needs of each stakeholder group are identified and translated into design requirments for the development of the PSS.

2.1 Research

Research Aim & Set-up

The research that was conducted over the course of 3 weeks inside the Imvepi settlement revealed the complexity of the project. A human centred design approach (Chapter 1.6) was employed to identify stakeholders with different connections to the project.

Visits to households and communal facilites in different parts of the settlement, as well as attending an organisational meeting for the Biodigester project were done in order to gain insight into the settlement context.

In depth interviews with inhabitants (fig 2.1) were designed to gain insight into their living conditions, culture, values and habits, as well as the state of their latrines and their sanitary preferences. For the full inhabitant research set up and results, see Appendix A & B.

The proximity of the research, conducted inside the settlement itself, to the project context allows for the identification of stakeholders that could have otherwise been overlooked. The flexibility to arrange interviews with them provided the research with additional depth.

The following subchapters discuss the results of the field research conducted in the settlement and provide insights on the stakeholders and systems found.

They give an overview of the people, materials, and infrastructure that influence the context and consequently the implementation of the PSS.

First, the settlement's context is presented, including its location, infrastructure, vehicles and materials.

Secondly, our 3 main stakeholder groups are introduced:

- **The Inhabitants**
- **The Gulper Group**
- **The Biodigester Group**

For each of these groups, a list of challenges and opportunities is compiled influencing the integration of the PSS. The chapter concludes with a visual overview of the current situation in the settlement and a list of design guidelines for the PSS.

Fig. 2.1 | Inhabitant Research

Fig. 2.2 | Imvepi Environment

2.2 Settlement Context

The settlement is isolated. Its distance and bad road connection to Arua, the nearest city, limits trade and contact between the two. (fig 2.3).

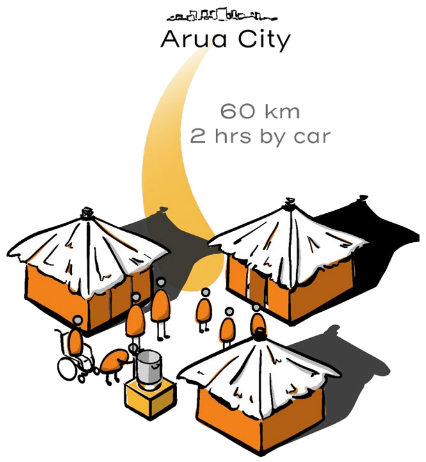


Fig. 2.3 | Distance Imvepi to Arua

Environment & Infrastructure

The environment (Fig. 2.2) of Imvepi is rocky and hilly, with greenery covering the hillsides. Clusters of houses form villages, which are alternated with farmland and bushes. There is significant space between the villages, typically around 50 to 100 meters, which is occupied by farms and wild bushes.

The main road (Fig. 2.4) connects the city of Arua to the settlement and link villages within the settlement. It is a network of wide, unpaved stretches of sand, and while they contain some potholes that can be problematic for vehicles with lower chassis, these roads are generally passable for most vehicles.

Following heavy rainfall, sections of the road at low altitudes or along rainwater flow paths become muddy and slippery (Fig. 2.5). Vehicles may become stuck under such conditions, and most transport comes to a halt until conditions improve.

Fig. 2.4 | Imvepi main road

Fig. 2.5 | Imvepi main road muddy after rains

The roads leading to residential areas within the settlement are referred to as 'settlement roads' (fig 2.9). They are often little more than narrow paths through grass. Steep and rocky sections pose challenges for non-off-road vehicles. During rainfall, some of these paths become difficult to navigate, even for off-road vehicles. Additionally, river overflows can submerge sections of the road, rendering them practically impassable for all vehicles.

The systems for emptying latrines or the treatment plants for fecal sludge are not adequate to service the settlement. Emptying people's home latrines via cesspool trucks is not possible, since the settlement roads are impassable for these types of large & heavy vehicles.

Modes of Transport

Motorcycles or 'boda boda's' (Fig. 2.6) are used to transport a everything in Uganda. Due to the nature of settlement roads, they are the predominant mode of transportation in the settlement.

Modified motorcycles in the form of tricycles (Fig. 2.7) are utilized as ambulances or transport vehicles. These tricycles can access all areas of the settlement under dry conditions.

Fig. 2.6 | Motorcycles are the main form of transportation in the settlement

Fig. 2.7 | An tricycle used as ambulance

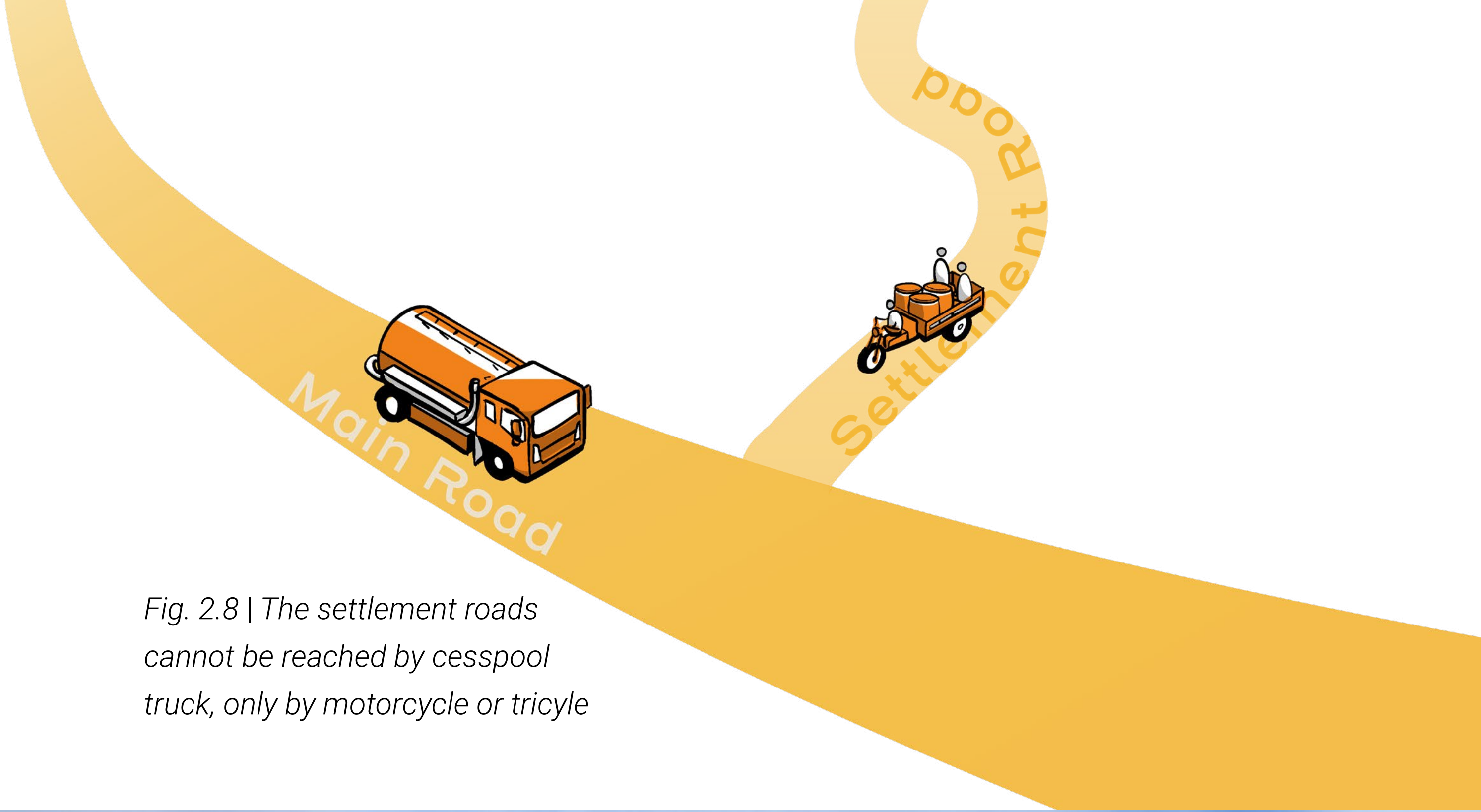
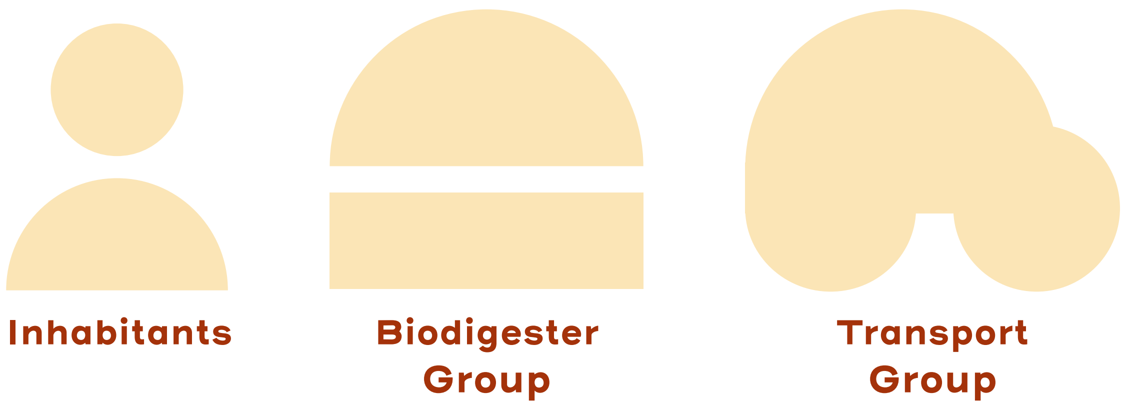


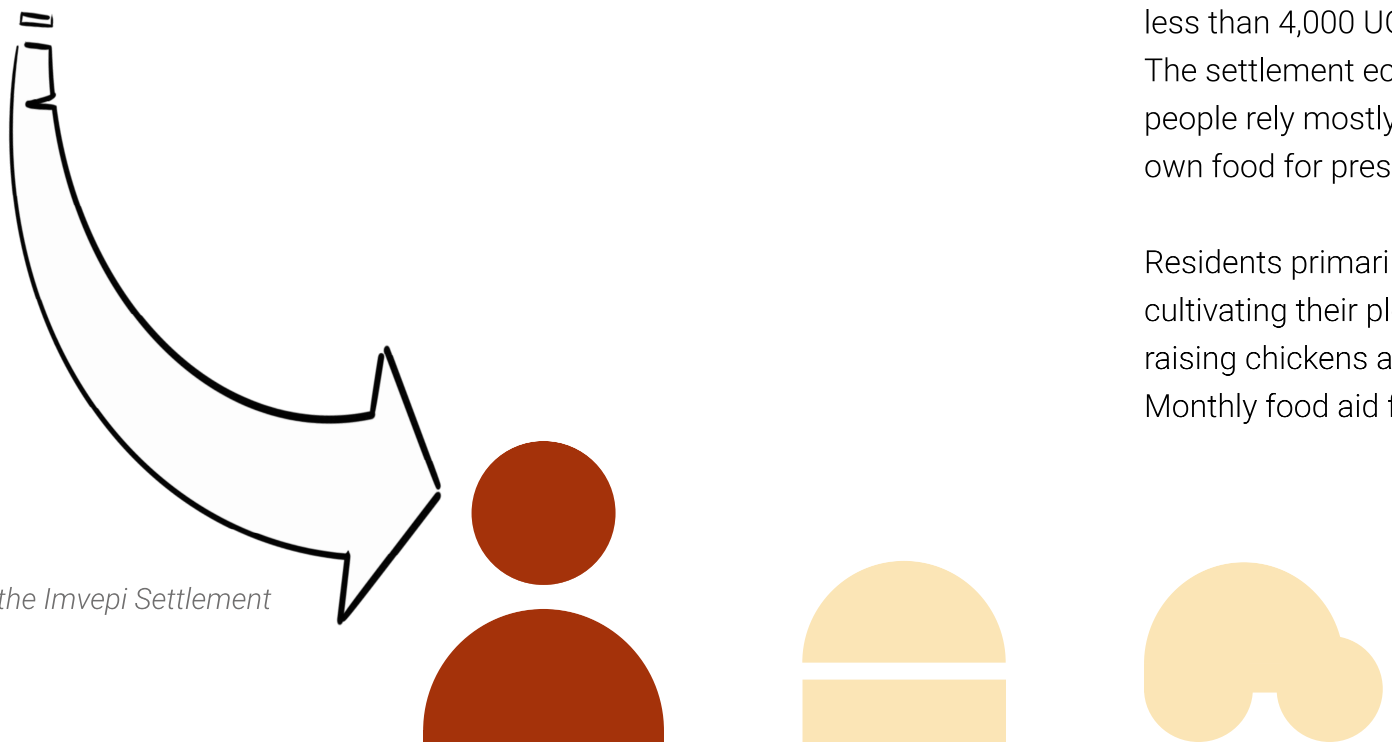
Fig. 2.8 | The settlement roads cannot be reached by cesspool truck, only by motorcycle or tricyle

Fig. 2.9 | Imvepi settlement road

2.3 Stakeholder Groups

The relevant stakeholders in the settlement are divided into 3 categories. The inhabitants, the Biodigester Group and the Transport Group. Their respective icons are shown below. Throughout the chapter, the icons are depicted at the bottom of each page, the icon of the group that is discussed is dark red. For the list of all stakeholders and their relationships, see Appendix D.





2.4 Inhabitants

Living Conditions

Refugees in the settlement are allocated land plots, originally 50x50 metres .Unfortunately, because of the increased influx of refugees (Chapter 1.2) the plots have been forcedly reduced to 30x30 meters, leading to an overcrowding of the area. This may lead to increased infection risks. Not only because of social interactions, but also because of the number of people using a single latrine.

Work opportunities are scarce, with a reported daily wage of 10,000 UGX (~€2.50) for an ambulance (Fig. 2.7) driver, who has to be available 24 hours per day. He reports salary funds often pass through intermediaries, leaving minimal amounts for on-ground maintenance. Other inhabitants report working for less than 4,000 UGX (~€1) per day. The settlement economy is weak and people rely mostly on farming their own food for preservation.

Residents primarily depend on cultivating their plots of land and raising chickens and goats for food. Monthly food aid from the World Food Programme (WFP) is also provided, although the quantity has been decreasing over recent years, from 30 kg's of food per month per family in 2019 to 3 kg's currently. This decline is attributed to insufficient funding, but also a strategic effort to gradually promote self-reliance among the inhabitants, reducing dependency on external assistance.

Despite economic challenges, the inhabitants exhibit a **strong sense of community**, with social gatherings commonly observed throughout the area. Inhabitants demonstrate a willingness to interact with strangers, offering assistance and guidance to those in need. During research activities, residents frequently approached to observe and contribute where possible. If a question arose to which the inhabitant did not have an answer, they would reach out to someone who could provide further assistance. This high level of social interconnectedness among residents highlights the collaborative and supportive nature of the community.

Multiple houses on a single plot belong to the same family. These houses are traditionally built in a communal arrangement (Fig. 2.10 & 2.11), positioned close together with an open living space in the centre. This central space is used for socializing and processing crops. The houses within these communes range in size from 8 to 20 square meters. They are generally square in shape, with grass thatched roofs forming into a point. **All participants reported having a latrine within their commune or sharing a latrine with a neighbouring family.**

The condition of inhabitants' latrines in the settlement varies significantly (Fig. 2.12). Some residents take great care to maintain their latrines,

Fig. 2.10 | A family's living commune

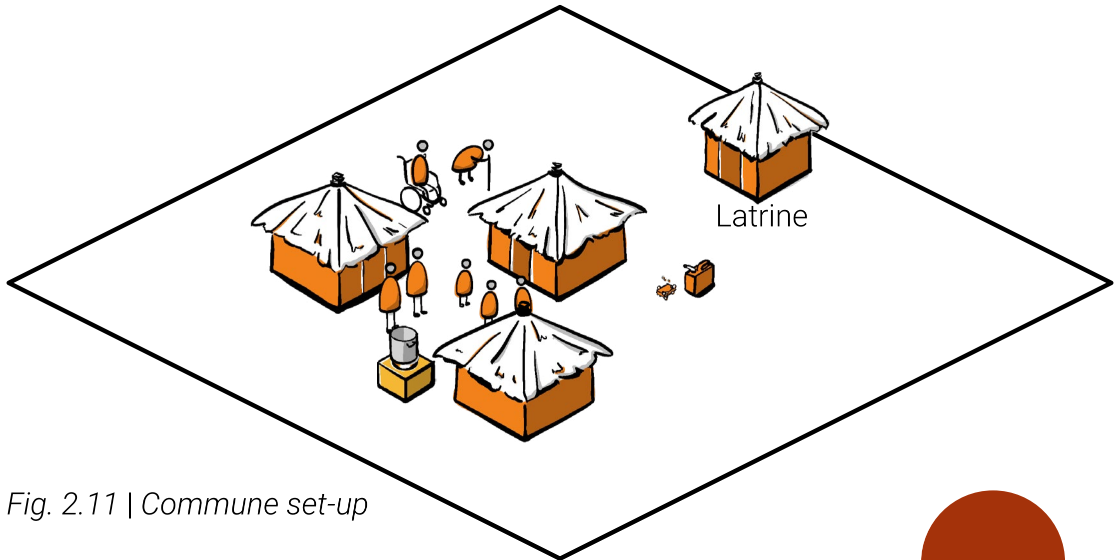


Fig. 2.11 | Commune set-up

Disabled & Elderly Inhabitants

Two primary user profiles were identified: **healthy, and disabled/ elderly individuals**. With the latter facing the biggest challenges with current latrines.

Fig. 2.12 | Elderly and disabled inhabitants

Disabled and elderly individuals face unique challenges when it comes to latrine use. A general lack of healthcare has resulted in disabilities caused by diseases such as polio and chronic malaria, while elderly individuals also face **difficulties using latrines because of mobility issues**. Around **30%** of participants reported having a disabled person in their commune who struggles to use the latrine.

A majority of disabilities (75%) involve issues with the legs or difficulties with **squatting**. Many disabled individuals rely on kneeling or using walls for support when using the latrine. Some individuals must kneel or sit on their crutches, positioned flat over the latrine hole to relieve themselves. Due to the inconvenience and shame of using public toilets that do not meet their needs, disabled individuals often avoid going outside.

One caregiving mother shared that her son deliberately refrains from eating and drinking to avoid the need for a bathroom when away from home (which had only occured twice to meet humanitarian workers). All disabled individuals expressed a preference for sitting toilets, and wheelchair users would greatly benefit from the ability to manoeuvre their chairs up to the toilet bowl for easier access.

While efforts by humanitarian aid have provided aids such as poo chairs (Fig. 13), **the sanitary needs of disabled and elderly inhabitants are currently not met at scale**, severely limiting their freedom to travel outside their commune.

Fig. 2.13 | A poo chair provided by humanitarian aid

2.5 Latrines

Construction

When refugees arrive in the settlement, one of the first tasks they undertake is **construct a latrine as quickly and cheaply as possible**. During this stage, considerations of structural integrity and waste management are often secondary priorities.

Latrines are typically constructed by first **excavating a hole** in the soil (Fig. 2.14). Due to the rocky nature of the soil and high water table in the settlement, the depth of the hole is usually limited to a **maximum of 3 to 4 meters**. The depth of the pit is directly related to the duration of the latrine's usability and should be sufficiently deep to prevent fecal matter from being visible.

Once excavation is complete, a "**slab**" is placed on top. This slab, which serves as the latrine floor, features a hole for waste disposal. Traditionally, these slabs are made by the inhabitants using sticks and mud (Fig. 2.15). This type of slab prevents the use of water for cleaning, as the mud would liquify upon contact with water. In contrast, humanitarian aid organizations have distributed concrete and plastic (Fig. 2.15) slabs throughout the settlement, which are compatible with water and soap for cleaning.

The walls of the latrine are typically constructed from "unburnt" bricks (Fig. 2.16), which are the most common and made from dried mud. Alternatively, "burnt" bricks (Fig. 2.17), which are fired for increased durability, are used but considered a luxury by the inhabitants.

The roof is most commonly constructed from thatched grass (Fig. 2.16), though some latrines—typically those built by humanitarian organizations or for public use—feature corrugated steel roofs (Fig. 2.17). Corrugated steel is viewed as a desirable option by the residents due to its long lifespan.

A door may be added to the latrine, often not more than a tarp (fig 2.16). In some cases, doors are fashioned from sticks and hinged with metal wires stitched between the doorpost and the door. In rare instances, doors are made from corrugated steel (fig 2.17), which is preferred by the inhabitants for its durability.

The average cost of constructing a latrine was reported to be 97,000 UGX (approximately €24.58).

Fig. 2.14 | Excavated latrine hole

Fig. 2.15 | Latrine 'slabs' from left to right: sticks & mud, concrete, plastic

Fig. 2.16 | Typical latrine stall

Fig. 2.17 | Latrine stall built by humanitarian aid

ensuring structural integrity and carefully considering placement to optimize hygiene and durability. These latrines were kept clean and in good condition. However, the majority were cramped, smelled, with flies circling in and around the latrine and frequently showed structural issues, such as holes in the walls, roof, or door, or lacked doors entirely. Cleanliness was not always prioritized. Some respondents cited a lack of responsibility for cleaning due to unauthorized use of their latrine by others. Others stated that after flooding had caused their latrine to tilt or become structurally compromised, they stopped maintaining it alltogether.

Fig. 2.18 | *Latrines in good (left) and poor (right) states*

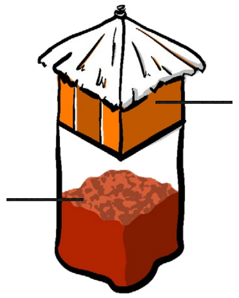


Fig. 2.13 | *Causes for low perceived value of latrines*

Perceived Value of Latrines

The lack of responsibility for latrine maintenance and the consequent poor state of latrines can be partially attributed to the low perceived value of latrines found. Causes for this low perceived value are identified (Fig. 13):

1. **The low lifespan** of latrines in Imvepi compared to other areas, such as South-Sudan, is caused by pit depth limitations. Imvepi has a rocky soil and high watertable, limiting the excavation of pits beyond 3 to 4 metres. A low lifespan lowers the latrine's value over time.
2. **Structurally damaged** latrines as a consequence of flooding (Chapter 2.5) are less valued due to their broken state and limited usability.
3. **Unsolicited use** of latrines by people outside of the family commune lower the feeling of responsibility for cleaning, since the cleanliness of the toilet will soon be undone by others.

Floodings

Heavy rainfall and flooding poses serious challenges. Rivers overflow and a lack of drainage canals mean concentrations of rainwater have nowhere to go. Flooding fills the latrine's pit, and in combination with the rocky, loose soil, often leads to structural damage or complete destruction of the latrines. Some inhabitants have reported that their latrine has collapsed after only a few months, due to flooding. Additionally, flooding could disperse the fecal contents of the latrines into the surrounding areas, contaminating communal living spaces and homes

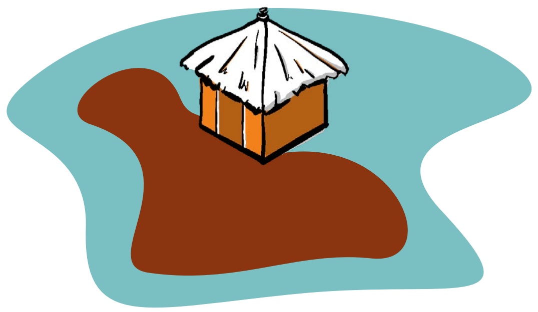


Fig. 2.19 | Flooding of latrine and spreading of fecal matter

(fig 2.19).

On average, 13.4 people shared a single latrine, with reportings of 5 to 29 individuals sharing one latrine. The average lifespan of a latrine is estimated to be around two years, though it may last an additional two years if properly maintained and placed on elevated ground, which helps prevent flooding and collapse.

Humanitarian organisation Water Mission has installed solar-powered drinking water taps throughout the settlement, ensuring free access to clean water for the inhabitants. This initiative helps improve overall hygiene and sanitation in the settlement, supporting the health and well-being of the residents.

Latrine Use

Prior to using the latrine, inhabitants ensure the availability of personal cleaning materials such as (toilet) paper, water or leaves. These may be stored in the latrine or brought from elsewhere. Store-bought toilet paper is rarely used due to the relatively cost for inhabitants. Only 1 out of 15 participants reported currently having it at their latrine. Some inhabitants mentioned that in the absence of other materials, rocks might be used to clean themselves, or individuals may even scrub themselves against the wall.

Once materials are gathered, the user enters the latrine, locks it if possible (though locks are uncommon), and squats over the hole (Fig. 2.20). After cleaning, the cleaning materials (papers, leaves, or water) are discarded into the pit.

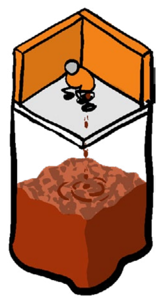


Fig. 2.20 | Latrine use

Hand Washing Facilities

Handwashing facilities for after latrine use are typically located outside the latrine. The most common type (33%) features a jerrycan, sticks, and a foot pedal (Fig. 2.21), allowing water to flow without touch and reducing disease transmission. This design, promoted by humanitarian aid organizations, minimizes health risks.

Other facilities include jerrycans placed on the ground (Fig. 2.22), requiring manual lifting and tilting, or buckets and basins, where users scoop water for handwashing. Only half of the participants reported having soap available for handwashing, while one out of 15 participants even indicated having no handwashing facility at all.

Fig. 2.21 | Handsfree hand washing facility using sticks, rope and a jerrycan

Fig. 2.22 | Standing jerrycan as a handwashing facility

Cleanliness

To prevent the latrine from smelling, ash from burnt firewood is spread in and around the latrine hole, and in some cases, washing with water and soap or detergent was done to mitigate smell.

Daily cleaning is done most often using locally made brooms (Fig. 2.23) and periodical cleaning with water if the slab material allows. In some cases, walls and floors are refreshed with a layer of mud.

Fig. 2.23 | Local broom used for cleaning

Latrines also function as garbage disposal sites, with items such as plastic bags, dead animals, and broken glass discarded into the pit.

End of Latrine Life

Latrines are sealed when completely full and the site is left unused for 4-5 years (Fig. 2.24). Then, a new latrine is built elsewhere. Both the old and new latrine location cost valuable farming land, which is frustrating for the inhabitants. Although interest in latrine emptying is reported, inhabitants do not know of emptying services. South Sudanese refugees reported emptying latrines every 3–4 years in South Sudan for 4,000 South Sudanese pounds (~€27.87).

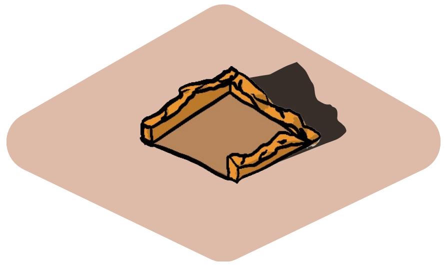


Fig. 2.24 | The closed latrine area cannot be used for farming for 4-5 years

Cultural Aversion to Seeing Fecal Waste

The pit depth is culturally important, as it should prevent fecal matter from being visible. A strong cultural aversion was observed to seeing old fecal waste. Inhabitants are sceptical of products derived from fecal waste, limiting biogas distribution. A common misconception that biogas from fecal matter is hazardous further hinders the WTCAP's success.

Latrine Knowledge

Inhabitants recognize that the primary advantage of using latrines over open defecation is the significant reduction in disease transmission. Handwashing is widely understood as a crucial step in preventing the spread of illness. The presence of hygiene campaigns is evident throughout the settlement, where billboards (Fig. 2.25) and murals (Fig. 2.26) promote regular handwashing and proper latrine use to support public health efforts.

Despite the camaigns efforts however, gaps in people's knowledge on latrine hygiene have also been identified. A common misconception among inhabitants was that if the latrine does not stink, they can not get sick from it. This leads to a knowledge gap on knowing how and when to clean the latrine and cleaning is not done as frequently or thouroughly as needed to prevent infection.

Fig. 2.25 | Hand washing infographic in the settlement

"If my latrine does not smell, I cannot get sick"

~Inhabitant

Fig. 2.26 | Hand washing mural in the settlement

Repairs

Throughout the settlement, it is observed that old materials are repaired, often in an improvised manner. This phenomenon could be attributed to the high cost of new materials, as opposed to the relatively low cost of labour, in combination with low employment rates, which cause people to often have significant amounts of time available to them. As Items are rarely discarded or repaired in a professional manner. Specifically for latrines, it is observed that leaks are patched, and structural faults are supported rather than fully repaired.

Values Regarding Latrines

A considerable portion of the inhabitant research (Appendix A) was set up to discover inhabitants' values in regard to latrines. **Safety** and **cleanliness** were found to be the most important values for latrines. For all latrine values, see Appendix B.

Safety

Inhabitants perceive safety as the most important value when it comes to latrines. The key attributes that contribute to a sense of safety include:

1. **Having a door**, which not only ensures privacy but also prevents dangerous animals such as snakes from entering.
2. **Clean surroundings**, as they allow users to see their environment and reduce the risk of snake attacks.
3. **A handwashing facility** is also crucial to prevent the spread of disease.

Cleanliness

Cleanliness is perceived as the second most important value for a latrine, according to inhabitants. The most important attributes for maintaining a clean toilet include:

1. **A cover for the latrine hole**, which helps to control odours and keep flies at bay.
2. **Access to water, soap and detergent** for latrine cleaning
3. **Access to cleaning materials** such as brushes and brooms for latrine cleaning

Repairs

Throughout the settlement, it is observed that old materials are repaired, often in an improvised manner. This phenomenon could be attributed to the high cost of new materials, as opposed to the relatively low cost of labour, in combination with low employment rates, which cause people to often have significant amounts of time available to them. As Items are rarely discarded or repaired in a professional manner. Specifically for latrines, it is observed that leaks are patched, and structural faults are supported rather than fully repaired.

Inhabitant Motivation to Improve Sanitation

Inhabitants show enthusiasm when learning about improved toilet facilities and demonstrate motivation to help in their with the latrine's construction and maintenance, e.g. excavation of the latrine hole, and the communication of their emptying needs.

Introducing Proper Sanitation

The results presented in this chapter reveal the complexity of the current situation and the challenges that are currently at play in the settlement. In the next part of this chapter, these research is evaluated to discover how it could influence the introduction of improved sanitation. On the next pages, an overview of the opportunites and challenges relating to the implementation of proper sanitation systems are presented.

Challenges

Cost of New Systems: Current pit latrines are inexpensive and last up to four years, alternatives require significant investment & operational costs.

Weak Economy: The weak economic state of inhabitants limits their ability to contribute financially.

Floodings: Heavy rainfall causes floodings, which can damage latrines and contaminate living areas with fecal matter.

Transport Disruption: Rainfall renders roads impassable, disrupting fecal sludge emptying and transport services.

Trash Disposal: Trash disposed in latrines could clog latrine emptying equipment.

Truck Inaccessibility: Cesspool trucks cannot traverse settlement roads to empty inhabitant latrines in most settlement areas.

Cultural Aversion to Fecal matter: Having to see fecal matter can deter proper cleaning and maintenance of latrines.

Latrine maintenance Issues: Lack of materials, knowledge and responsibility hinders regular latrine upkeep.

Mud Construction: Mud slabs & latrine stall walls cannot be cleaned effectively with water and soap, posing hygiene risks.

Material Replacement & Repairs: Broken or lost materials are difficult to replace due to cost or unavailability and unprofessional repairs pose possible safety risks.

Accessibility for Disabled/Elderly: Squatting latrines and cramped stalls pose challenges for the disabled and elderly inhabitants.

Hygiene Gaps: Limited hygiene knowledge increases disease risks.

Privacy Concerns: Many latrines lack doors, compromising privacy and safety.

Opportunities

Desire for Improved Sanitation: Inhabitants' interest in latrine emptying and enthousiastic response to sanitation innitiatives suggests their desire for improved waste management solutions.

Community Involvement: Inhabitants' willingness to assist in construction, maintenance and emptying communication can lower implementation costs and increase community involvement.

Improved Latrine Placement: Placing toilets on elevated areas can prevent flooding and increase toilet longevity.

Innovative Sludge Transport: Small vehicles such as off-road tricycles can traverse the settlement roads and facilitate fecal sludge transportation.

Reusing Latrine Materials: Reusing materials from existing latrines reduces costs.

Durable Materials: Durable, water-resistant construction materials can make toilets more suitable for proper maintenance, improving hygiene, and increasing latrine longevity & perceived value.

Sitting Toilets: Providing sitting toilets improves accessibility for disabled and elderly individuals and consequently the inclusiveness of the design

Broad doors and stalls: Fitting toilets with broad doors and stalls improves the accessibility for wheelchair users, increasing the designs inclusiveness

Standardized Design: Standardized construction with durable doors and roofs can enhance safety, privacy, usability and perceived toilet value.

Education: Expanding educational initiatives can address knowledge gaps in cleaning practices and maintenance.

Improved Product Perception: Emphasizing safety, cleanliness, and durability can increase perceived toilet value and facilitate adoption of introduced solutions.

2.6 Biodigester Group

Introduction of proper sanitation begins with proper human waste management systems. The WTCAP (Chapter 1.4) relies on active participation from a diverse group of project partners, collectively referred to in this report as the "Biodigester Group". Together, they aim to provide a sustainable human waste management solution while enhancing sanitation and energy production.

2.4.1 Sludge Quality

The quality of fecal sludge plays a crucial role in determining the efficiency and output of a biodigester system. The potential for biogas production is highly influenced by the **storage time** and **composition** of the sludge. As fecal sludge is stored, it undergoes changes that can either preserve or degrade its biogas production potential. Understanding these factors is critical for optimizing biogas production. Several strategies can help extend storage times and preserve biogas production potential:

1. **Proper lining and sealing of pit Latrines** ensures moisture retention and prevents water leaching out, which helps in retaining organic matter for longer periods. This moisture retention is essential for maintaining the potential for biogas production, as it slows down the mineralization process of organic materials (Strande et al., 2022). It was found that adding urine to cow dung improved its biogas producing qualities (Kim et al., 2020), it is expected by HS Green Energy that this also applies for human fecal matter.

2. **Improving Anaerobic Conditions** within the pit latrine is crucial for maximizing biogas production. Airtight seals, digesters, and biogas collection systems help ensure that the organic materials do not undergo aerobic decomposition, which would otherwise deplete the organic matter available for biogas generation (Maqbool et al., 2021).

3. **Layering sludge with cover materials** such as soil, ash, or other organic cover materials can reduce surface evaporation and maintain anaerobic conditions by limiting the entry of air. This prevents the organic matter from being exposed to oxygen, which would accelerate aerobic decomposition and reduce biogas production (Kilucha et al., 2022).

4. **Temperature Control** plays a vital role in microbial activity within the fecal sludge. Lower temperatures help slow down microbial degradation, thus extending the time during which biogas production remains viable. Storing the sludge in shaded or cooler environments can help maintain its organic load and delay mineralization (Maqbool et al., 2021).

5. **Addition of Co-Substrates**, such as food waste or agricultural residues, can increase the organic load available for digestion. This process, known as co-digestion, not only helps preserve the organic matter in the sludge but also enhances the overall biogas yield by providing additional nutrients and improving the microbial community's stability (Kilucha et al., 2022).

Sludge Collection and Transport

Efficient collection and transport are critical for biodigester operations. Fresh, liquid sludge ensures smooth extraction and transport, while non-organic contaminants such as trash can clog hoses and disrupt operations. Reducing contaminants is essential for system efficiency.

The biodigester requires a consistent supply of fecal sludge, fecal sludge from public latrines can be acquired and transported via cesspool trucks, however, a robust latrine emptying service for home latrines is needed to guarantee a consistent supply of sludge to the digester

The system's success also depends on inhabitant cooperation and education. Residents must adhere to proper latrine maintenance, refrain from waste disposal in the latrine, and communicate their sludge removal needs. Educational initiatives can promote these practices, ensuring sustainable operation.

Influence on the Project

The research done on the Biodigester Group is important for the project's viability, since the revenue from selling biogas finances the system. Research on the Biodigester Group is related to the inhabitant research (Chapter 2.3) to determine challenges and opportunities for the PSS design.

Challenges

Quality and consistency of sludge: Unregulated quality and inconsistent supply of fecal sludge can result in suboptimal biogas production and reduced output capacity.

Wet sludge storage: Storing fecal matter and urine together leads to increased smell, unlike unlined pit latrines, where fluids are absorbed into the soil and sludge is dried out, reducing smell.

Presence of soap or detergents: Soap and detergents harm microbial life in the sludge, reducing biogas production efficiency.

Reduced biogas production with extended storage: Prolonged storage causes mineralization of organic matter, decreasing the biodegradable material needed for biogas production.

Maintaining anaerobic conditions: Failure to keep storage systems airtight leads to aerobic decomposition, reducing the organic matter available for biogas.

Temperature effects on biogas production: the settlements tropical high temperatures increase microbial activity, negatively impacting the fecal sludge's biogas producing qualities.

Oppportunities

Co-digestion of organic material to enhance biogas production: Incorporating additional organic materials, such as food waste, into stored fecal sludge can replenish the organic load, boost microbial activity, and improve biogas yields.

Charcoal additive for biogas production: Adding charcoal to fecal sludge can enhance biogas production while providing additional energy resources for the community.

Use of cover materials to preserve anaerobic conditions: Covering fecal sludge with materials such as ash or soil reduces evaporation, maintains anaerobic conditions, and consequently improves biogas yields.

Temperature control for extended storage: Storing sludge in shaded, cooler environments, e.g. under the ground, helps regulate temperatures, extending the fecal sludge's potential for biogas production.

Moisture retention with lined pit latrines: Lined pit latrines retain moisture, preserving organic matter in the sludge and extending its biogas production potential.

Sludge collection efficiency: Efficient collection and transport of fresh, liquid sludge to the biodigester can improve biogas production quality and enhance the system's financial sustainability.

2.7 Transport Group

The Transport Group refers to the organisations providing latrine emptying services in the settlement, consisting of professional cesspool truck companies and the community lead Gulper Group.

Traditional latrine emptying services use cesspool trucks (Fig. 2.27) capable of collecting 4,000 to 10,000 liters of fecal sludge. These trucks have built-in pumps for quick, hygienic operation but are limited to main roads and must travel 60 km from Arua, taking approximately two hours. The charge for a round trip is 400,000 UGX (~ €100,00). The cesspool trucks are used to empty public latrines, but are unable to traverse the settlement roads (Chapter 2.2) and therefore unable to empty home latrines.

Fig. 2.27 | Cesspool emptying truck

The Gulper Group (Fig. 2.28) is a community lead latrine emptying service, set up in Odupi, a refugee camp neighbouring Imvepi. It is composed of 30 local individuals who provide services for both public and private latrines. Water Mission (Appendix C) has equipped the team with essential tools and resources, alongside education on proper latrine emptying techniques. The financial set-up of the Gulper Group, makes them a standalone entity, but also brings financial risks.

Tools & Materials

The Gulper Group uses a manual device called a **gulper** (Fig. 2.29), which is hand-pumped to remove fecal sludge from latrines (Mausin, 2009).

The Gulper Group utilizes tricycles (Chapter 2.2), to transport fecal sludge within the settlement.

To store and transport fecal sludge, drums (Fig. 28) are used. Each drum can hold 200 litres.

A tricycle can carry up to three 200-liter drums of fecal sludge at a time (600 L total).

Fig. 2.28 | The Gulper Group

Fig. 2.29 | *A gulper*

Financial set-up

The total cost of the set-up is around 10 million UGX (~€2.500,00). The tools are donated to the Gulper Group by Water Mission. The group's operational, maintenance and repair costs now all fall under the responsibility of the Gulper Group.

The group charges a fee for their services, with prices ranging from 7,000 to 15,000 UGX (~€1,75 - 3,80) per barrel for private latrines, and 20,000 to 30,000 UGX (~€5,00 - 7,50) per barrel for public latrines. The group retains the revenue from these services. The collected waste is taken to a treatment plant, where the Gulper Group is charged 1,000 UGX (~ €0,25) per drum to offload the sludge (Fig. 2.30) . The estimated daily wage of a member of the Gulper Group is estimated at 10.000 UGX (~ €2.50).

Fig. 2.30 | *Offloading sludge*

Operational Challenges

Through interviews with members of the Gulper Group and image analysis, pain points were found on hygiene, safety and financial levels.

The use of the gulper requires the operator to be directly above the fecal sludge being pumped, risking the inhalation of airborne fecal particles which can carry sickness.

The thickness of sludge in unlined pit latrines means the sludge often has to be rehydrated. This process involves putting water in the pit and stirring with a stick. This manual handling of sludge often means the worker comes into direct contact with fecal material (Fig. 2.32).

Manual handling of buckets of fecal sludge from the gulper to the drums (Fig. 2.31) risks direct contact as well.

The transport of sludge happens while the drums are unfixed on the back of motorized trycicle. Also on the back are members of the Gulper Group, holding the barrels in place to ensure they do not fall over. The transport through the steep, rocky settlement roads poses safety risks, since barrels falling onto the workers and workers falling off the tricycle risk worker **injury and death**. This mode of transport also poses health risks, since spilling of the sludge from the barrels could cause workers to come into direct contact with the fecal sludge, risking infection.

While the gulper is effective, it is a labor-intensive process. Each 200-liter drum takes approximately 10 minutes to fill, and the group must work in shifts to operate the device due to fatigue. This process is slow and requires significant physical effort.

Fig. 2.31 | *Operators of the gulper work directly above the fecal sludge*

Fig. 2.32 | *Rehydrating sludge in an unlined pit latrine causes direct contact between the worker and fecal matter*

Overall, the Gulper Group's community-led approach to latrine emptying poses as a significant asset to latrine emptying service models, but also faces challenges on hygienic, safety and financial levels. The challenges and opportunities for the development of the PSS are identified below.

Challenges

Limited cesspool access to remote areas: Cesspool trucks cannot reach beyond main roads, restricting their ability to service latrines in residential or remote areas.

Cesspool's high operational costs: The cost of cesspool truck services makes the service financially challenging and potentially inaccessible for many inhabitants.

Cesspool's long distance and travel time: Cesspool trucks must travel 60 km (around 2 hours) from Arua, leading to delays and logistical inefficiencies.

Hygiene Challenges: The use of the gulper and unregulated mode of operations pose hygiene risks for members of the of the Gulper Group.

Safety Challenges: Members of the Gulper Group have to hold the drums on the back of the truck while it is driving, posing serious safety issues.

Financial insecurity: The set up of the Gulper Group's financial system, makes them vulnerable to material breaks, potentially leaving them without an income.

Manual labour intensity: The slow and labour-intensive process of manually emptying latrines with a gulper, poses physical health issues for the Gulper Group.

Limited transport capacity: Current tricycles can carry only three 200L drums per trip, reducing the volume of sludge that can be transported efficiently.

Maintenance responsibility: The Gulper Group is solely responsible for maintaining tools and equipment, which can strain their financial and operational resources.

Oppportunities

Efficient emptying of public latrines: Cesspool trucks can quickly empty large public latrines, providing substantial fecal sludge supply to the digester.

Minimized human contact: Built-in pumps in cesspool trucks reduce manual handling of sludge, enhancing safety and hygiene.

Community-led service model: The Gulper Group's community-led approach aligns with local needs, promotes ownership of sanitation services, and retains revenue to incentivize performance.

Job creation: The sanitation system can create local employment opportunities in latrine installation, maintenance, and fecal sludge transport, through community lead models such as the Gulper Group, promoting economic development within the settlement.

Increased reach: Tricycles, being affordable and versatile, can access hard-to-reach areas, allowing for toilet emptying services via settlement roads.

Low-cost equipment and infrastructure: The affordability of gulpers, tricycles, and drums makes the Gulper Group's service accessible and scalable compared to larger mechanized systems.

2.8 Current System Overview

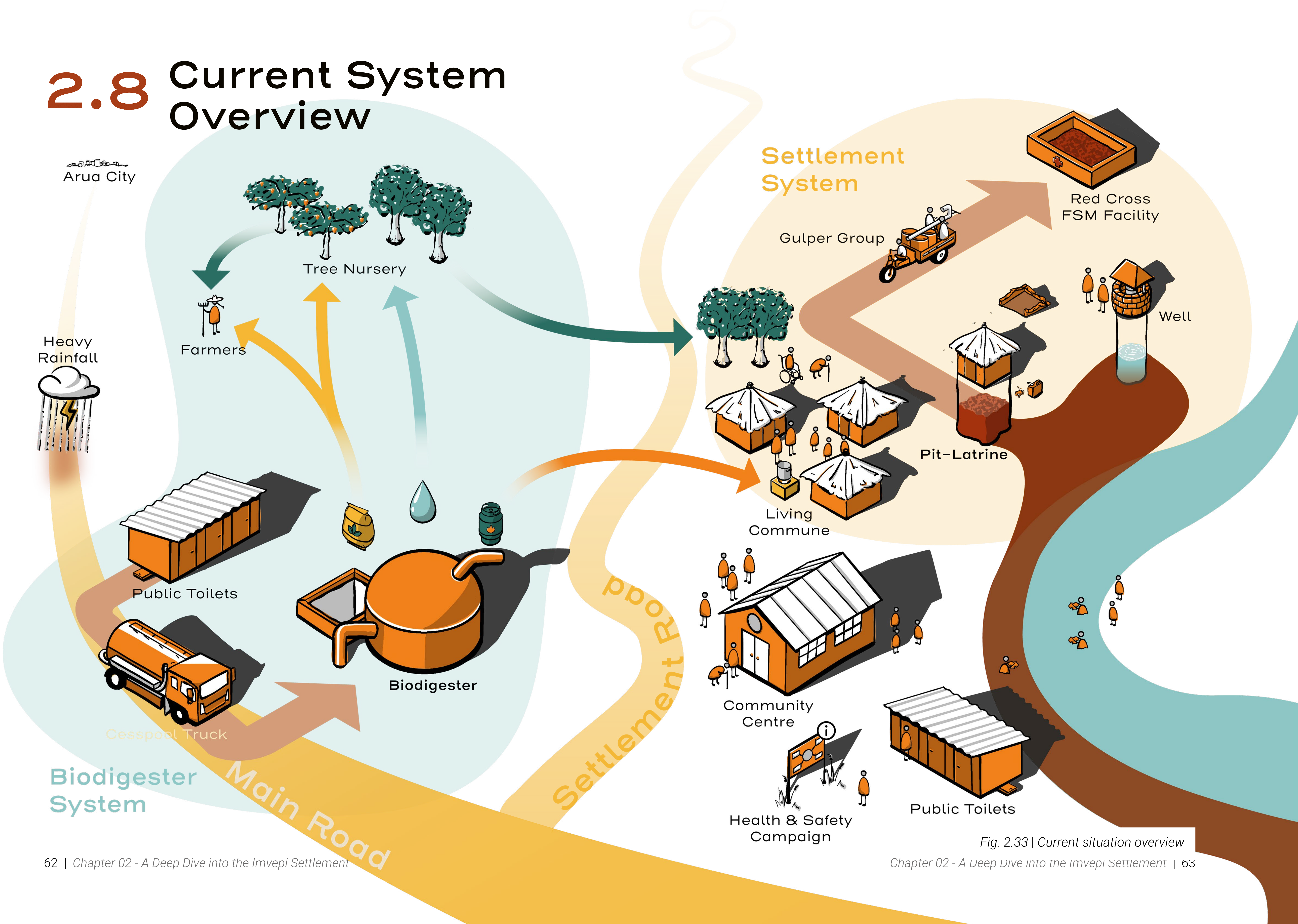


Fig. 2.33 | Current situation overview

Runthrough of Current Systems

The findings of the research are summarized in the current system overview (Fig. 2.33). The most important stakeholders and systems with regards to the project are visualised to give an overview of the current situation.

The biodigester and the settlement system are mostly separated. Some of the biodigesters products go into the settlement, but there is no way of acquiring the sludge from the inhabitant pit-latrine as of now.

Additionally, pit latrines are currently contaminating groundwater, which comes into contact with inhabitants, leading to infection, disease and in the worst case epidemics of waterborne diseases caused by fecal matter.

In the following subchapter, the challenges and opportunities found during research are translated into guidelines for the design of the PSS.

2.9 Design Goals & Guidelines

The insights presented in this subchapter, contribute to the understanding of systems and stakeholders at play in the settlement. In order to create a **meaningful design** for this context, these insights insights need to be translated into concrete design goals and guidelines.

The goals and guidelines presented below are divided per stakeholder group:

Inhabitants

Design Goal

To provide **an inclusive toilet** that is **safe to use** and an **efficient system for proper cleaning**.

- **An inclusive toilet**: including the elderly and individuals with disabilities.
- **Safe to use**: minimizing risks such as disease transmission and structural compromise.
- **Efficient system for proper cleaning**: ensuring toilet is easy to clean and inhabitants have both the materials and the knowledge required to clean the latrine properly.

Design Guidelines

- The toilet should **prevent leakage** of fecal material into the ground water, to prevent the contamination of water sources and consequent human infection with fecal particles.
- The toilet stall must not become **structurally compromised** under standard conditions.
- The toilet location should be on an elevated patch of land to prevent the toilet being **submerged** during floods
- The toilet should be **flood proof** to prevent fecal matter from entering the sludge container and contaminating living areas or cause the toilet stall become structurally compromised.
- The toilet should be made from **materials that are easy to clean** with locally available products.
- **Cleaning materials**, such as soap and jerrycans, should be **made available for sale** as part of the toilet service.
- The toilet should provide a **seating option** to accommodate elderly and disabled individuals.

- The door and stall should be **wide enough** to allow a wheelchair to approach the toilet seat.
- The toilet should include **a cover** and additional features **to prevent odours** in the toilet stall from wet fecal sludge storage.
- Faeces must **not be visible** from within the toilet stall.
- The service should **ensure the latrine is cleaned and provide education** to the latrine owner where needed.
- The toilet should be **accessible without stairs** or other obstacles that would hinder individuals with disabilities.
- The structure, including the walls, door, and roof, must **ensure privacy and be free of holes**.
- **Locally sourced building materials** should be used when feasible to reduce costs and increase user involvement and perceived value.
- Components requiring quality assurance, which cannot be reliably produced with local materials, should be **manufactured professionally**.
- **Standardized construction methods** should be developed through building instructions, and the system's employees or other builders should be **trained and adhere to these instructions** to maintain safety and quality.
- Improper repairs to the toilet should be discouraged and the PSS should have designed features that **prevent potential unsafe repairs**

Digester Group

Digester Group Goal

To create **favourable conditions** that enable the digester to produce **high-quality outputs** and **evaluate the effects** of the system on the biogas producing quality of the sludge.

- **Conditions**: ensuring a consistent and high-quality supply of fecal sludge.
- **High-quality outputs**: sludge that has high biogas producing potential.
- **Evaluate the effects**: measuring the system's effect on the production of biogas by the biodigester.

Design Guidelines

- The odour should primarily by **layering the sludge with ash**, improving anaerobe sludge conditions
- Contamination of the sludge with substances such as s**oap and detergents**, should be minimized as these can hinder biogas production.
- Fecal sludge should not be stored in the toilet container for **more than one month** to ensure its biogas producing capability
- The container should be **installed underground** to create a stable, cool environment for the fecal sludge, without the need for electronic cooling devices.
- Moisture should be maintained by **adding urine** and cleaning the toilet with water, which may also increase biogas yields (Chapter 2.6).
- The toilet should be simple yet effective, so it is **ready for reproduction** and a test set-up to be set up.
- The test set-up should allow for **data to be collected** on user habits, specifically on cleaning habits, since this could influence the biogas producing potential of the sludge.

Transport Group

Transport Group Goal

To establish a **reliable and robust** fecal sludge transport system capable of **accessing all areas** of the settlement and ensuring the **safe, healthy and efficient** working conditions for its employees.

- **Reliable and robust**: able to function effectively despite weather, logistical, or material challenges.
- **Accessing all areas**: capable of reaching even remote and hard-to-navigate areas within the settlement.
- **safe, healthy and efficient**: ensuring worker safety and health and financial stability

Design Guidelines

- The extraction process should be **streamlined for efficiency**, without requiring additional procedures such as liquefying the sludge.
- The toilet should **store fecal sludge in liquid state** to facilitate quick emptying without the need for sludge rehydration to prevent direct contact with fecal sludge by workers and improve pumping efficiency.
- The PSS must **discourage the disposal of trash** into the toilet to prevent blockage of equipment during sludge pumping
- The toilet must have a well-defined and easily reachable **access point** for sludge removal.
- The amount of **manual labour** required for the Gulper Group should be **minimized** through automization of pumping and transport activities.
- The system should be well equiped for **system failures, natural disasters, equipment failures or other setbacks** and be flexible to deal with them.

Detailed Design of the SaniSecure Toilet

03.

The SaniSecure Toilet is designed during this project to replace pit latrines. It addresses the needs of the three stakeholder groups identified in Chapter 2: the inhabitants, the Biodigester Group, and the Transport Group. For the inhabitants, it ensures safety against flooding, hygiene for users through ease of cleaning, ventilation and the toilet's closing feature, as well as inclusivity for all users, including elderly, disabled individuals, and children. For the Biodigester Group, it is capable of storing high-quality sludge for up to one month, with an additional month of reserve capacity to ensure the system's flexibility in case of logistical delays. For the Transport Group, the design facilitates efficient and safe emptying, with multiple options for emptying in case of material failures, providing additional flexibility in compromising situations.

3.1 Design Overview

The SaniSecure Toilet was designed to replace the unlined pit latrines in the Imvepi settlement. In this subchapter, an overview of the main components of the toilet's design and their respective features are presented. These features are related to the problems identified in Chapter 1 & 2. Finally, the interactions between the toilet and its users are presented.

Components and Features

The PVC ventilation pipe is used to direct air from the container out of the toilet stall. It is a common feature for improving latrines (Reed et al., 2014) to reduce smell and keep flies away that could transmit fecal diseases.

The toilet stall is constructed using traditional methods widely practiced in the settlement. The design is standardized to address common issues with latrines, such as the absence of doors.

The Sato toilet, either squatting or sitting. These toilets are easy to clean and feature a closing mechanism that only opens when the toilet is used, putting a barrier between the fecal sludge and the toilet stall,reducing smell and keeping flies out of the fecal sludge container.

The stainless steel box, extending 150 mm extending above ground, is designed to be watertight to ensure the toilet's container does not flood during heavy rainfall. There are two holes on top of the box, one for the installation of the toilet and one for the ventilation pipe, which can be taken off to insert a toilet emptying pump. The design allows for emptying with multiple types of pumps.

The stainless steel frame (1,6 m x 1,6 m) is designed to hold the weight of the toilet stall and user and ensure the structural integrity of the toilet over time.

The Gentex container (2000L), serves as an underground sludge container, to prevent fecal matter from leaking into the groundwater, as well as optimize conditions for biogas production and efficient transport.

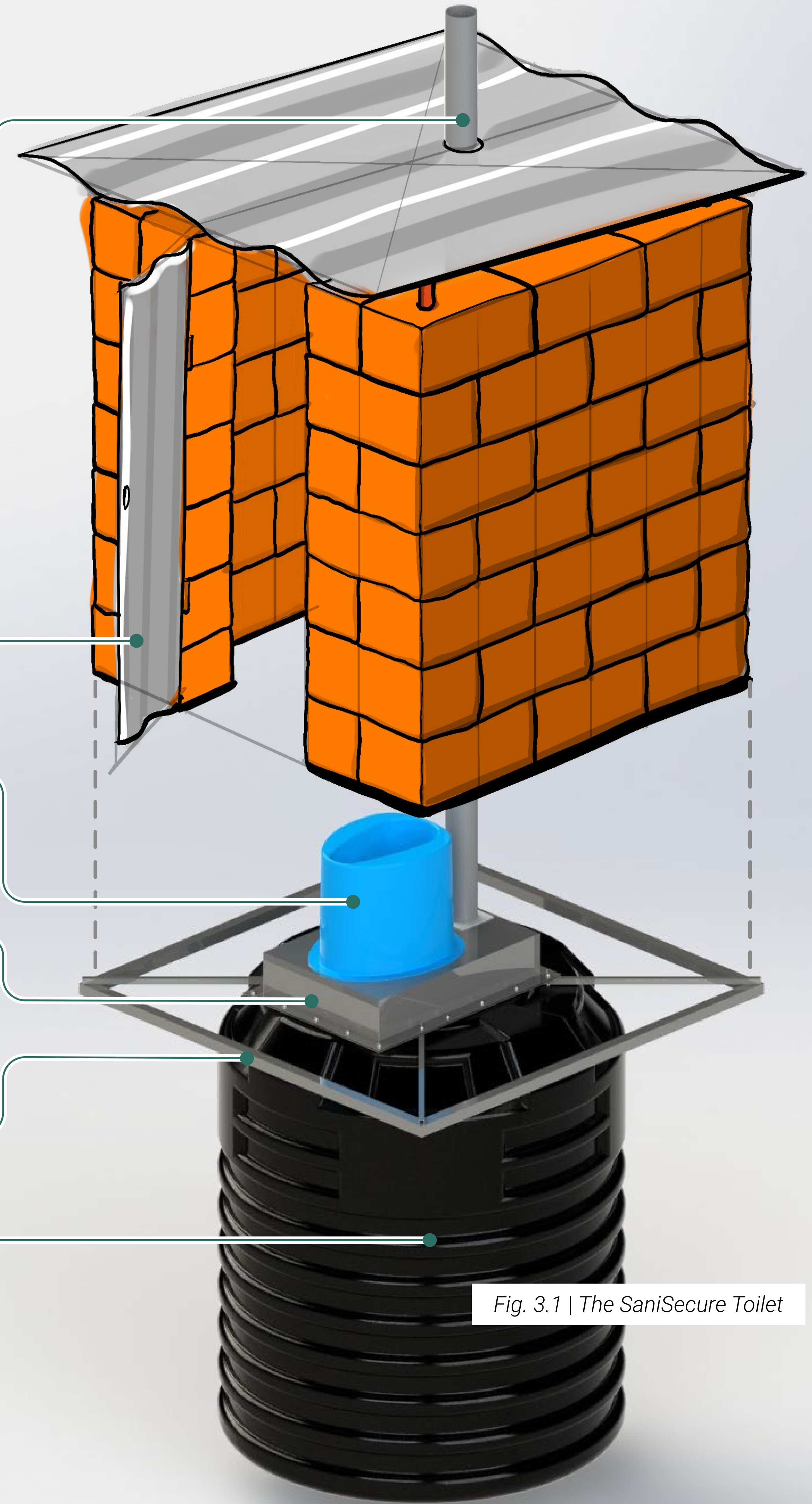


Fig. 3.1 | The SaniSecure Toilet

The SaniSecure Toilet was designed to adress the safety and hygiene needs of inhabitants, safely store fecal matter in a way that preserves its biogas producing qualities and ensure safe emptying conditions for workers. The relationship between the features of the toilet and the problems they solve are discussed here.

Problems Adressed by the SaniSecure Toilet

For the **inhabitants**, four problems are adressed by the SaniSecure Toilet:

1. **Fecal water contamination**: The toilet safely captures and stores fecal matter without it leaking into the soil, preventing the contamination of water sources with fecal matter.
2. **Hygiene**: The toilet is made of materials that are easy to clean, is well ventilated and the toilet closes the stall off from the sludge container when not in use. Locks on the doors prevent unsollicited use and increase privacy, improving WASH practices, perceived toilet value and cleaning responsibilit.
3. **Flooding**: The toilet is raised and has been made watertight to ensure the pit does not flood. Therefore not damaging the latrine or spreading fecal matter into living areas.
4. **Inclusivity**: The toilet features a sitting option for elderly and disabled users, absolving them of the need to squat allow them to use the toilet. The stall dimensions ensure usability for wheelchair users.

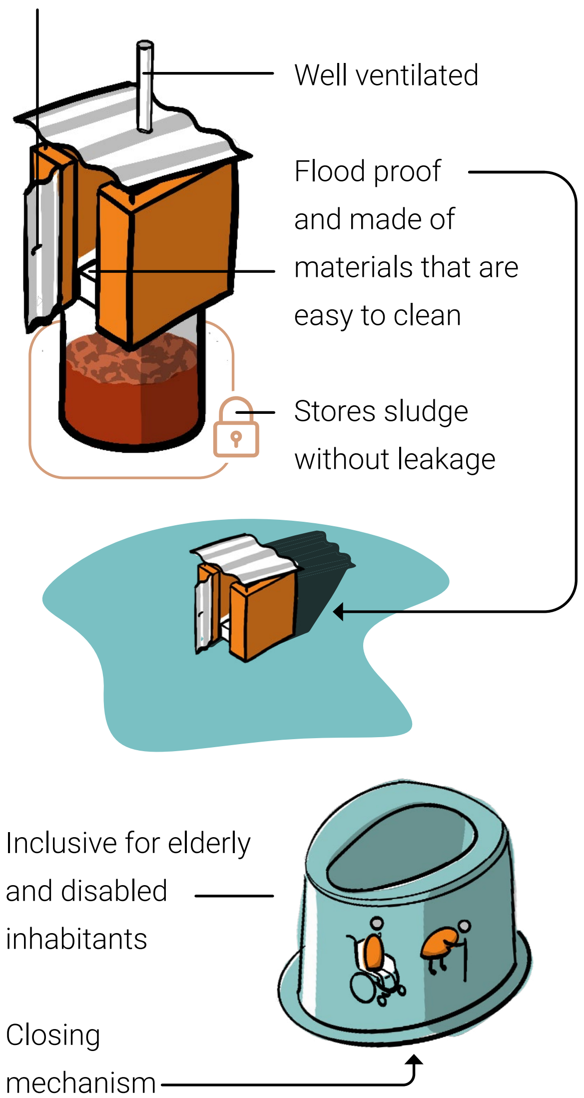


Fig. 3.2 | Toilet features for the inhabitants

For the **Biodigester Group**, three problems are adressed by the toilet:

1. **Sludge quality**: by storing sludge in liquid, anaerobe and cool condition for up to one month, the sludge conditions in the container are optimized for biogas production, an additional month of reserve storage accounts for logistical delays.
2. **Microbial life**: suitable cleaning agents are identified that preserve microbial life and are suitable for toilet cleaning.
3. **Sludge supply**: multiple toilets placed in a system can supply the biodigester with a constant supply of fresh fecal sludge. To ensure sludge output per toilet, a minimum of 10 users per toilet is required. The maximum amount of users was found to be ~30 (Chapter 2.x).

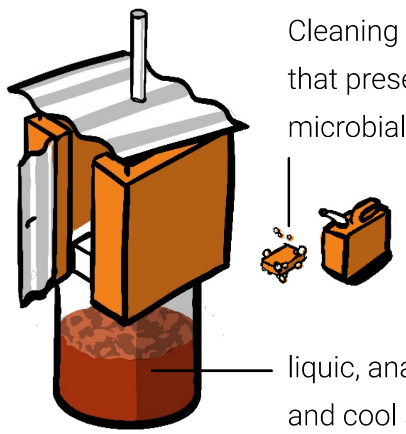


Fig. 3.3 | Toilet features for the Biodigester Group

For the **Transport Group**, two problems are adressed by the toilet:

1. **Hygiene**: the toilet ensures that fecal sludge is stored in a liquid state, and the design discourages the disposal of trash in the sludge container, which makes the sludge easy to pump, minimizing manual handling.
2. **Efficiency**: the design supports multiple modes of emptying to assist the system's flexibility in case of sludge pump failures. The toilet also stores liquid fecal sludge without garbage, facilitating efficient pumping without blockage of equipment.

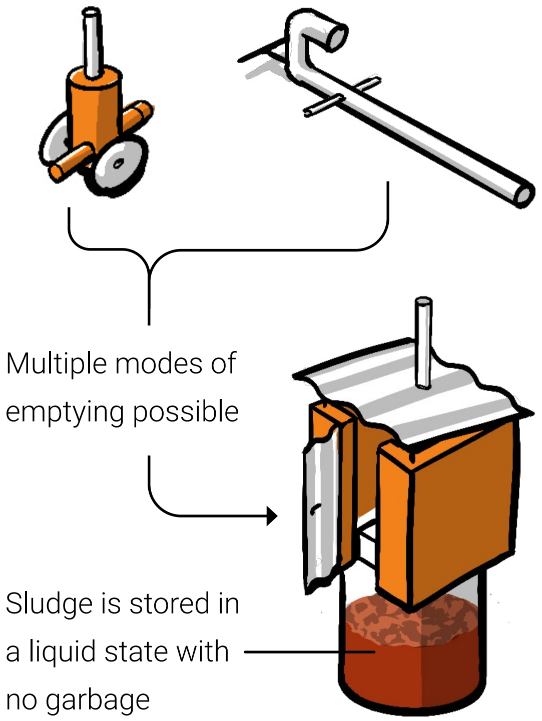


Fig. 3.4 | Toilet features for the Transport Group

The toilet design is of added value to the stakeholders through the issues it solves. The design features provide solutions on problems with different levels of complexity: environmental, hygiene, safety, inclusiveness and efficiency. To put the toilet in context, two main user interactions two main user interactions are depicted here: toilet use and toilet cleaning: **toilet use** and **toilet cleaning**. The interactions between the toilet and the workers emptying it are discussed in chapter 4.4.

Scenario: Toilet Use

Using the toilet is relatively similar to the current situation for inhabitants, but changes are also present. The steps taken by the user during a visit to the toilet are discribed here, with a focus on differences between the old and new situation.

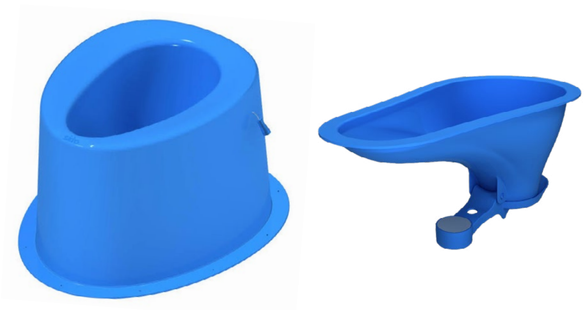


Fig.3.5 | Sato sitting (left) and squatting (right) toilet (SATO, 2024)

When an inhabitantneeds to use the toilet, they will find the necessary personal cleaning materials needed. Paper, leaves or water are used for personal cleaning, which can be thrown into the toilet after use, without risking clogging. This was determined in collaboration wit Practica (Practica, n.d.), a bureau which specializes in latrine sollutions for low resource settings.

Once ready, they open the toilet stall, which can be locked from outside to prevent unsollicited use. They then enter the toilet stall, which does not smell, due to proper ventilation and feces cannot be seen through the toilet hole, since the Sato toilet trap door (Fig. 3.5) is closed. These factors ensure there are no flies inside the toilet stall. Therefore, the toilet space is hygienic, improving the experience and increasing toilet ownership and cleaning responsibility.

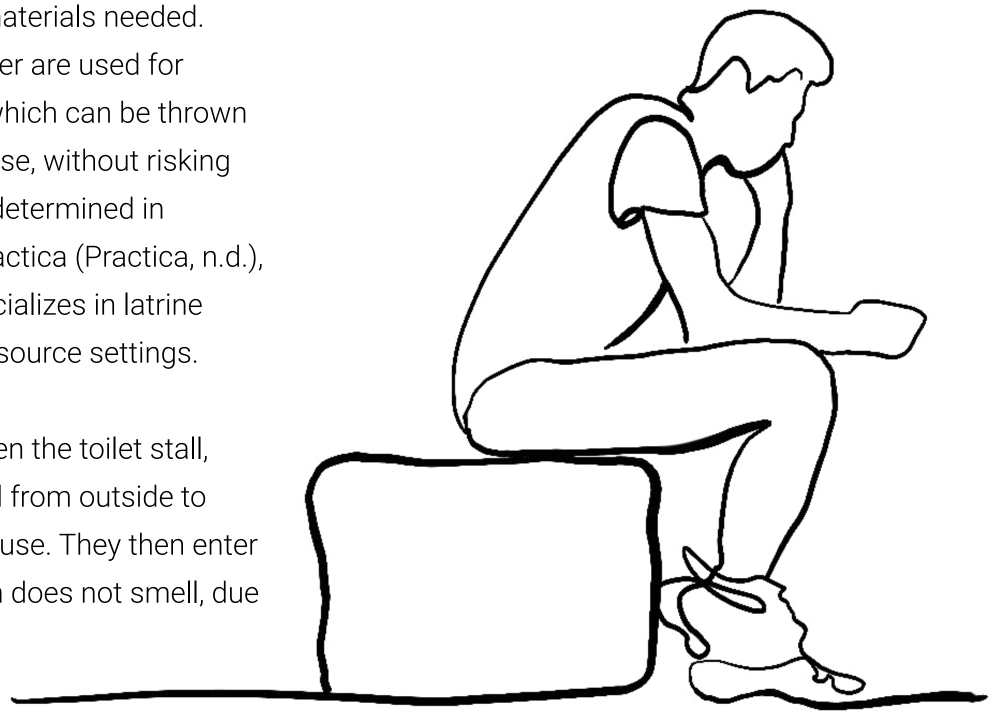


Fig. 3.6 | User on a SaniSecure Toilet (sitting configuration)

Inside the toilet stall, the user sits (Fig. 3.6) or squats and relieves themselves. The excrement falls through the Sato trap door . Once done, the personal cleaning products are thrown in the toilet and the user can choose to pour ash into the toilet bowl for smell mitigation. Finally, the user pours water into the bowl to flush the toilet (Fig. 3.8). After flushing, the trap door closes and both smell and view of fecal matter are blocked, addressing the cultural need for inhabitants to not see fecal matter from previous days, creating a more comfortable user experience. creating a comfortable user experience.

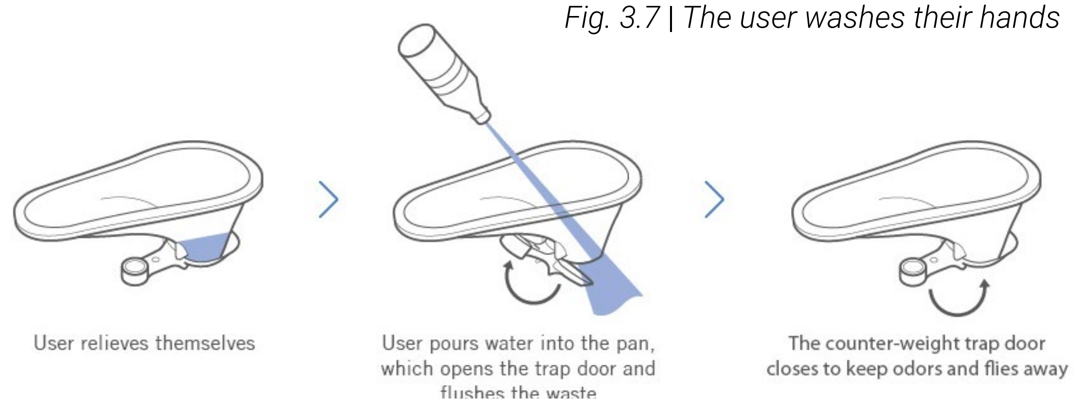


Fig. 3.8 | Flushing the Sato toilets (SaTo Pans — WaterSchool, n.d.)

After the user is done and clean, they exit the toilet stall and lock it if desired.

The hand washing station is located outside. This needs to be a hands free construction, such as the one described in Chapter 3.5. Hands free stations minimize the spreading of fecal particles through contamination of the station with dirty hands after toilet use. The user washes their hands with water and soap (Fig. 3.7) before engaging in other activities.

Fig. 3.7 | The user washes their hands

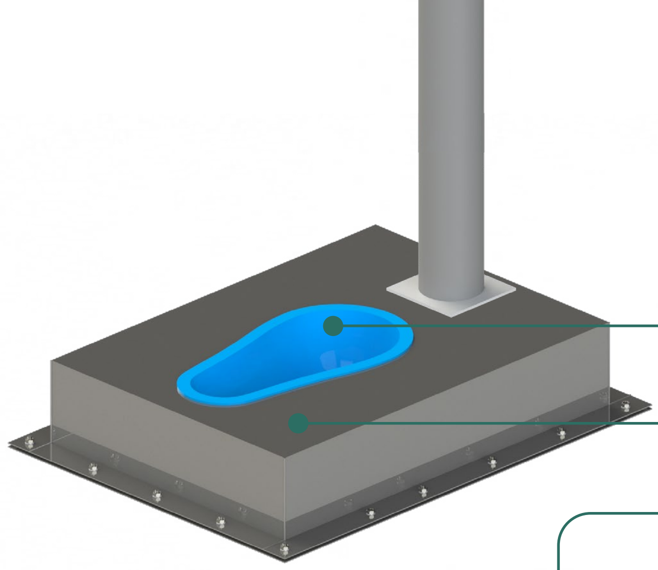
Scenario: Toilet Cleaning

Toilet cleaning with water and soap needs to happen daily. Since the toilet is meant to be used by 10 to 30 different people, many touchpoints with potential contamination occur. Periodic cleaning of the stall with a brush or broom (Chapter 2.5) can remain unchanged from the current situation. The increased hygiene and perceived value of the toilet are designed to increase inhabitant responsibility on toilet cleaning and maintenance. Additional strategies to verify latrine cleanliness and maintenance, educate users on WASH practices and adjust bad sanitary practices are discussed in chapter 4.3.

For the sludge to retain its biogas producing capabilities, three types of cleaning agents were identified to succesfully clean toilets, without killing beneficial microorganisms (Fig. 3.9)

Fig. 3.9 | Microorganism friendly toilet cleaners by Bio-Gen (left) (Affinity, 2025) *Satopradhan (middle)* (Satopradhan, n.d.) *and Bio-D (right)* (Bio-D Eco Friendly Toilet Cleaner, n.d.)

1. **Microbial-based toilet cleaners cleaners** use beneficial microorganisms to clean and maintain bacterial balance. For example, the Bio-Gen Eco Toilet Cleaner (Affinity, 2025) contains microbes that continue working after application, providing a food source for microbes
2. **Organic enzyme-based toilet cleaners** by e.g. Satopradhan (Satopradhan, n.d.) use natural enzymes derived from fermented citrus peels to ensure cleaning without harming beneficial microorganisms. These cleaners can improve septic tank performance by creating a healthy microbial environment
3. **Toilet cleaners using plant-based ingredients** that are effective at cleaning without killing all microorganisms. For instance, the Bio-D Eco Friendly Toilet Cleaner (Bio-D Eco Friendly Toilet Cleaner, n.d.) is made with plant-based ingredients that are tough on dirt and stains but gentle on the environment.



Areas of focus during cleaning are:

1. **The toilet bowl**, since it comes into direct contact with fecal matter.
2. **The box**, since it can contain fecal particles, resulting from splashing.
3. **The door handle and locks**, since people's hands touch them after toilet use, potentially contaminating them with fecal matter.

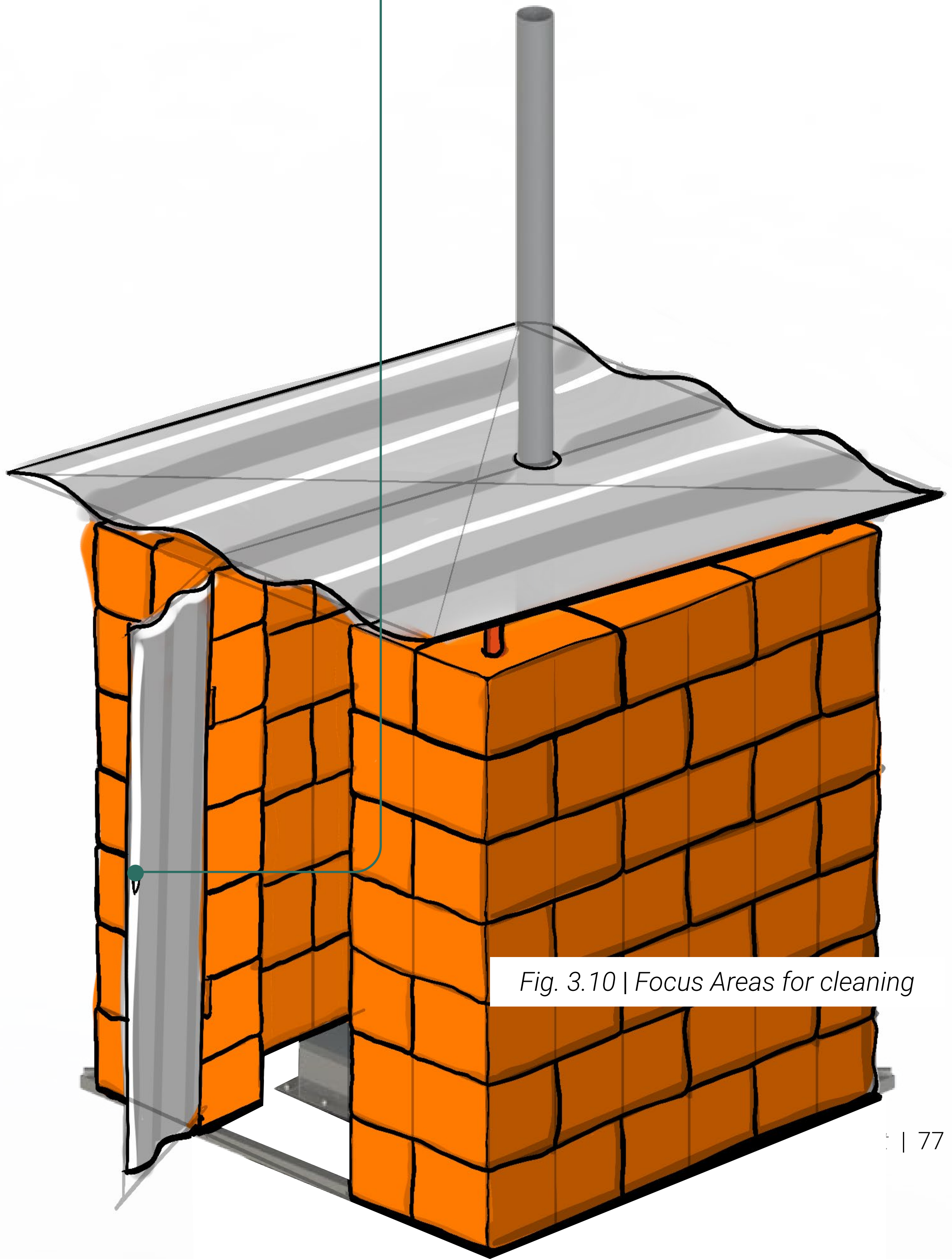


Fig. 3.10 | Focus Areas for cleaning

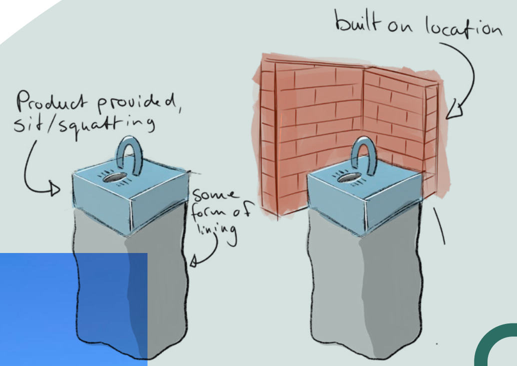
3.2 Embodiment

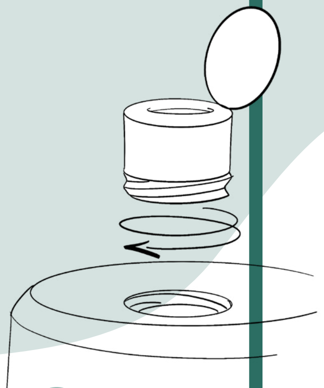
To embody, test and improve the features presented in chapter 3.1, prototyping was done in Kampala over the course of four weeks. Kampala is Uganda's capital and its large production industry made it a suitable site for the embodiment phase.

The chosen method was rapid protoyping (ProductPlan, 2024). Rapid prototyping requires a quick iterations of prototypes, which can be tested, evaluated and improved upon for next iterations. The prototyping journey is summarized here. For full details on the prototypes and insights, see appendix F.

The first week was spent building a prototype with basic functionalities, which was sent to the Imvepi settlement to be installed. Feedback from this installation influenced the design of the second prototype, which was built in the following three weeks. In the Netherlands, a final prototype was built in one week using feedback from the first two.

The choice for rapid prototyping was substantiated by the high amount of unknowns in the foreign context, allowing for adjustments when new information came to light.

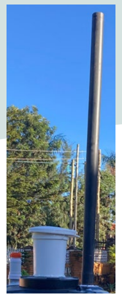




1.

The first prototype featured a fixed sitting toilet mounted on the container lid, along with a ventilation pipe and an emptying connection that extended to the bottom of the container.

While the main features were there, the toilet wobbled on the container, the sludge extraction solution would implode if a pump was attatched and it, and upon installation, the weight of the stall caused the container to buckle

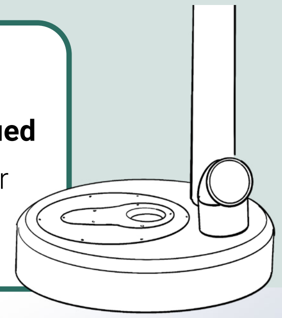


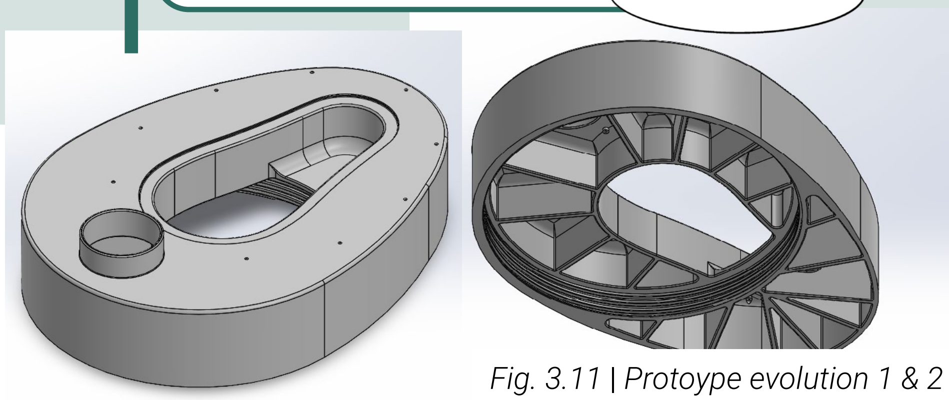
Key insights:
Without support, the container will buckle and **compromise the structural integrity.** Sitting toilets are related to **UTI's** &

2.

The second prototype was initially designed to be 3D printed., as this is a common practice in the Netherlands. However, consultations with G-Nex Engineers revealed that metal work with welding is the standard practice in Uganda, offering a cheaper, stronger, and more durable solution.

Key insights:
The product needs to be **simplified for metal work** and needs tighter fits to become **watertight**





This second prototype was therefore made of metal, but the organic shape meant the product became complicated to produce. The screwing function also became too complicated. Instead, a pressfit using rubber rings was made using car tire strips, however, the prototype was not waterproof.

Fig. 3.11 | Protoype evolution 1 & 2

3.

The third prototype incorporates the insights from both previous prototypes into a more square design. The hole for ventilation is also used for emptying, further simplifying the design. The bottom plate can be tightly fastened to the box with bolts and nuts.

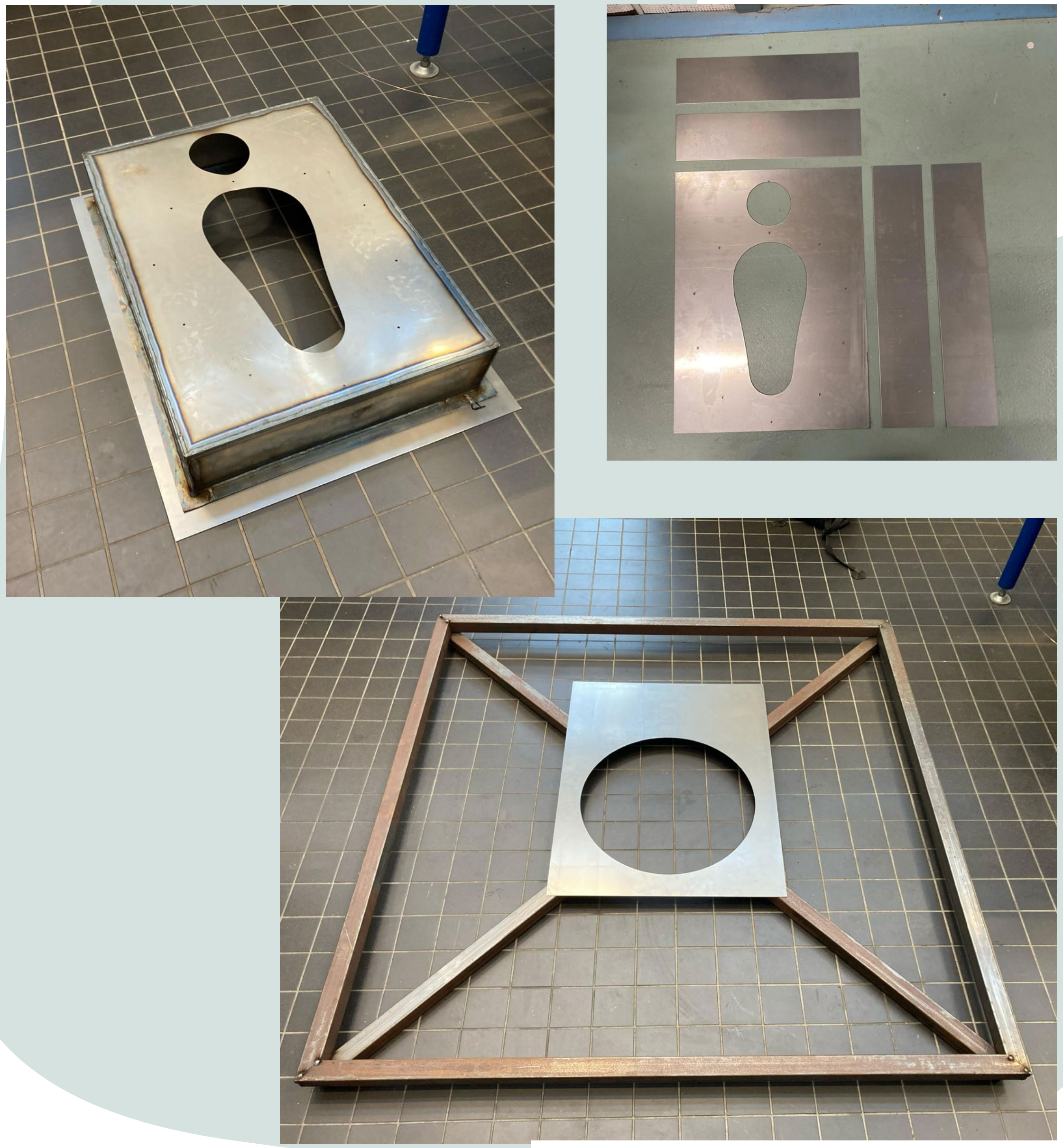
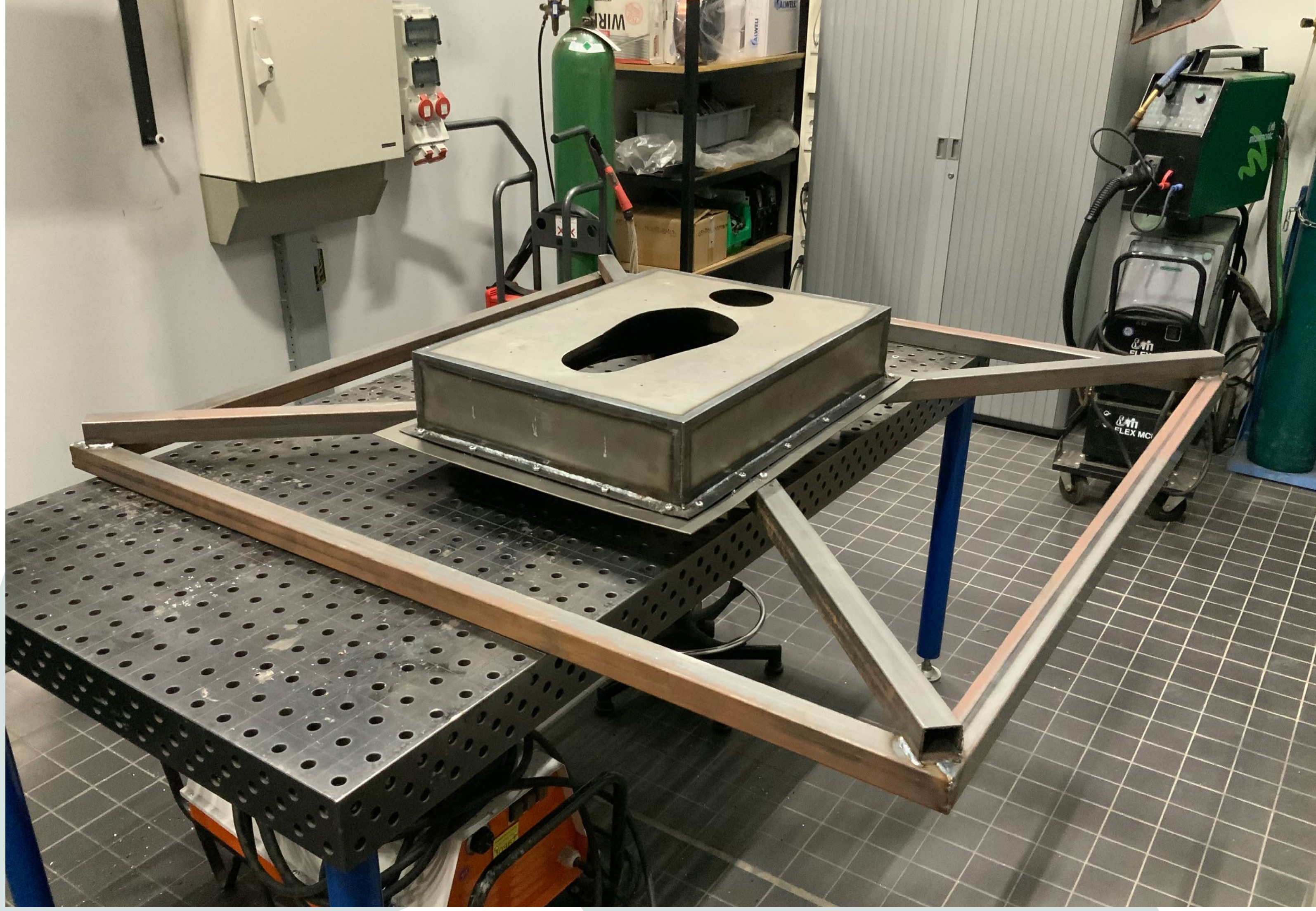


Fig. 3.12 | Development of prototype 3



The improvements to the box ensured its watertightness when tested in a controlled environment. The structural frame supports the weight of a person (90 kg), when standing on the box, without flexing more than 20 mm. Overall, this final prototype **meets the requirements** for the toilet design and is therefore considered a **success**. In the following phase of the project, 40 SaniSecure Toilets will be built and installed in the Imvepi Settlement for the installation of a pilot test, presented in chapter 5.

Key insights:
The product can be ever further **simplified for metal work** and needs **smaller profiles** for the inner frame to fit between the box and the container.

3.3 Product Components

The Container

The container used in the product is a Gentex 2000 L water tank (Fig. 3.13). These containers are commonly seen in Uganda on top of watertowers. They are relatively cheap at 320,000 UGX (~€80,00), aiding product viability.

The standing edge of the container is used to put a rubber ring around, made from car tire strips. On top of this, the box can be placed. The weight of the box pushes down on this ring to form a watertight seal between the two parts. However, this feature still needs to be tested in the field (Chapter 5.1).

The container is stored under the ground to keep it cool, which is advantageous for the biogas producing quality of fecal sludge (Chapter 2.6). Underground, the container is not exposed to direct sunlight, which would heat the tank, and the relatively cool ground temperature transmists to the tank via conduction.

Storing the container underground also eliminates the need for stairs or ramps, which is advantageous for elderly users and people with disabilities, especially wheelchair users.

Several types of containers were considered, the list below lists the insights that lead to the decision on which type of container to use:

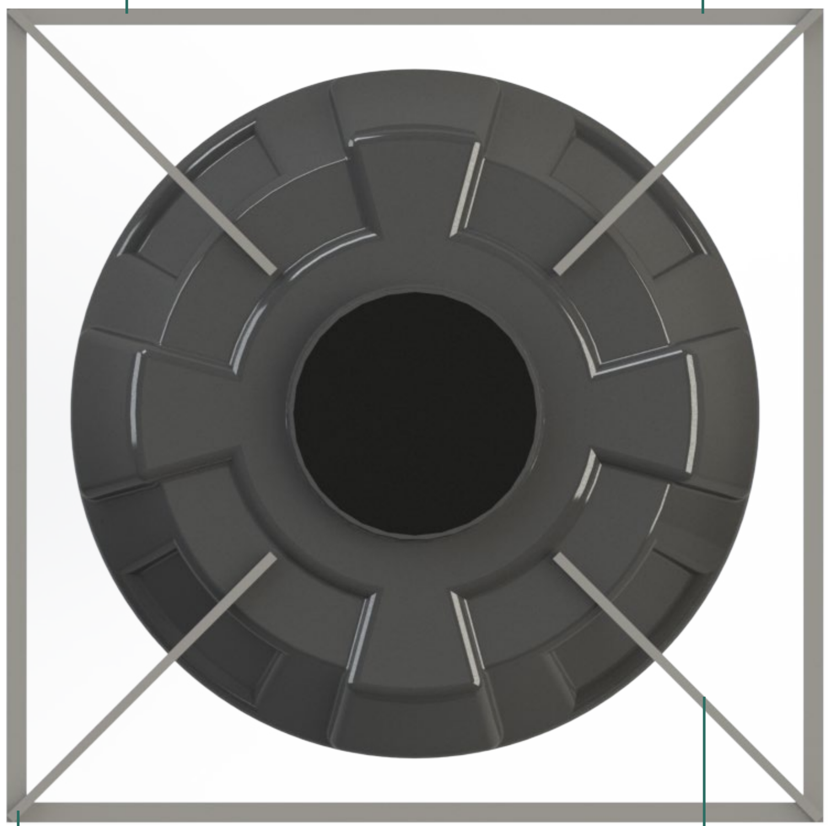
1. Concrete: Eliminated due to high costs.
2. Steel sheets: Unsuitable due to potential corrosion and leakage from groundwater exposure.
3. Septic tanks: Inefficient for biogas production, as they separate solids and liquids in different compartments, this feature also complicates emptying of the tank, since there are two compartments to access and one has solidified sludge, which would require rehydration (Chapter 2.7)
4. PVC water tanks (Gentex): Selected due to affordability, availability, and functional suitability. These tanks are widely used across Uganda.

A potential drawback is that the tank has not proven functional in underground conditions.

Fig. 3.13 | *Gentex 2000 L container*

The stainless steel frame protects against corrosion

40 mm square profile to support the toilet stall weight



The frame's structure is designed to support the weight of the product, toilet stall, and users

20 mm square profile to fit in the tight space between the container and the box

Fig. 3.14 | The *SaniSecure Toilet frame*

The Frame

The frame (Fig. 3.14) provides structural support for the toilet stall and redirects the user's weight away from the container, preventing it from buckling.

One of the requirements for the toilet is structural integrity (Chapter 2.9). The frame was designed to ensures an equal load from the toilet stall and user to the ground without putting weight on the container, wich would cause buckling (Chapter 3.2), and instead redirects the weight of the user away from the container to the ground surrounding it.

This redistribution of weight is accomplished by the frame's design through the play of forces shown in Fig. 3.15. In this force diagram, the red arrows indicate the weight of the user on the box. The orange arrows show the subsequent pulling force on the inner beams of the frame through the triangle structure. The yellow arrows show how this force is transferred to a pushing force on the outside of the frame. This stiff structure does not deform significantly, as is proven through testing (Chapter 3.2), so the downward force caused by the weight of the user is applied to the ground below the outside of the frame instead of the container.

The outside of the frame will be dug into the ground untill level and encased in cement to ensure its position. The toilet stall walls are built on top.

If the frame breaks, this means the entire toilet stall structure needs to be taken down in order to maintain it. Although arduous, this feature was purposefully designed to prevent unsafe situations in which the frame or container are removed with the toilet stall structure still standing, since this would risk collapse.

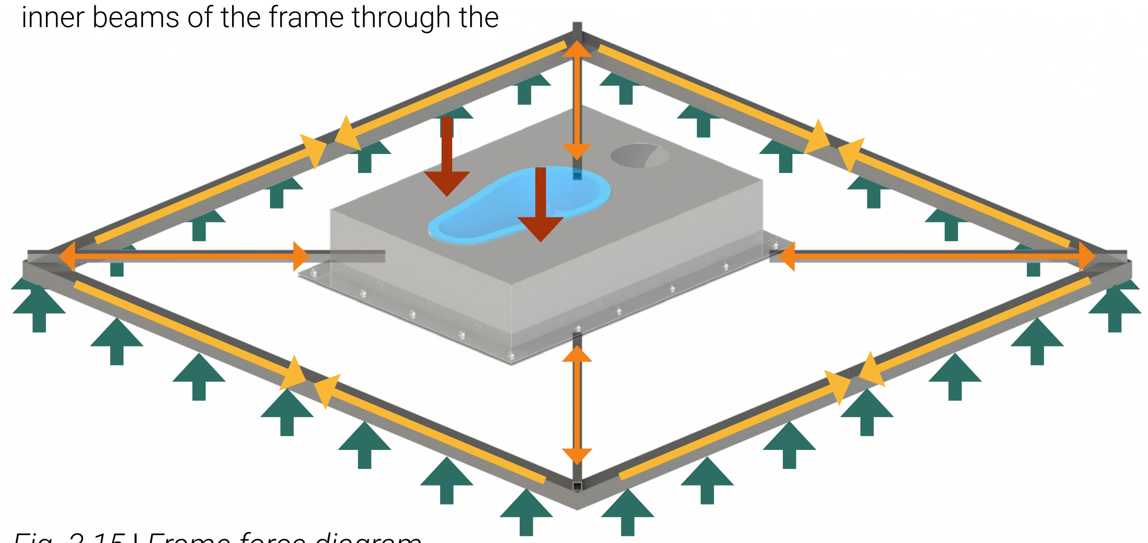


Fig. 3.15 | *Frame force diagram*

The Box

The stainless steel box (Fig. 3.17) was designed to ensure the tiolet would be flood proof. To accomplish this, it forms a watertight connection with the container and is elevated 15 cm's off the ground This prevents flooding due to heavy rainfall from entering the container, posing structural integrity and hygienie risks (Chapter 2.5). It is important to note that the box is not proof to submersion, since water would then enter the container through the toilet bowl. Therefore, placement of the toilet on an elevated patch of land is crucial for the toilet's flood proof functionallity.

The first prototype of the toilet featured separate connections for ventilation and emptying, with the latter incorporating a pipe extending to the container's bottom (Fig. 3.16). However, feedback from PRACTICA, a bureau specializing in latrine solutions, highlighted clogging risks associated with this design. Such a configuration could lead to repairs requiring individuals to enter the container, posing significant health hazards through direct fecal matter contact. To mitigate these issues, the internal pipe was removed and replaced with a single hole capable of accommodating various emptying tools, improving emptying flexibility. This modification reduced clogging risks. Additionally, this change simplified the design by merging ventilation and emptying functions of the toilet into a single connection hole on the box.

Fig. 3.16 | Prototype 1's internal pipe for sludge emptying

The larger hole in the box is suited for fitting with a squatting bowl. A sitting toilet can be installed on the surface of the box if preferred, to improve inclusivity for the elderly and disabled (Chapter 2.4). It facilitates repairs through easy disassembly using bolts and nuts.

Testing confirmed that the box's design is watertight on itself (the rubber between the bottom and top plate). However, the entire toilet in context has not been tested for watertightness in the Imvepi context. Chapter 5.1 discusses the initial pilot testing and further implementation.

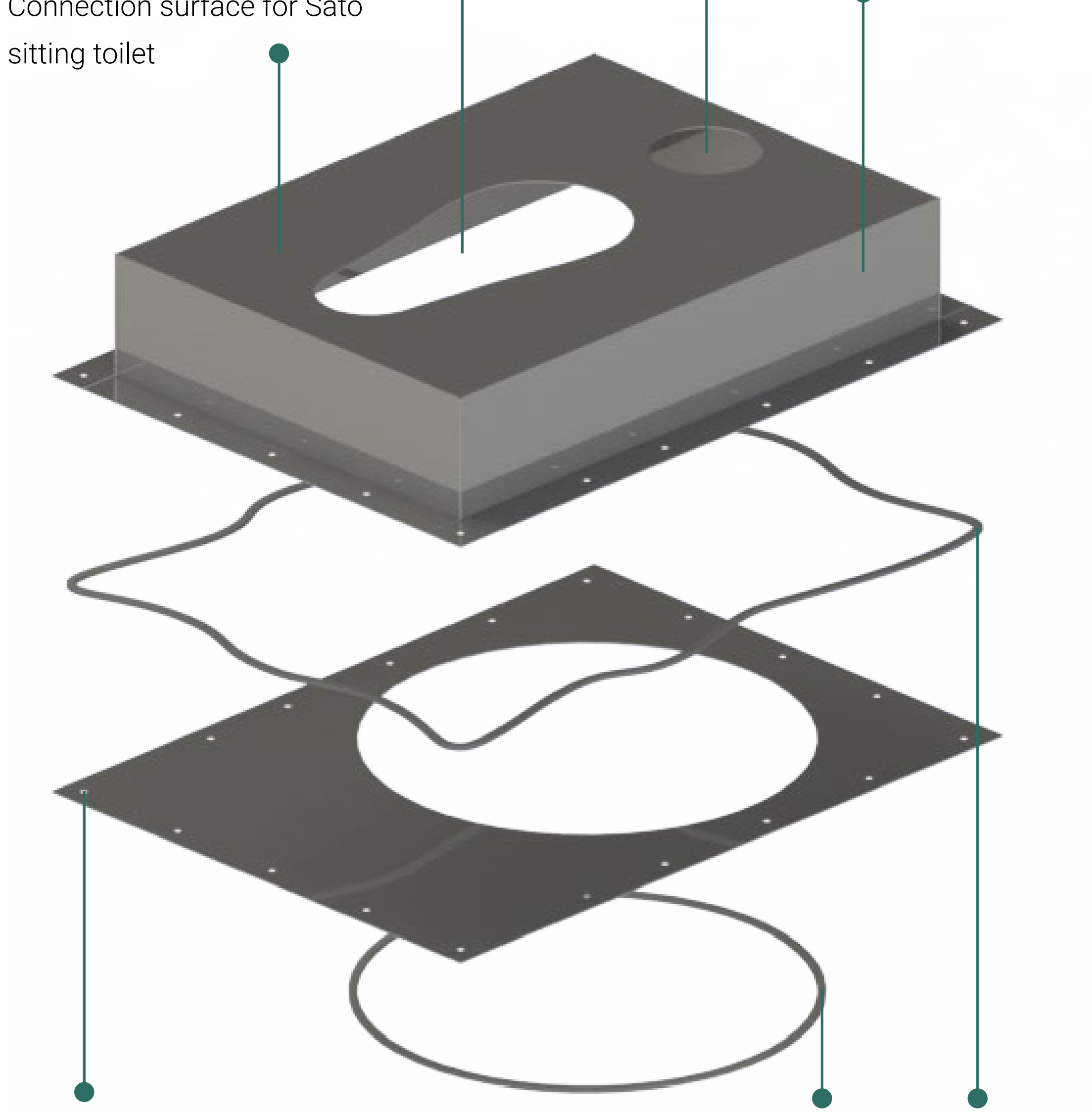
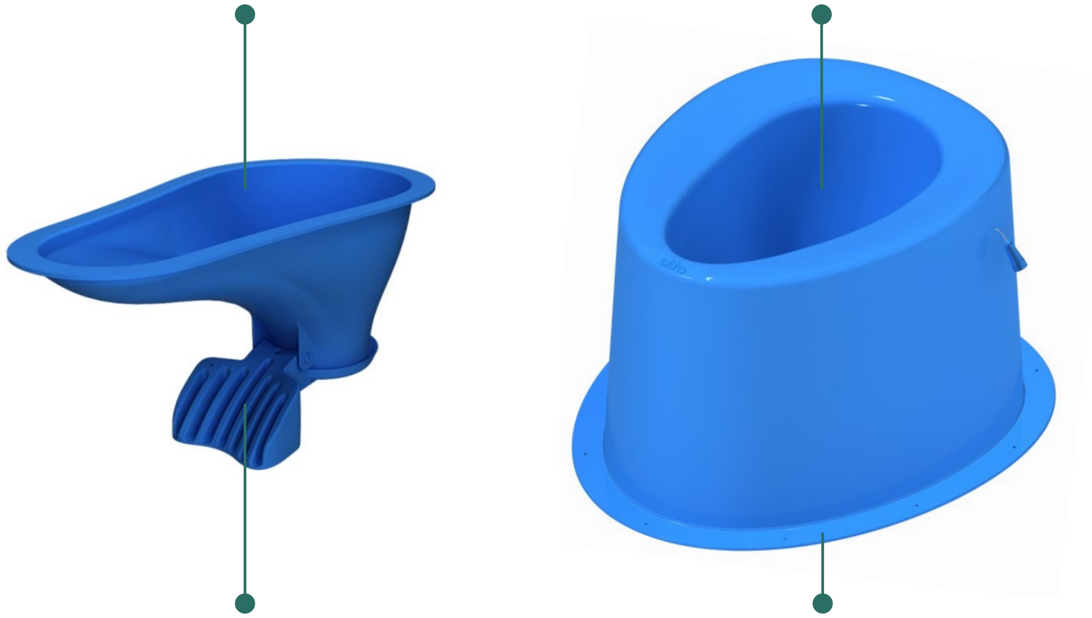


Fig. 3.17 | The SaniSecure Toilet box

The squatting pan from Sato closely resembles the existing toilets in the settlement, providing a familiar option for those who prefer this design

The Sato sitting toilet is preferred by elderly and disabled individuals whose sanitation needs are currently unmet, as discussed in Chapter 2.2



The closing mechanism creates a physical barrier between the fecal matter and the toilet stall, reducing odor

The toilet includes a brim with pre-cut holes, allowing for easy connection to the box using bolts and nuts

Fig. 3.18 | *The Sato squatting (left) and sitting (right) toilet bowls* (SATO, 2024)

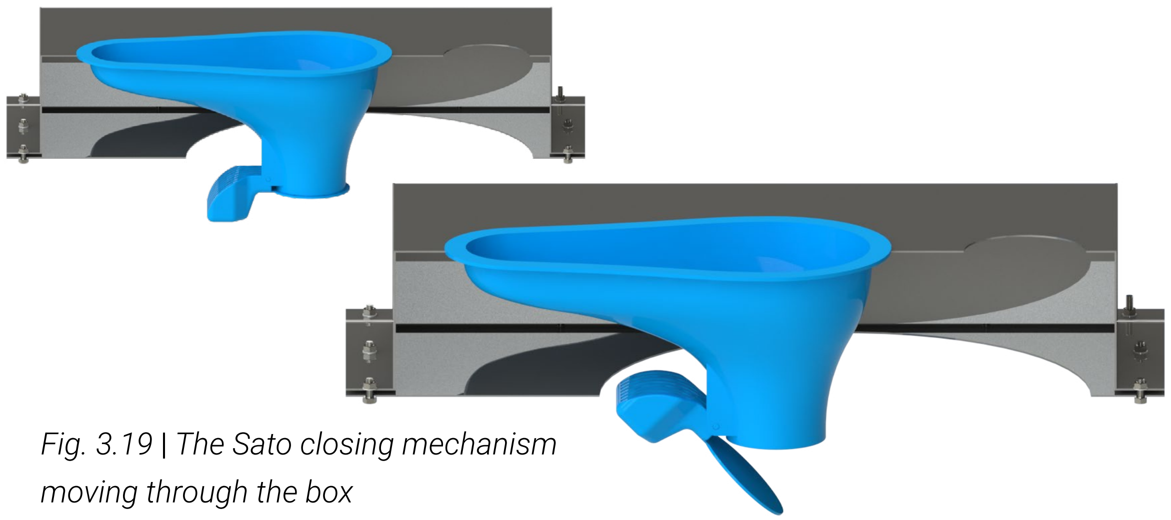


Fig. 3.19 | *The Sato closing mechanism moving through the box*

The Toilet Bowls

The toilet bowls used for the product are made by Sato . The toilets are made from blue High Density Polyethylene (HDPE) and are produced and widely distributed in Uganda.

The Sato products are developed for low resource settings. Therefore, they are affordable and suited to latrine style toilets, in which the fecal matter is collected below the toilet bowl. The two configurations seen in Fig. 3.18 are a squatting bowl (left) and a sitting bowl (right).

The choice to make the toilet compatible for both bowls originates from evaluation of the first prototype with the designers at Design Without Borders (Design Without Borders Africa, n.d.). The prototype included a seated toilet with a bucket and a standard toilet seat (Fig. 3.20). However, cultural concerns came to light, particularly in rural villages with shared latrines, where seated toilets were associated with urinary tract infections (UTIs). Design Without Borders also introduced the Sato products to the project as a solution. As a result, Sato squatting and sitting toilet bowls were selected for their affordability, proven field performance (SATO, 2024), and integrated smell-reduction mechanism.

Fig. 3.20 | The f*irst prototype toilet bowl*

Fig. 3.19 shows the way this mechanism is able to move freely through the box in the squatting configuration. For the sitting toilet, the mechanism moves freely over the holes in the box.

To clean the bowl, desinfectants are used. However, in order to not harm microbial life, three types of cleaning agents were identified to succesfully clean toilets, without killing microorganisms beneficial to biogas production in Chapter 3.1

Toilet Stall

The toilet stall (Fig. 3.21) is made in a manner traditional to the area. It features upgrades to improve the toilets safety, hygiene, ownership and responsibility.

Initially, it was assumed that the entire latrine stall would need to be redesigned to replace the current stalls, However, research with inhabitants (Chapter 2.3) revealed that the issues with latrine stalls were mostly due to flooding, and a lack of time or funds to build a proper stall.

The research also identified that some stalls were structurally sound and clean, showing that it can be accomplished. As a result, it was decided that traditional building methods could be used to create standardized toilet stalls that meet all the required standards. This approach also supports the local economy by utilizing local builders and materials.

The roof and door are made from corrugated steel sheet, which is seen as a high quality material by inhabitants (Chapter 2.5). These materials are durable, ensuring the toilets longevity. The door improves safety by keeping out snakes (Chapter 2.5) and locks on the inside ensure privacy while using the toilet. Locks on the outside prevent unsollicited use of the toilet (Chapter 2.5), improving the feeling of toilet ownership by inhabitants and aims to improve their sense of responsibility to maintain and clean the toilet via proper WASH principles.

The toilet stall base is laid out by the frame. It ensures a wide toilet set-up, which is beneficial for wheelchair users to maneuver or have a caretaker be present inside the stall. The door is made 1,00 metre wide to ensure wheelchairs can move inside the stall. This improve the toilet's inclusivity.

'Burnt' bricks are used for the construction of the walls due to their improved longevity over unburnt bricks (Chapter 2.5).

The Ventilation Pipe

The ventilation pipe is a common feature for improving latrines (Reed et al., 2014) to prevent smells and flies from entering the toilet. The ventilation pipe can be taken off to allow for the 75 mm hose of the emptying pump (Chapter 4.2) to enter the container (Fig. 3.22). In case the emptying pump fails, the ventilation pipe holder can be taken off as well to allow for a 100 mm gulper to empty the container. However, this action has been purposefully designed to be more arduous, due to the gulper's unfavourable hygiene conditions (Chapter 2.7).

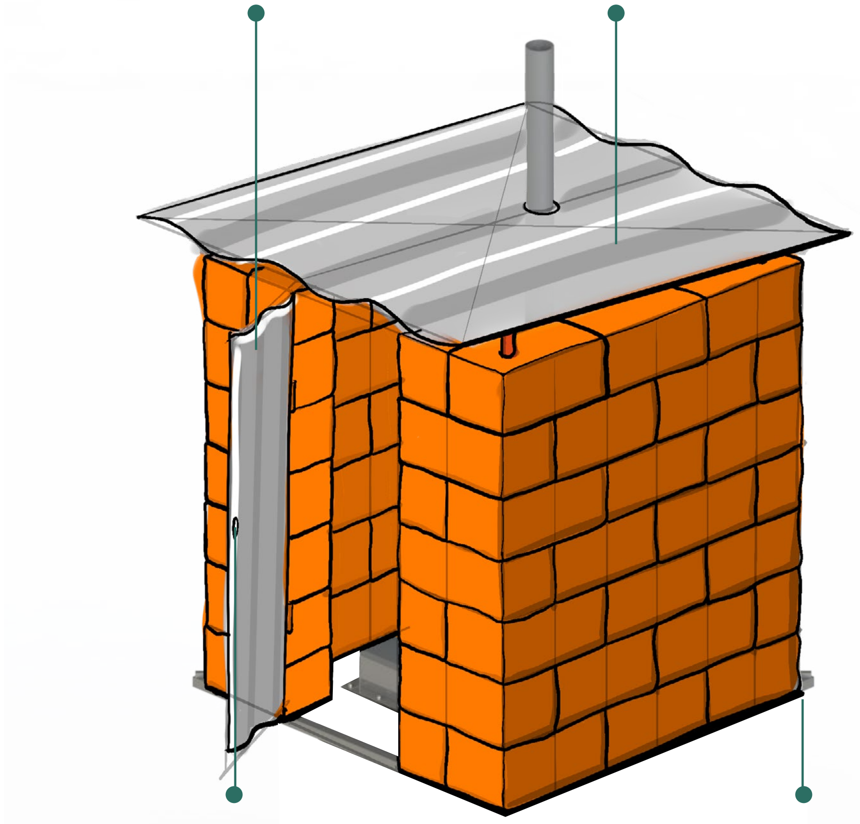


Fig. 3.21 | The toilet stall

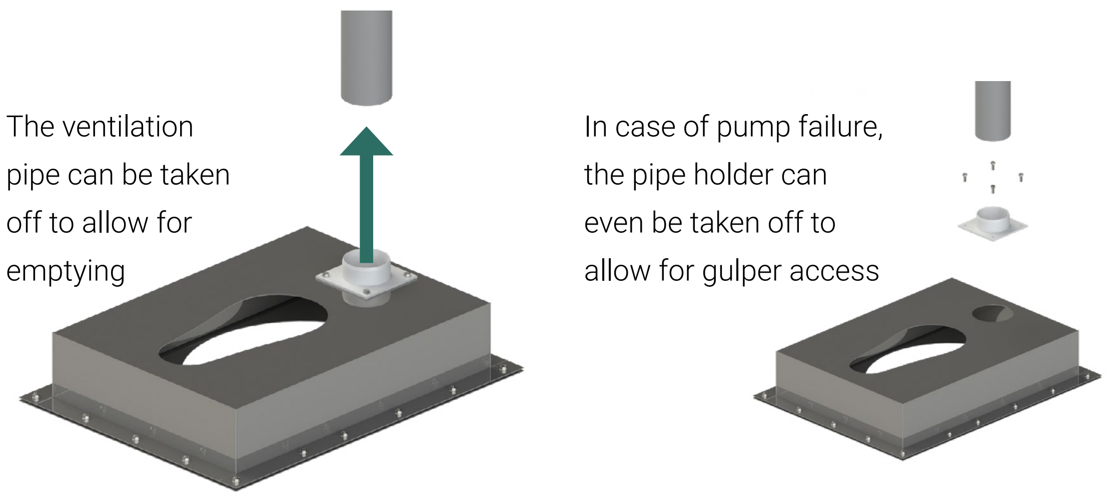


Fig. 3.22 | The emptying procedure

3.4 Manufacturing

Manual

A manual was developed to guide the manufacturing process of the SaniSecure products and ensure consistent quality.

This manual is intended for local manufacturers and includes visuals for each step (Fig. 3.23 & 3.24). During research, it was noted that "Ugandan English" differs from the English commonly used in the Netherlands. To address this, the manual was reviewed and adapted by G-Nex Engineering, the Ugandan agency who assisted in building the second prototype in Kampala.

Through iterative refinements, the manual has been optimized for simplicity and comprehensibility. Special emphasis has been put on the quality of welds for the frame, since breaking of welds on this part are arduous to repair (Chapter 3.3) On the following pages, the manual is presented. The complete manual can be found in Appendix G.

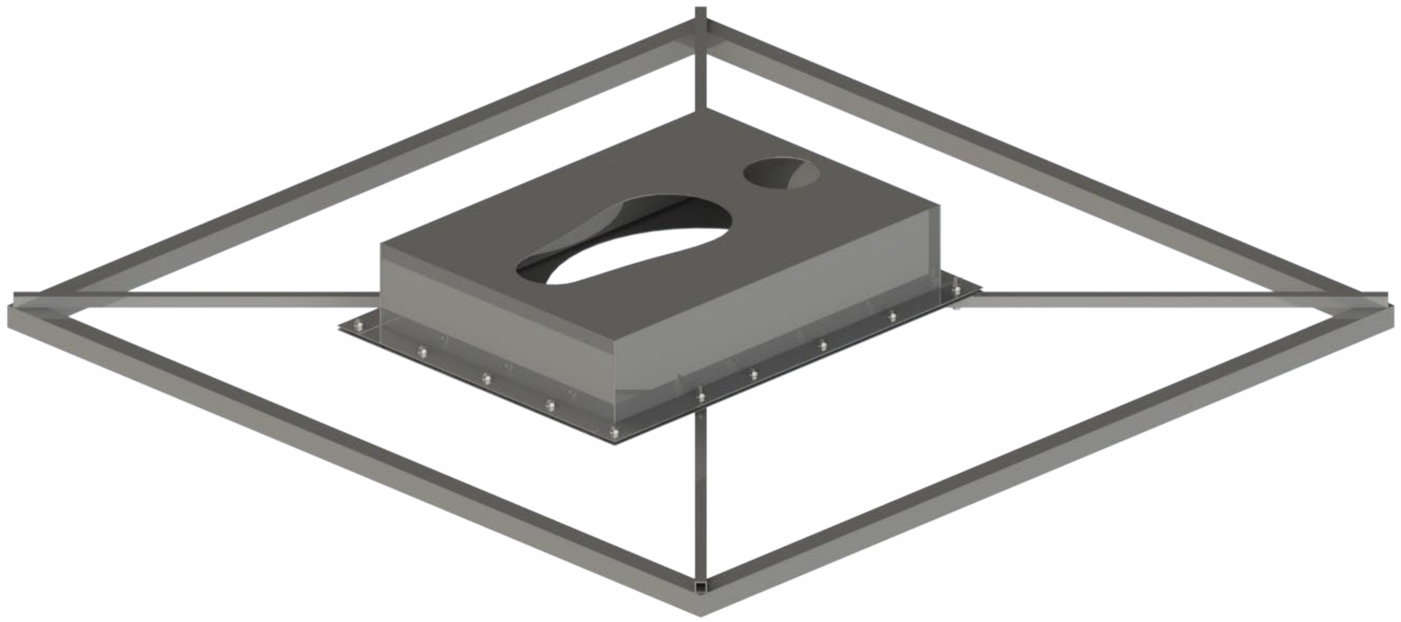
On the first page of the manual, the required supplies are found. Note that the metal sheets on this page are laser cut in Kampala to ensure the product proportions and quality (Chapter 2.9).

Budget

The budget for the manufacturing of the SaniSecure Toilet was determined in collaboration with the client. The maximum cost per toilet unit is capped at €300. However, for the pilot phase, a higher budget of €600 per unit was allocated to account for the additional expenses associated with small-scale testing. The manufacturing cost of the SaniSecure Toilet is currently estimated at €356 (Appendix J), which falls well within the limits for the first test set-up.

The business model for the recovery of costs and the SaniSecure's financial sustainability are left out of the scope for this project (Chapter 1.6). This is due to the unknown influence of the product on biogas yields. In Chapter 4.5, a suggestion is done on the recovery of part of the system's operational costs through emtpying public latrines.

Through testing, the toilet's financial susstainability needs to be assessed. This is critical to prevent the system from becoming a "ghost system"—one that fails due to insufficient financial planning for logistics, repairs, maintenance, and depreciation.



Building Manual
SaniSecure Toilet

Fig. 3.23 | Manufacturing manual front page

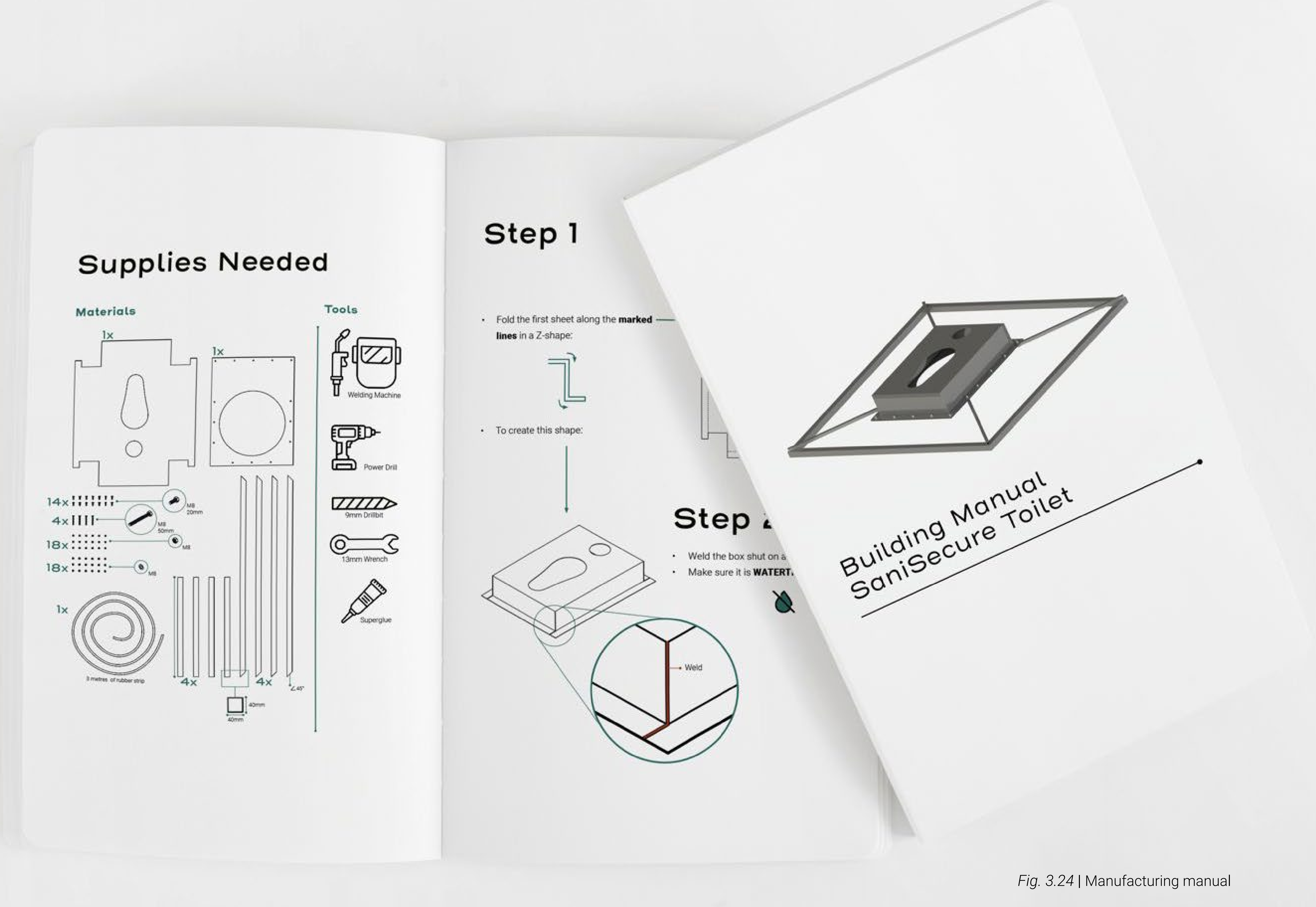


Fig. 3.24 | Manufacturing manual

3.5 Installation

Manual

Similar to the manufacturing manual, a toilet installation manual has been created to guide the installers with fitting the SaniSecure System on-site (Fig. 3.25). For the full Installation Manual, see Appendix H.

Prior to installation, inhabitants receive a preparatory briefing, including instructions and user manuals detailing maintenance, usage limitations, and cleaning protocols. This manual is will be developed by SkillEd (SkillEd, n.d.), the educational partner of the project. By emphasizing safety, cleanliness, and the longevity of the toilet, the values found to be most important among inhabitants, the system enhances the perceived value of the facilities, encouraging community adoption.

The toilets are installed and maintained by the Service Group, introduced in Chapter 4.2, a team trained in both the installation and management of the toilet.

Before the toilet can be installed, a couple steps need to be completed at the inhabitant's installations site:

1. The inhabitant has found an elevated spot of land to build the SaniSecure Toilet.
2. The Service Group has visited the site and deemed it appropriate to build.
3. The Service Group has explained the procedure to the inhabitants and they have agreed on its execution.
4. The inhabitant needs to dig a hole of 1,4 m in diameter and 1,7 m deep in the allocated spot, this step is developed to lower installation costs and is substantiated by the willingness of inhabitants to help (Chapter 2.5).
5. The inhabitant has cleared the surrounding area, to ensure the Service Group can manouver and to increase safety of snakes (Chapter 2.5).
6. The Service Group has visited the site to see if it is ready for installation and given the go-ahead.

The installation manual is less detailed than the manufacturing manual, since the training of the Service Group is still under developedment in collaboration with SkillEd.

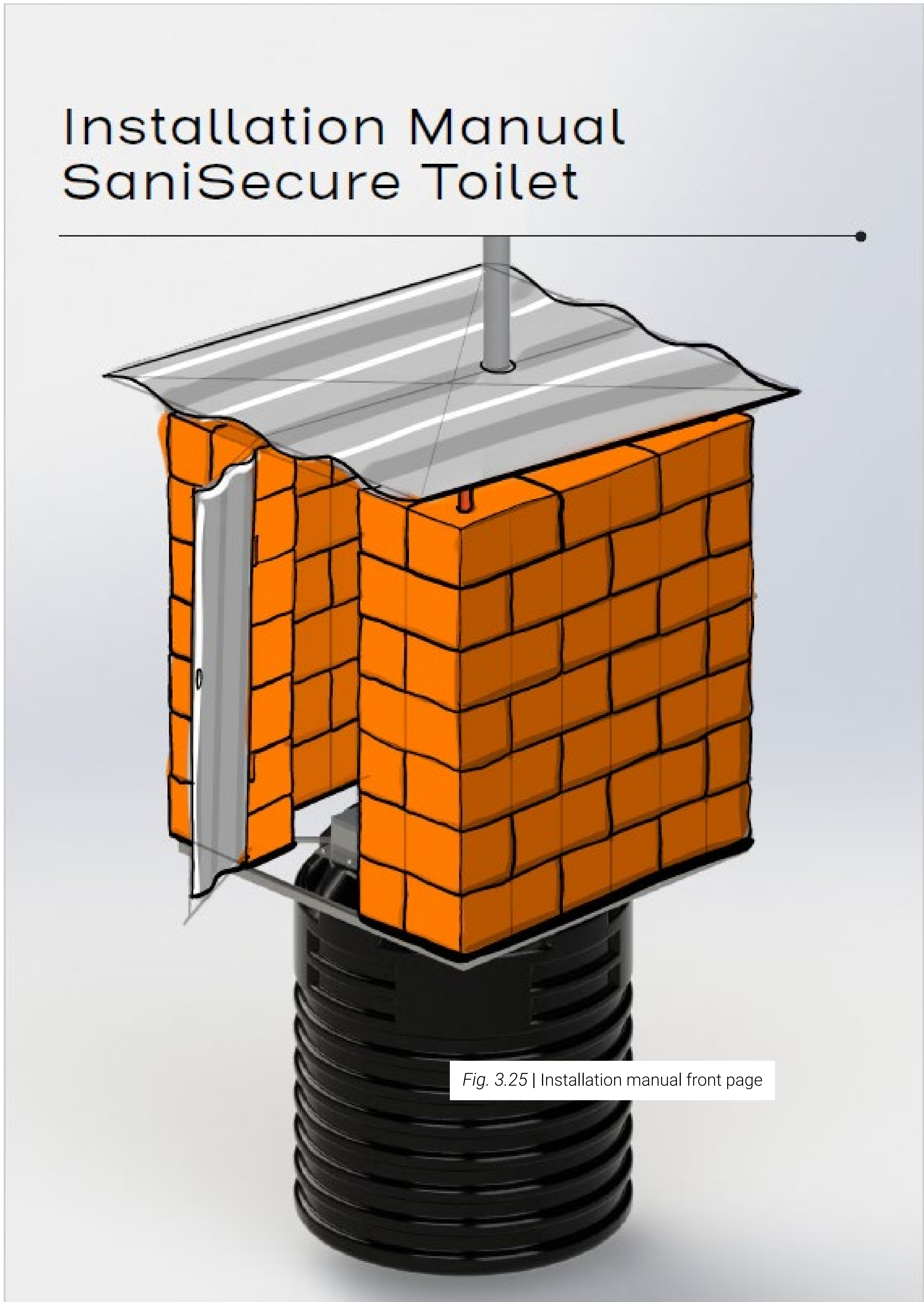


Fig. 3.25 | Installation manual front page

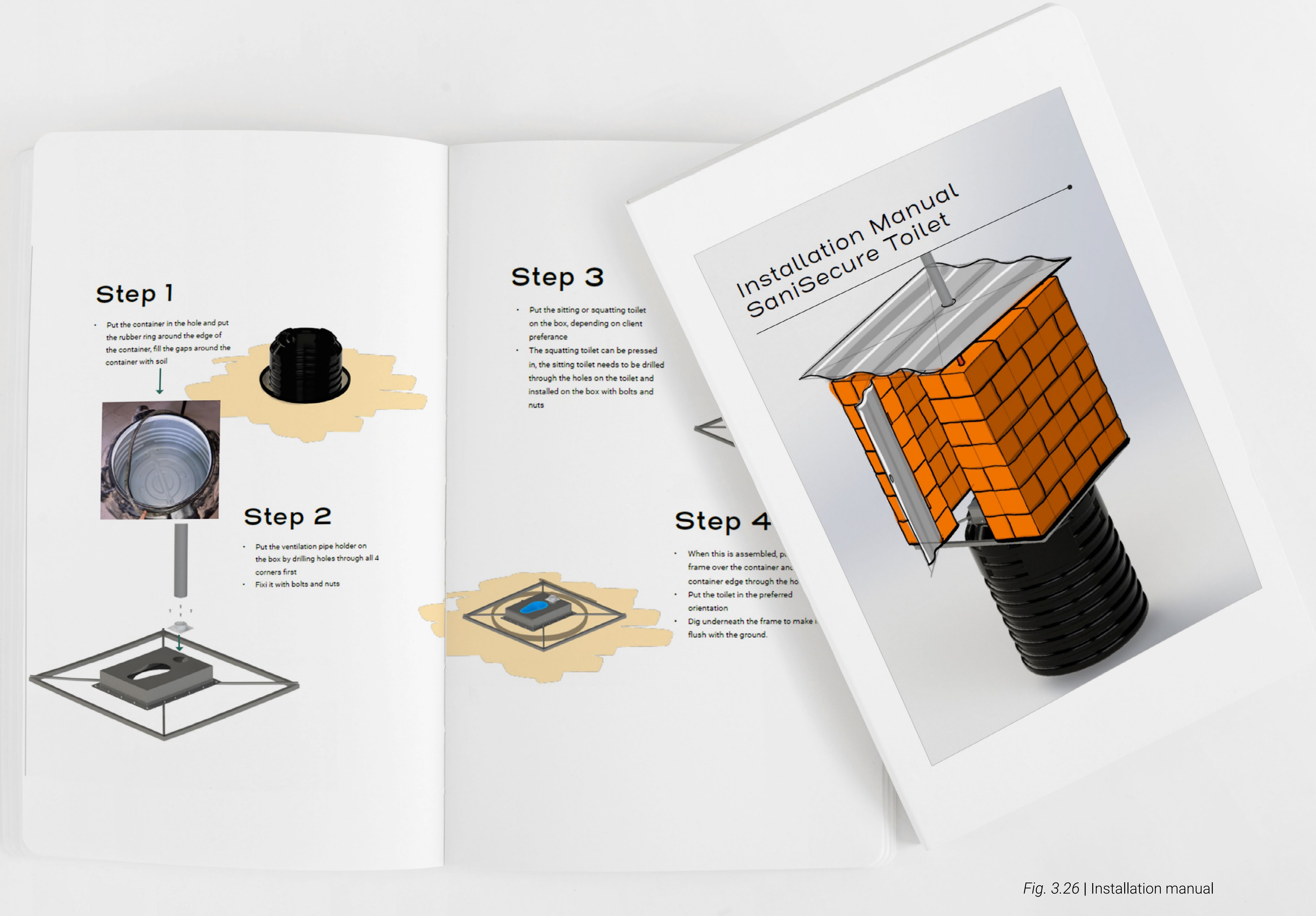


Fig. 3.26 | Installation manual

3.6 Repairability & End of Life

Repairability

The product is designed to be modular (fig. 3.27), so most components can be (dis-)assembled with bolts and nuts.

The Sato products, ventilation pipe, box, and bottom plate can all be removed, repaired, or replaced in this way.

The frame is encased in cement, forming the foundation for the housing. Therefore, the housing needs to be taken down and the concrete broken to repair or replace the frame, making it a labour intensive and step, but deliberately put in place to ensure safety, since the frame and container can only be safely removed if the toilet stall is removed. This prevents risk of collapse. The qualitative manufacturing of the frame (Chapter 3.3) is therefore crucial for the toilet's success.

Under the frame, the container sits in the ground, in order for the tank to be replaced, the same steps have to be taken as for the frame's replacement. This is a purposeful desicion however, since taking the container out of the ground with the toilet stall still in place poses risks for collapse, compromising the safety of workers.

End of Life

The system is designed to last between 5–10 years. Over time, components may degrade due to environmental factors, including corrosion and soil conditions. The system's modularity ensures that degraded components can be replaced safely, extending the overall longevity of the system. Bearing in mind the limited modularity of the frame and container.

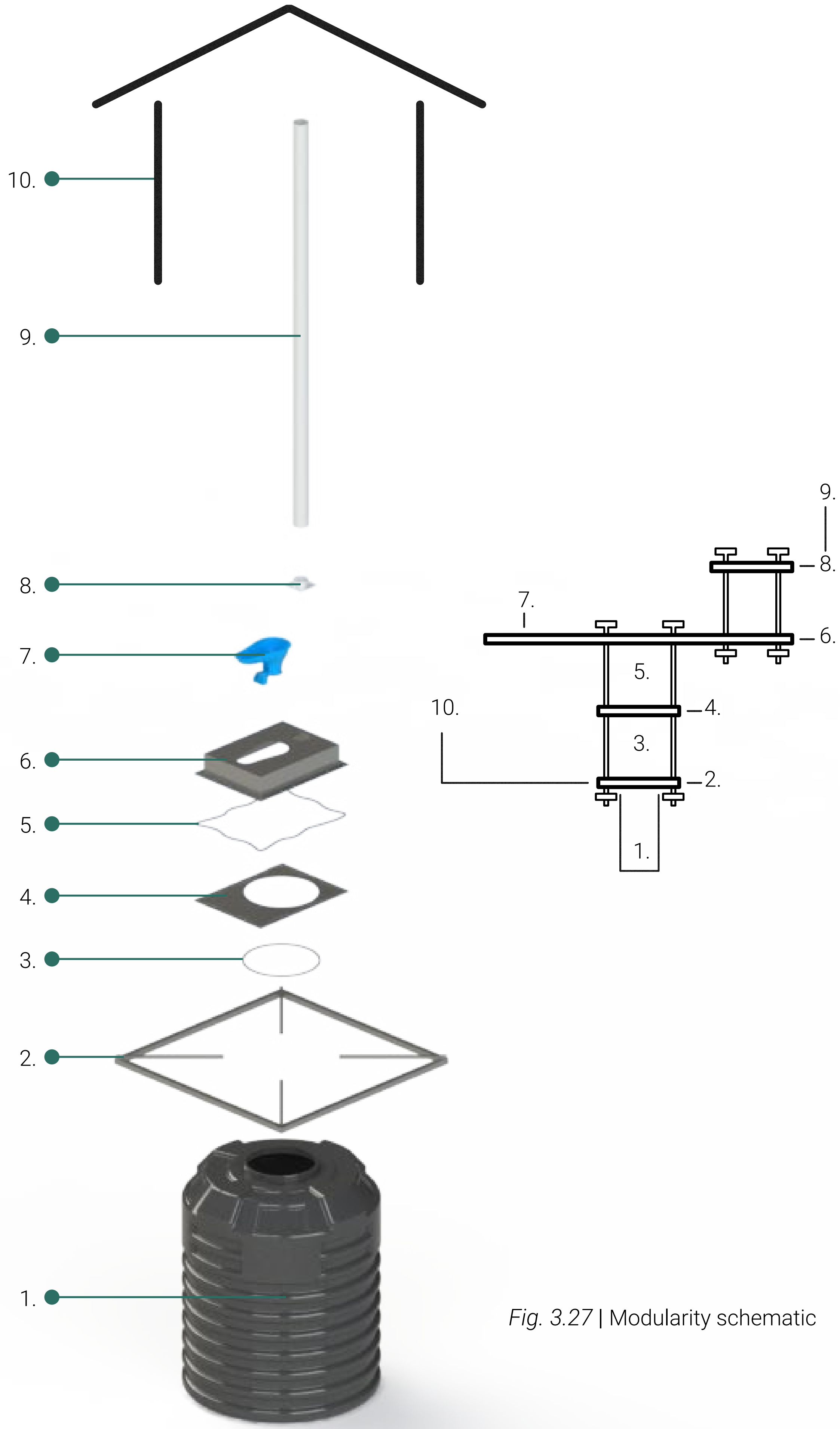


Fig. 3.27 | Modularity schematic

3.7 Conclusion

Safety, Inclusivity, Ease of cleaning and Longevity

In conclusion, the toilet (fig. 2.28) introduces several interventions to improve **drinking water quality** and facilitate **hygienic toilet practices**. A container stops contamination of groundwater by unlined pit-latrines, infecting drinking water sources with fecal diseases. The toilet bowl is made out of easy to clean materials: HDPE and stainless steel, facilitating easy cleaning. The toilet is more **inclusive to users with disabilities and elderly** users through its sitting option and spacious set-up, and its **safety** and **longevity** is improved through its flood proof design, solid foundation and repairability.

Additionally, the project prioritized the **use of locally available materials** and the (re-)utilization of components from the inhabitants' existing latrines to expedite implementation and reduce costs.

The toilet relies on the SaniSecure Service in order to function properly. In Chapter 4, the service is presented.

Fig. 2.28 | Prototype 3 under construction

Design of the SaniSecure Service

04.

The SaniSecure Service is designed to empty, maintain and repair the toilet. However, it also addresses the needs of the three main stakeholder groups. Pain points identified in the Gulper Group's method of operation regarding employee health, safety and financial security are used to set up an improved transport system, which provide the Service Group employees with the tools, education and protocols they need to operate safely and efficiently. A lack of WASH knowledge amongst inhabitants prompted the design of the interaction between the Service Group and the SaniSecure Toilet users. During this interaction, Service Group employees educate inhabitants on safe WASH practices, closing knowledge gaps and improving WASH among inhabitants.

4.1 Service Overview

The SaniSecure Service (Fig. 4.1) is responsible for the operations surrounding the toilets and ensures they function, as well as transport the sludge from the toilet to the Biodigester. It also provide additional education to inhabitants to ensure inhabitant health and the proper maintenance of the toilet.

The **SaniSecure Toilet and Service together** are referred to as the **SaniSecure System**.

Service Tasks

The service's tasks are performed by the Service Group. Their tasks are:

- **Installing** the SaniSecure Toilet
- **Emptying** the SaniSecure Toilet
- **Transporting** fecal sludge to the biodigester
- **Repairing/maintaining** the SaniSecure Toilet
- **Educating** the inhabitants on WASH practices
- **Collecting data** for the SaniSecure System's improvement

Components & Features

The Service Group are the people performing the service tasks.

The motorized tricycle is used for sludge transportation. It has a maximum carrying capacity of 1000 L.

The transport container is a 1000 L water container commonly found in Uganda. It has a hole with a lid on top of the container for sludge loading and a valve at the bottom for unloading.

The Pupu Pump is a motorized pump that empties the latrine and pumps the sludge into the transport container. It is capable of pumping 1000 L of sludge in 10 minutes.

The suction hose is a 75 mm reinforced hose, which can be inserted into the container for sludge pumping after removing the toilet's ventilation pipe.

The inhabitant interaction is designed to increase inhabitant WASH knowledge, as well as to collect data on the SaniSecure System for improvement

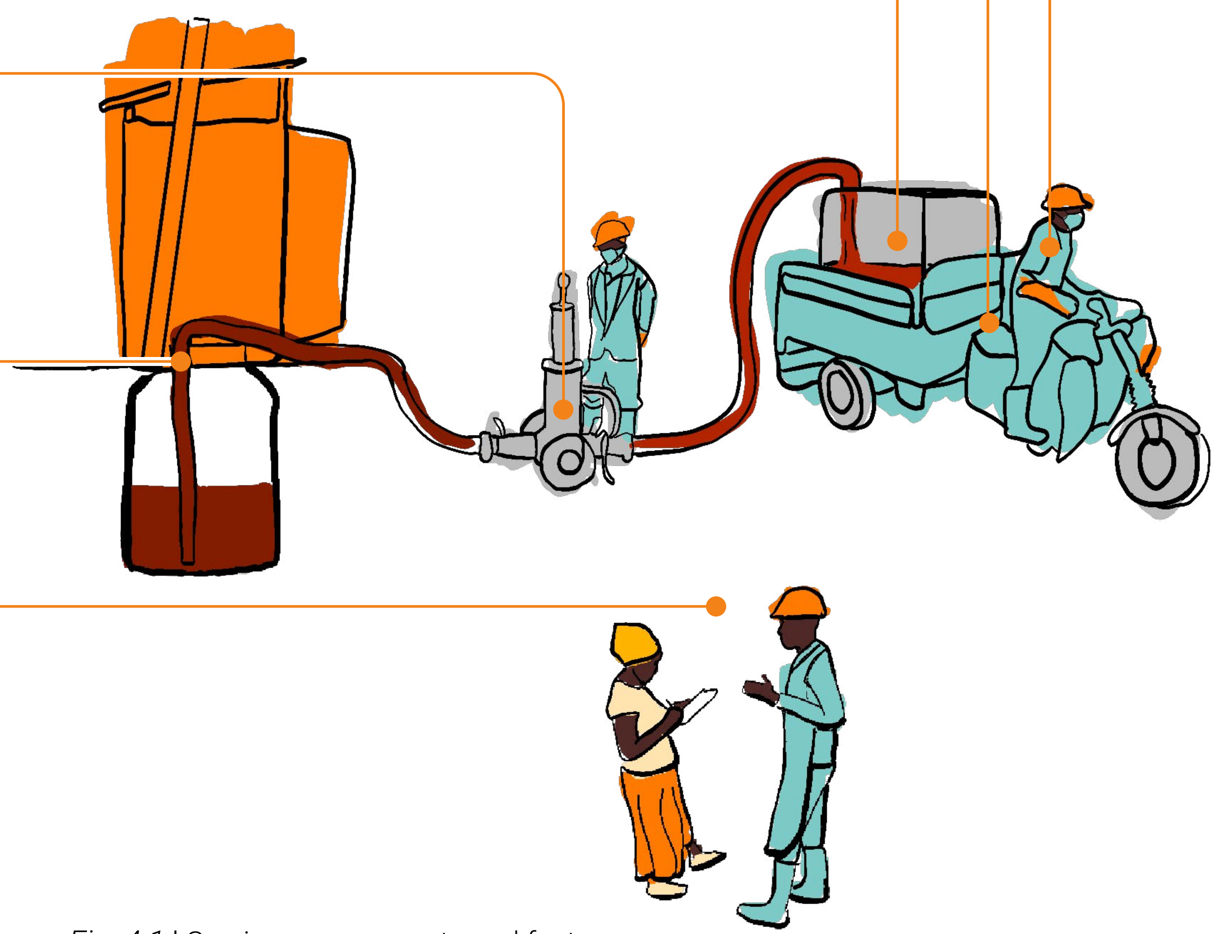


Fig. 4.1 | Service componenets and features

The SaniSecure Service was designed to empty the SaniSecure Toilet in a way that is hygienic for Service Group members and safely transport the fecal sludge to the digester, as well as educate inhabitants on WASH practices and provide fair working conditions and salaries to the Service Group members.The relationship between the features of the service and the problems they solve are discussed here.

Problems Adressed by the SaniSecure Service

For the **tranport group**, three problems are adressed by the SaniSecure Service (Fig. 4.2):

1. **Sludge Transport on Settlement Roads:** Motorized tricycles with better sludge containers are able to transport fecal sludge safely over the settlement roads.
2. **Unsafe, Unhealthy & Inefficient Work:** A combination of a motorized pump, training, standardized practice, better equipment, and luiquid sludge without garbage ensures the Transport Group's health, safety and efficiency.
3. **Unstable and Weak Financial Situation:** Fair wages for the Service Group and relieving them of the financial responsibility for equipment repairs or replacements improves their financial stability and strength. This is also expected to increase safe working conditions through immediate professional repairs and replacements.

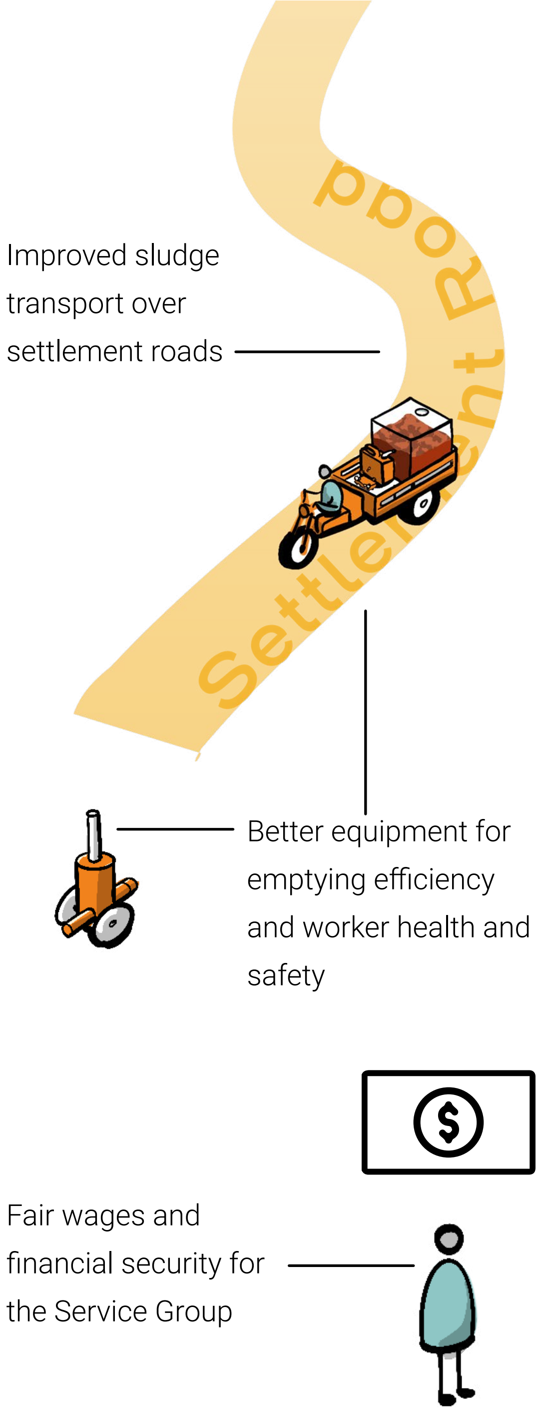


Fig. 4.2 | Service features for the Transport Group

For the **inhabitants**, three problems are adressed by the service (Fig. 4.3):

1. **Affordability of Clean Sanitation Service**: Inhabitants are not charged financially for the SaniSecure System (toilet & service), instead, they are expected to help with installation, cleaning and maintenance.
2. **WASH Knowledge**: Members of the Service Group are trained to educate inhabitants on good WASH practices and adjusting misconceptions leading to health risks.
3. **Availability of cleaning materials**: The Service Group will assess if all required cleaning materials, e.g. a handwashing station and soap, are present during service, and act as a distribution point for cleaning materials at an affordable price for inhabitants.

Fig. 4.3 | Service features for the inhabitants

For the **Biodigester Group**, two problems are adressed by the toilet (Fig 4.4):

1. **Constant Sludge Supply**: The service ensures a constant supply of fresh sludge is brought to the digester, which is expected to increase biogas yields, increasing income from sales.
2. **Data Collection**: Through inhabitant interactions, collected data on system functionality and cleaning practices is used to assess system functionality and sludge biogas producing qualities.
3. **Viability**: To partially finance the system, public latrines are emptied at a fee.

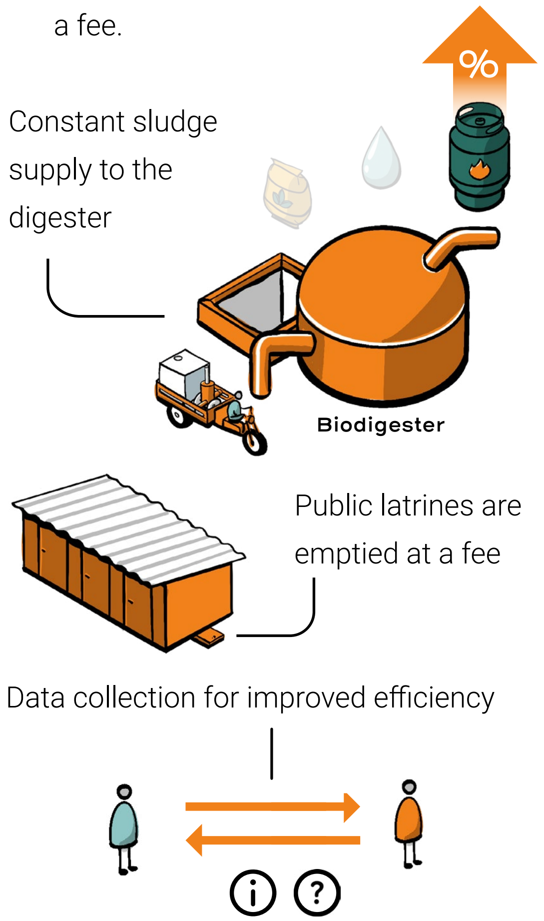


Fig. 4.4 | Service features for the Biodigester Group

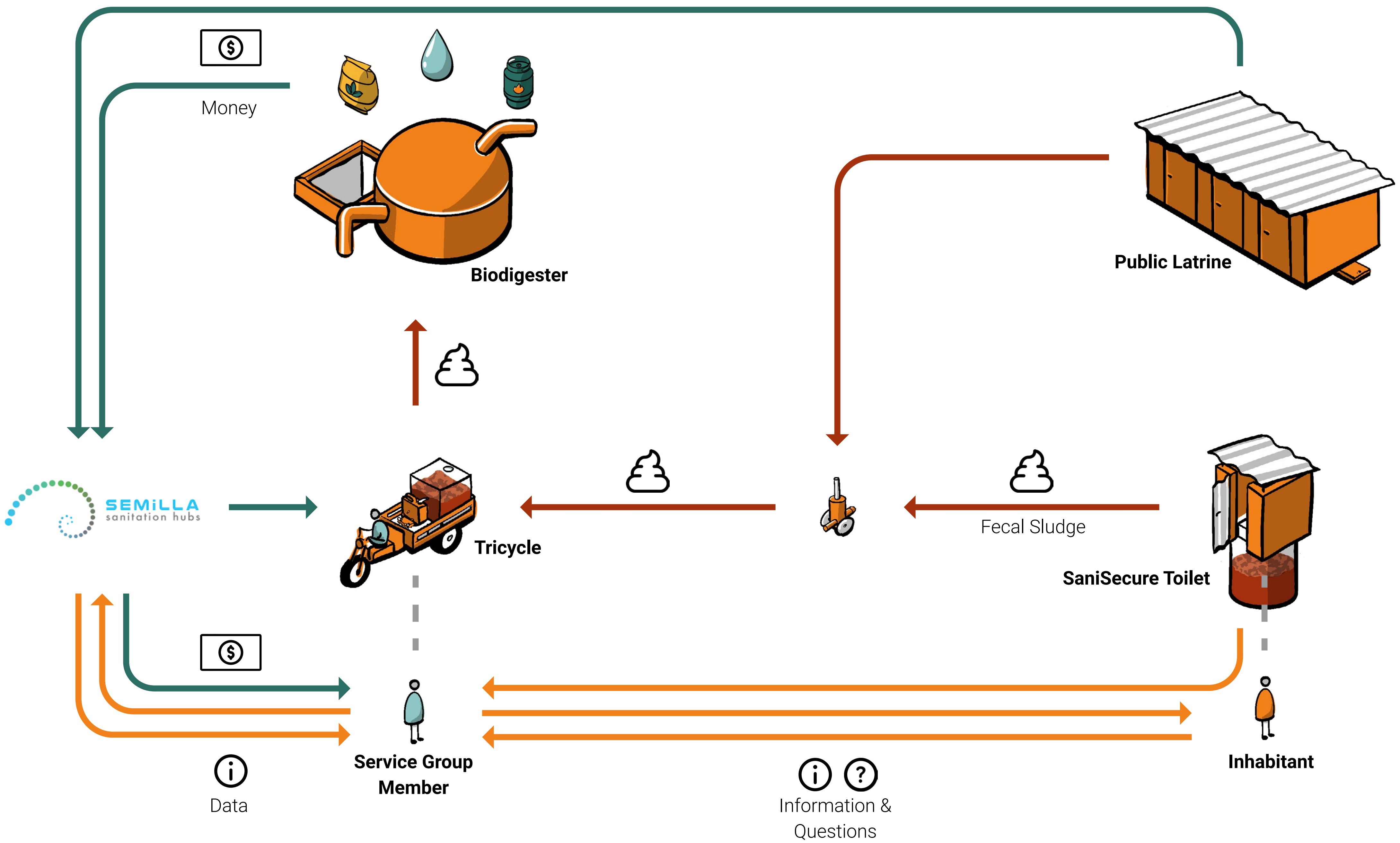


Fig. 4.5 | New system interactions

System Interactions

The **relationships** between the toilet, Service Group, inhabitants, tools and materials are illustrated in Fig. 4.5. The tricycle and Pupu Pump are used to pump fecal sludge from the latrine and transport it to the digester. This is done by members of the Service Group. The yield from the biodigester products, as well as the fee charged for emptying public latrines (explained in further detail in Chapter 4.5) finance the materials, operational costs and and salaries included in the system. During the interaction between the Service Group and the inhabitants, an exchange of information happens, with the inhabitants asking questions or advice. The Service Group is trained to provide the inhabitants with WASH knowledge. The Service Group also collects information both from the inhabitants and by inspecting the toilet. They report this information back to Semilla who can then collect data and implement systematic improvements or communicate action points to the Service Group.

In the following segment, the materials and interactions included in the SaniSecure System are discussed in more detail.

4.2 System Components

The people, vehicle, equipment and cleaning materials used for service are defining for the Service's improvement on worker health and safety. Therefore, they are introduced in detail in this chapter.

Service Group

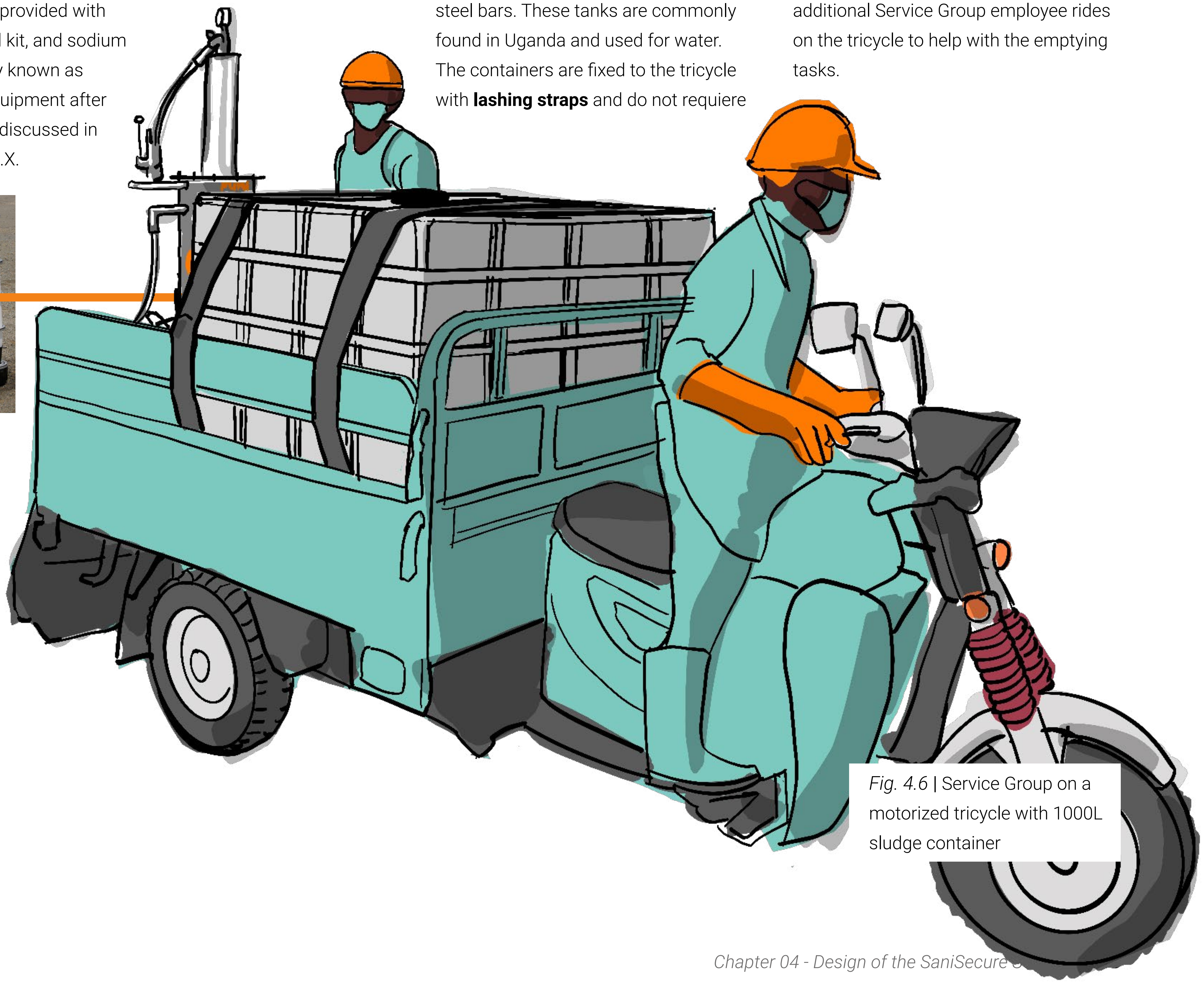
The Service Group's set up (Fig. 4.6) is inspired by the Gulper Group discussed in Chapter 2.5. It is a community lead organisation, employing local inhabitants for its activities. The issues faced by the Gulper Group have been adressed by providing the group with the additional tools, personal protective equipment (PPE), education and salary needed to ensure the Service Group's health, safety and financial stability.

Protective Equipment

The Service Group is provided with Personal Protective Equipment (PPE), consisting of:

- **Hard hats**
- N95 **face masks**
- Safety **goggles**
- Waterproof **overalls**
- Heavy duty rubber **gloves**
- Waterproof rubber **boots**

In addition, the group is provided with hand sanitizer, a first aid kit, and sodium hypochlorite (commonly known as bleach) to wash their equipment after every emptying activity, discussed in more detail in Chapter 4.X.



Transport Vehicle

A **motorized tricycle**, similar to the one used by the Gulper Group, is used by the Service Group for the emptying activities. However, this tricycle has a fixed **1000L tank** (Fig. 4.6) which is reinforced with steel bars. These tanks are commonly found in Uganda and used for water. The containers are fixed to the tricycle with **lashing straps** and do not requiere rempval during filling or emptying, but instead can be filled and emptied while fixed. This modification means that there are no longer men necessary to hold down any container on the back of the tricycle. Apart from the driver, one additional Service Group employee rides on the tricycle to help with the emptying tasks.

Fig. 4.6 | Service Group on a motorized tricycle with 1000L sludge container

PuPu Pump

The use of gulpers posed health and safety issues for the Transport Group. An automated pump called the Pupu Pump (fig 4.7) was identified as a viable alternative. The pump and accesoiries weigh around 100 kg's and enable remote and rapid sludge extraction. It can pump sludge for up to 100 meters between the toilet and the transport vehicle and takes 10 minutes to pump 1,000 litres of liquid sludge (Practica, n.d.). Built in features are in place to clear clogged hoses (Practica, n.d.). Remote-controlled pumping reduces direct exposure to waste, increasing worker hygiene and improving healthy working conditions for the Gulper Group, while the rapid pumping time and anti-clogging features improve the service efficiency.

The Pupu Pump was tested (Fig. 4.8) in Kisumu, Kenya, where it has been implemented in an informal settlment setting, with similar conditions to the Imvepi settlement (Practica foundation, 2024).

Practica, the company that developed the Pupu Pump, is a bureau that specializes in sanitation sollutions for low resource settings and has not only provided information on the Pupu pump, but assited the consideration of alternative pumps and has assisted throughout the SaniSecure System development with their expertise.

While alternative pumps were evaluated, they either still required manual sludge handling or proved unreliable in terms of availability and performance.
The Pupu Pump was ultimately selected as a cost-effective, lightweight intermediate solution between a traditional gulper and a cesspool truck, in collaboration with Practica (Practica, n.d.), a bureau that specializes in sanitary solutions for low resource settings.

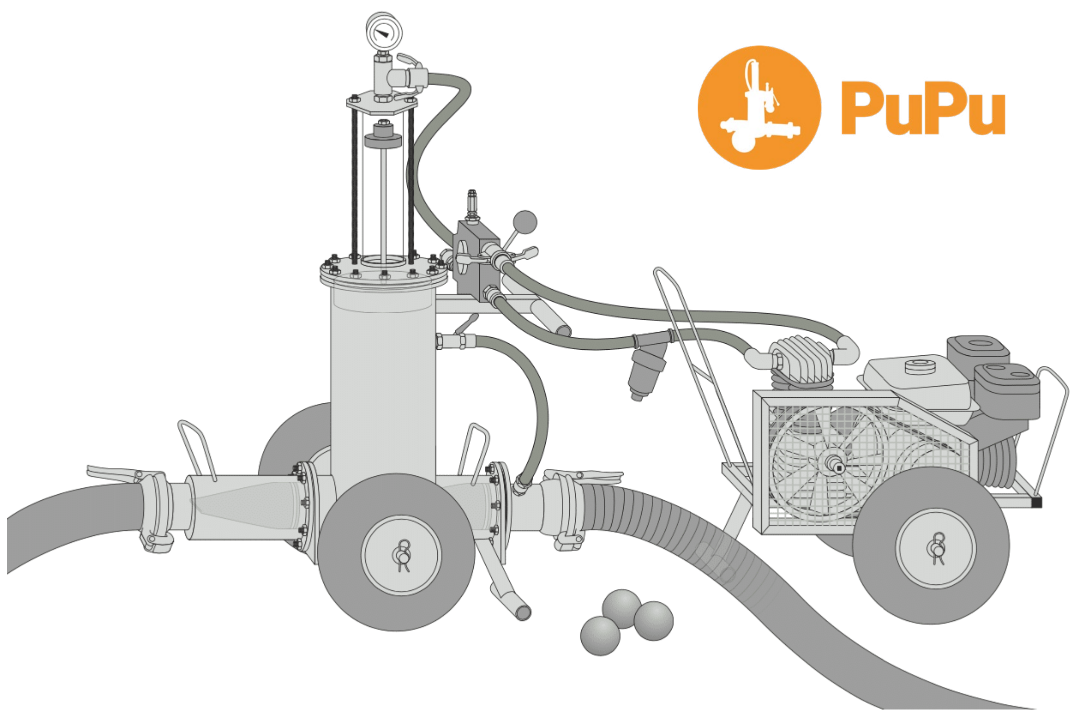


Fig. 4.7 | The Pupu Pump

Fig. 4.8 | The Pupu Pump being used to empty a latrine

4.3 Service Conditions

To ensure that the components of the service contribute to the desired solution, service conditions apply. Without the right conditions, the desired impact is will significantly diminish. The conditions needed are described in this chapter

Education

Training of the Service Group is essential to ensuring safe and hygienic working practices, as well as allow the Service Group to extend their WASH knowledge to inhabitants during toilet servicing visits.

An educational program for the Service Group will be developed by SkillEd (SkillEd, n.d.), the educational partner of the project. This program has the following focal points:

- Safe and hygienic **emptying practices**
- Hygienic **Toilet cleaning** practices
- **Teaching** WASH principles
- **Installing** the SaniSecure Toilet
- **Maintaining & repairing** the SaniSecure Toilet
- **Reporting** efficiently

Financial Security

The system employees are paid a fixed salary of 30.000 UGX (~ €7.50) per day. Although this may seem low for Western standards, this is 4.5x the Ugandan minimum wage. In comparison to the Gulper Group, this is an estimated increase in daily wage by 200% (Chapter 2.5).

In addition to this increase, the wage is more stable, since the Service Group is not responsible for the acquisition and maintenance of their equipment. This responsibility instead falls on Semilla and is financed through biogas yields and public latrine emptying, further discussed in Chapter 4.5. The lack of financial responsibility for the Service Group will ensure that they are free to report material failures or breaks, without suffering negative consequences. This results in adequate maintenance and repair of equipment, resulting in safer working conditions.

The low financial risk and high reward for the Service Group employees increases their economic freedom and boosts the local economy.

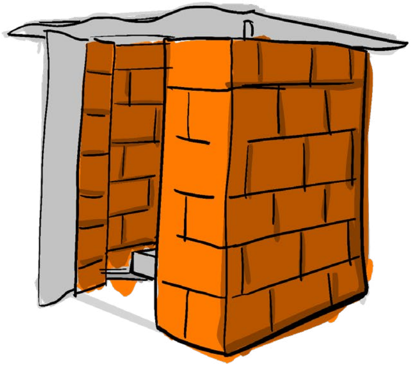
4.4 Service Scenario

Several service interactions have been introduced to ensure hygienic, safe and efficient service. In this subchapter, the emptying, transport, and inhabitant interactions are discussed.

During the servicing visit, the pump is installed and the toilet checked for cleanliness and maintenance. The emptying of the toilet takes around ten minutes. During this time, one operator has to be present at the pump and operate it. The other talks with the owners of the toilet. If necessary, the Service Group can educate or give pamphlets of information to the inhabitants. Questions or suggestions by the inhabitants are answered where possible. Any issues are reported to the Semilla, which can initiate targeted educational sessions. To support hygiene practices, consumables such as soap and toilet paper can be sold during service visits. A similar sales model could extend to biogas distribution to promote its use within the settlement.

After emptying, the pump is securely fastened to the tricycle using lashing straps. Both operators get on the tricycle with the now full container and head to the digester. Once arrived, the tricycle can be positioned, the hose attatched to the bottom of the container is positioned in the digester's pit and the valve is opened.

On the next pages, the envisioned emptying scenario is presented (Fig. 4.9).

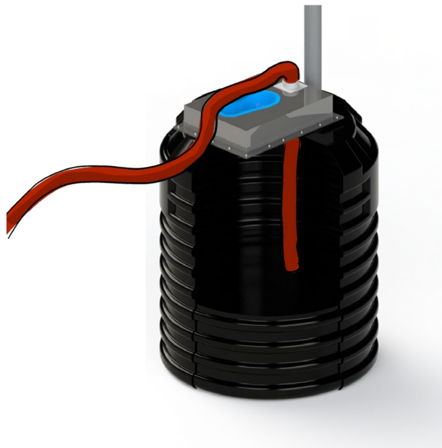


1.

The tricycle parks as close as possible to the SaniSecure Toilet

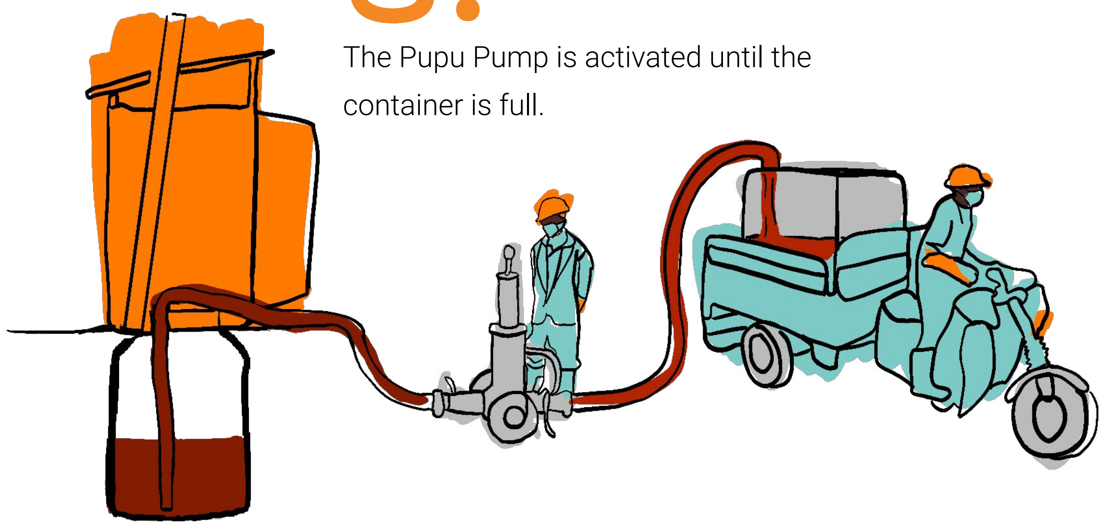
2.

The Pupu Pump is offloaded from the tricycle and set up. The ventilation pipe of the SaniSecure Toilet is lifted and put aside. The hoses of the Pupu pump are inserted into the toilet and the tricycle container. During the installation, the Service Group checks the cleanliness and maintenance of the toilet



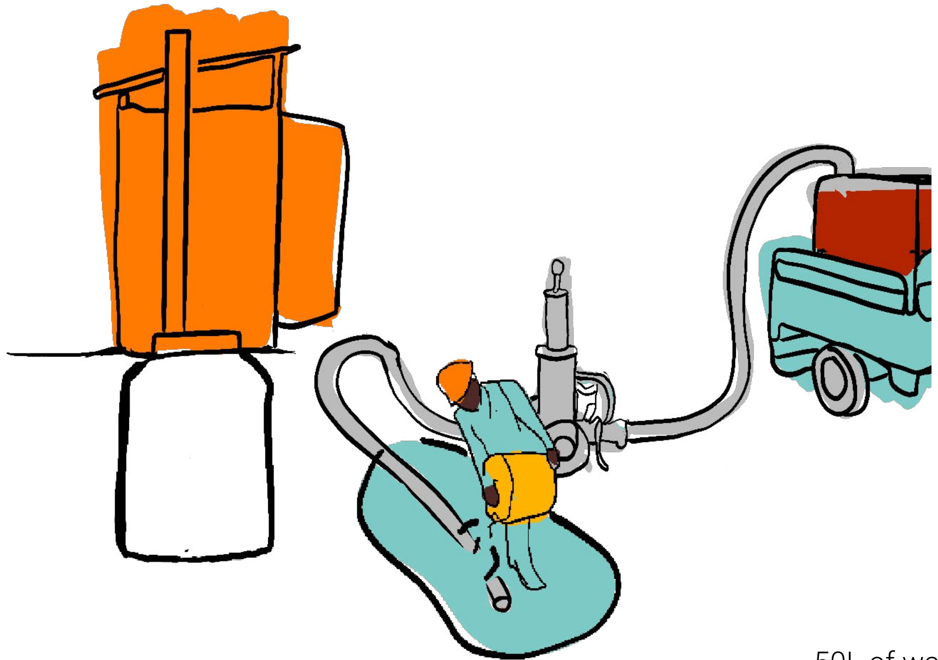
3.

The Pupu Pump is activated until the container is full.



4.

This gives the Service Group 10 minutes to talk to the inhabitants about the state of their toilet, or about questions or suggestions they might have. The Service Group reports this to Semilla via Whatsapp voice message.

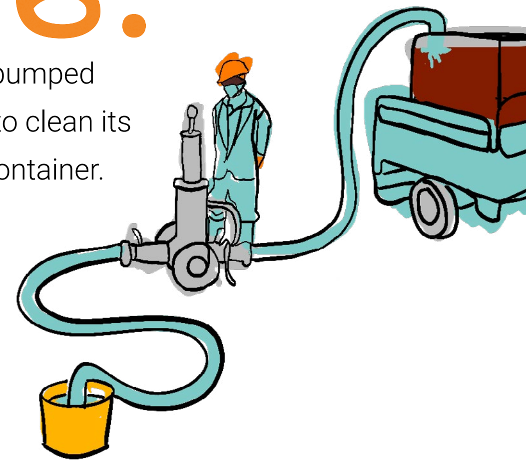


5.

After pumping is done, the hose is taken out of the toilet and the outside is rinsed with water and bleach.The ventilation pipe gets put back in place.

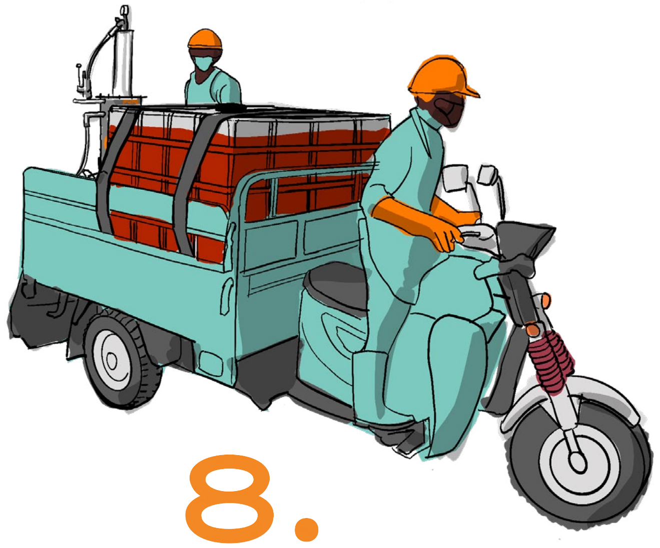
6.

50L of water need to be pumped through the Pupu Pump to clean its inside. This goes in the container.



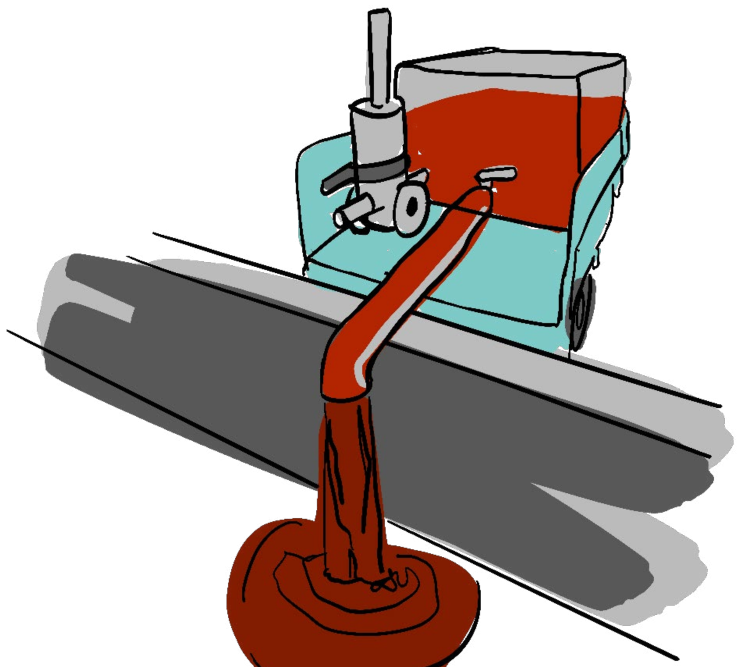
7.

While the pump cleans itself, the Service Group wash their PPE with bleachwater as well



8.

Finally, the container is closed off and the Pupu Pump is packed onto the tricycle and secured with lashing straps. Now, the tricycle is ready for transport to the biodigester



9.

Once at the digester, the tricycle is positioned with its back to the sludge pit of the biodigester.

The container hose is positioned to direct the sludge into the pit.

The valve at the bottom of the container is opened and the sludge flows into the sludge pit.

After this, the tricycle is ready to head back out into the field and go again.

Fig. 4.9 | The envisioned Service Group visit

4.5 System Numbers & Risk Mitigation

To put the SaniSecure System into context, the most important numbers and Fig.s with regards to people, materials, capacities and service frequency are calculated and the results presented here. For all calculations, see Appendix I.

Number of Toilets

The bioidigester requires 4000L of fecal sludge daily, from which, 2000L will come from public latrines (at a fee) and 2000L will come from the SaniSecure, which is free for inhabitants. 2000L of fecal sludge is produced by roughly 1000 people.

Research found that, on average, 14 users share one toilet, this amounts to roughly 70 toilets.

Number of Tricycles & PuPu Pumps

Two Service Group employees per tricycle get their predetermined routes at the start of the day at the digester. All toilets in the service area are within 2 minutes of driving from the digester. For the service area estimation, see Appendix E. One visit takes around 80 minutes, so no more than 6 routes are in a day's work. To utilize full daylight, one 8 hour shift and one 4 hour shift can be completed in one day. Uganda is on the equator, so it gets roughly 12 hours of daylight each day. In total, a maximum of 9 trips can be made throughout the day, with a maximum carrying capacity of 7200 L sludge.

The maximum amount of sludge that can be fed to the digester is 4000 L. Therefore, one tricycle with one PuPu Pump is enough to run the system. two teams of two Service Group employees (four in total) can operate the system full time.

Costs

The capital cost of implementing the system, including the toilets, tricycles, Pupu Pump, PPE and cleaning materials, as well as training the Service Group amounts to almost €55.000. The operational costs of the system ar €35.000 per year. For the calculations, see Appendix J.

Public Latrine Emptying

Public latrines will also be emptied by the Service Group at a fee. This was done in collaboration with Semilla, in order to increase the project viability.

The distribution between SaniSecure Toilets and public latrines emptied by the Service Group is 50% each, meaning that daily, 2000 L of public latrine sludge are transported to the digester.

Normally, these public latrines are emptied by cesspool truck, costing 400,000 UGX (~ €100,00) for a round trip carrying 4000 - 6000 L of sludge.

The Service Group will charge the public latrines 60.000 UGX (~ €15,00) per 1000 trip of 1000 L of sludge. Therefore, the public latrines can be emptied at a rate that is 40.000 - 160.000 UGX (~ €10,00-40,00) cheaper for them, while supporting the local Service Group initiative.

This practice is estimated to finance 30% of the SaniSecure System. For the full calculation, see Appendix J.

Tricycle Failure

Tricycle failure brings the greatest risk, since transport becomes impossible without the tricycle. Through the 1000 L buffer in the toilet container, it is estimated that the system can run for 17 days without a container before the first toilets are full.

To mitigate this risk, The help of the Gulper Group might be asked, it is estimated this might be stretch the time to system failure to one month.

This should be enough time to get the tricycle repaired or replaced, but for extra safety measures, another tricycle is recommended. This could allow for more public larines to be emptied, given another place to offload sludge is found. This could increase financial income into the SaniSecure System, further improving its viability and impact.

PuPu Pump Failure

Considering PuPu Pump failure, the same timeframe of 17 days applies before system failure.

In this time, the PuPu Pump should be repaired in order for the system to become operational.

The Pupu Pump's high acquisition costs make it undesirable to buy a reserve, since this would impact the system's viability. The pump comes with a 2 year warranty, so repairs should not come with extra cost.

However, in case of emergency, emptying can be done by means of gulpers, which are cheap and proven to work. Using gulpers will add time to the emptying process, however, calculations show that the system can stay operational, although public latrine emptying will likely not be possible to the full extent.

The bigger issue is that gulpers were identified as a risk factor to health and safety of the Service Group. Using gulpers means that they have to operate directly over the sludge container and pump sludge into buckets which are then carried to the container. There are a lot of points of contact between the Service Group and the sludge in this scenario which could lead to contamination and infection.

It is therefore imperative that this is only used as a last resort to prevent system failure.

Raining and Floods

Through the set up of the system, it should remain functional for up to 17 days in case rains and floods make the roads impassable. Consideration done with the Ugandan firm Desing Without Borders concludes that a system failure scenario due to rainfall is highly unlikely.

Toilet Breaks

In case of toilet breaks, the Service Group employees will visit the inhabitant and assess the damage. They report to Semilla. Together with HS Green Energy, the technical partner for the project, they can decide on the course of action for a qualitative repair. Members of the Service Group will be provided with the tools, materials and training needed for this. Four members of the Service Group doing repairs or other forms of maintenance have been accounted for in the system

Toilet Cleanliness

If a toilet is not maintained properly, it prompts health risks for its users. When the Service Group encounters toilets that are not well kept, they are trained to provide the user with information and instructions on proper toilet maintenance.

In all cases, a note will be made to management (Semilla Sanitation), stating what was wrong and what measures have been taken. On the next visit, the situation is assessed again. It is expected that progress has been made, but if not, the Service Group will issue a warning to the inhabitants. The SaniSecure System is set up as a free service to them and improvements need to be made if they want to keep being a part of it.

In extreme cases, the SaniSecure Toilet could be removed to be installed somewhere else.

4.6 Conclusion

Toilet Longevity, and Educates Users on Good WASH Practices

The service introduces interventions to increase **toilet longevity** and increase good **WASH practices and knowledge** among inhabitants. Service Group employees perform scheduled visits monthly. During which, the toilet is emptied and inspected for structural or hygienic deficiencies by employees of the Service Group, who have been **trained to educate** inhabitants on WASH practices if they identify knowledge gaps amongst them. They **collect data** by reporting irregularities to management for evaluation and development of the system.

Safe Working Conditions and Fair Wages for the Employees of the System

The Service Group's set-up is inspired by the community lead latrine emptying 'Gulper Group'. The set-up of the Service Group substantiates **safe & hygienic working conditions** by providing its employees with **adequate tools**: a motorized pump and tricycles with fixed containers; and a **stable income**: a monthly salary of 4.5x the Ugandan minimum wage. Improving their financial security and boosting the economy.

The system's costs are partially covered by emptying public latrines at a fee (30%) and partially by the sale of biogas (70%).

On the next pages, the SaniSecure System overview (Fig. 4.10) is presented. It is an overlay of the current system, which includes the SaniSecure Toilet, no longer contaminating water sources, and the service, transporting sludge from the toilet to the digester, where the high quality sludge is expected to **boost biogas yields**.

4.7 SaniSecure System Overview

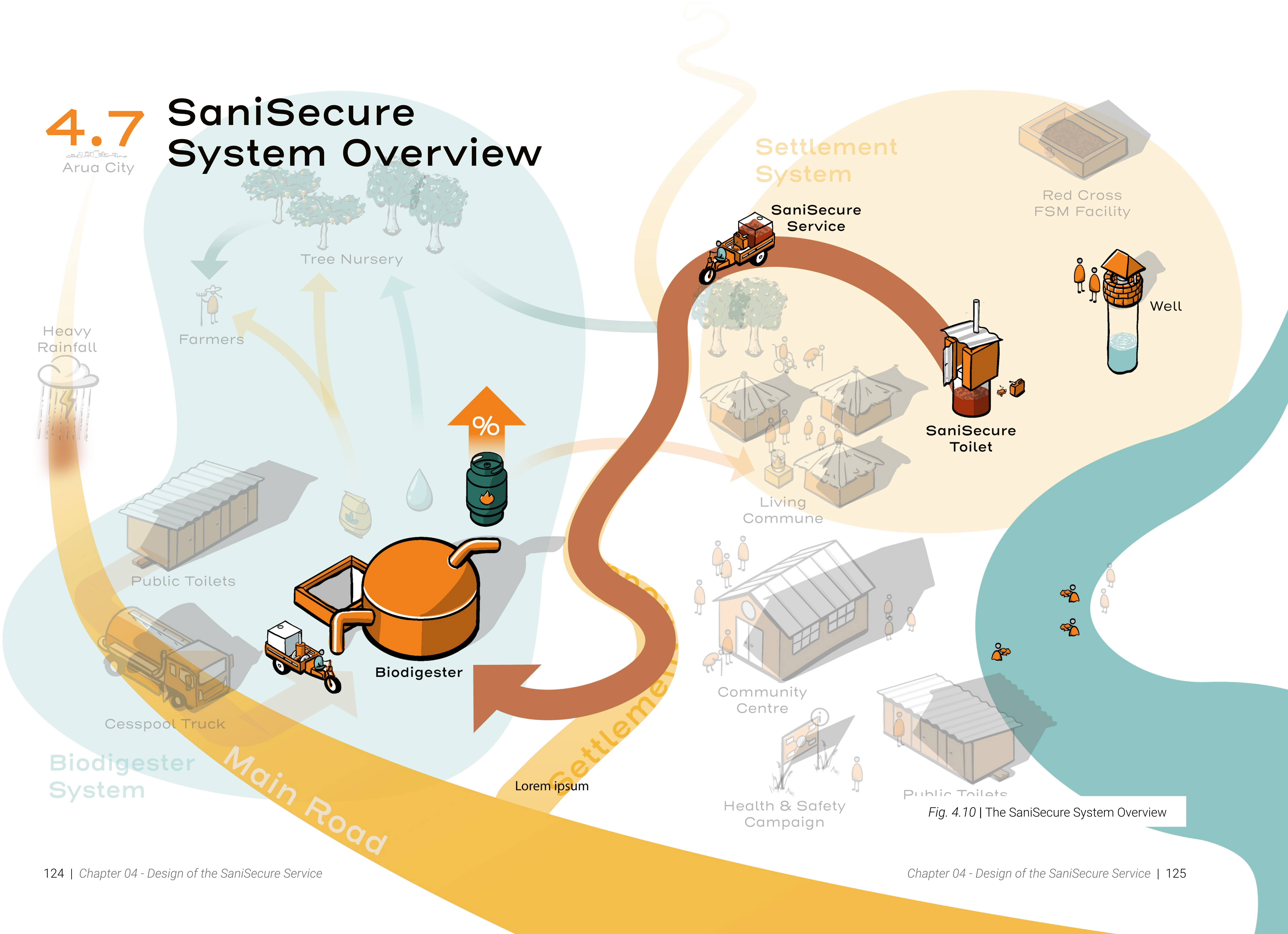


Fig. 4.10 | The SaniSecure System Overview

Implementation Plan & Scaling Strategy

05.

The project pioneers a new concept in an untested context. Consequently, it is expected to not have taken into account all factors influencing the implementation of the system. In an attempt to mitigate the risks of operating at full scale from the start, a phased implementation plan is presented.

In this chapter, three stages of the system's implementation are discussed. First, the short term implementation strategy for testing is presented. Second, based on the first strategy, a long-term implementation plan can be defined for the Imvepi Settlement digester system. Lastly, a strategy is discussed for the use of a different scale biodigester in different contexts.

5.1 Pilot Implementation

A pilot involving 40 prototype toilets will be conducted in a community adjacent to the biodigester. This test set-up will **gather data for two years** before scaling. The goal is to compare the envisioned SaniSecure System against the real data. Several modes of data collection are deployed in order to create a holistic overview of the real world data.

The Service Group will assist with installation under the supervision of an experienced project coordinator of HS Green Energy. The two year-long pilot will include regular emptying services and monitoring of sludge quality, effect on biogas output, transport logistics, and user feedback.

The implementation strategy has been developed to test the theoretical service against the real world context.
The specific materials needed are discussed first, together with the intended timeline of the test. Next, the data collection goals and methods are presented together with the stakeholders involved in them. Finally, a roadmap of the 4 stakeholders involved in the implementation of the test set-up is presented.

Materials & Timeline

The pilot set-up in Imvepi (Fig. 5.1) will consist of 40 toilets servicing 600 people. The area around the biodigester has been analysed (Appendix E) and it was found that these 40 toilets can all be installed within a 1 km (1 minute) drive from the biodigester. For this test set-up, one Pupu Pump is needed and one motorized tricycle, equipped with a 1000L container. The 8 Service Group Employees will be running operations and Semilla will be overseeing operations. Semilla will be responsible for collecting data and mapping the system, through which adjustments can be done to improve the system. The test set-up is planned to go operational in the July of 2025.

Data Collection

The data is collected on 3 different levels, which are discussed in further detail below. Per level, the modes of data collection are presented together with the stakeholders involved.

Product Level:
To determine if the products in the PSS meets the requirements or needs improving, it is evaluated on:

The **structural integrity** of the toilet
- Service Group – through inspection and talking with the user, communicating this in a WhatsApp voice message (this app is already used for communication) to management

Toilet **cleanliness**
- Service Group – through talking with the user, communicating this in a WhatsApp voice message to management

Sludge produced per toilet per day
- Digester Operator – counting the tricycles coming from SaniSecure Toilets and the volume of sludge they are carrying

The assumed **capabilities of the tricycle** with the container
- Service Group - Testing the tricycle with the container filled with various volumes of water on the settlement roads to find out the maximum load

The assumed **capabilities of the Pupu Pump**
- Service Group - Reporting of issues with the Pupu Pump such as clogging or stalling by the Service Group to management through WhatsApp voice message.

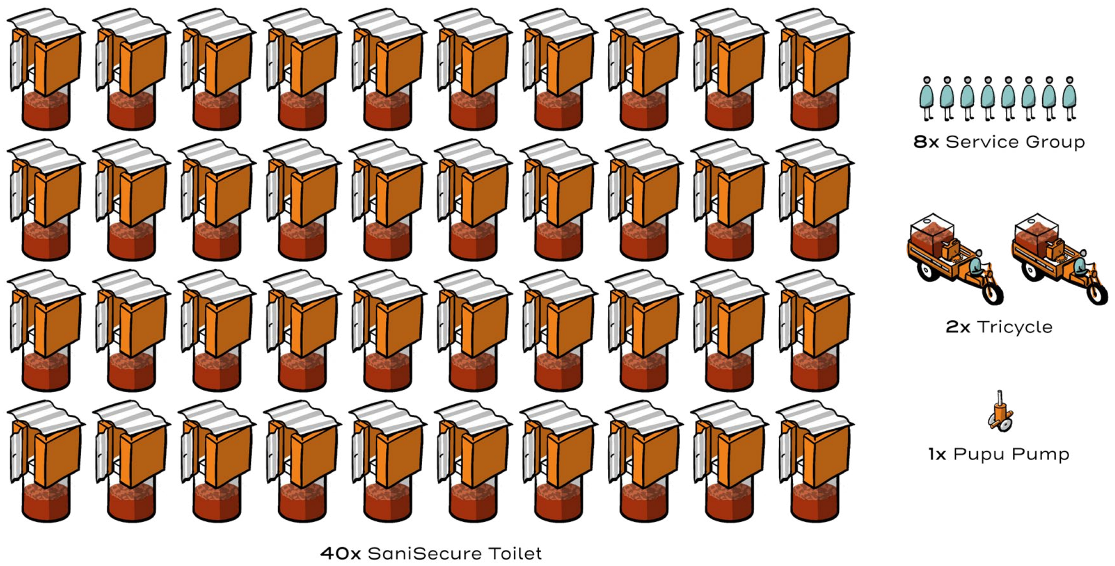


Fig. 5.1 | The pilot set-up in Imvepi

Service Level:
To determine if the service meets the requirements, data is collected on:

The **capability of the Service Group** to install, empty and service the toilets & inhabitants
- SkillEd – through training, practicing and monitoring the Service Group' toilet building capabilities

The **capability of the Transport Group** to report findings and issues to management
- Service Group Manager – Analysing the data given by the Service Group and calling users to confirm if the data is correct

The **biogas producing quality** of sludge from the toilets
- Semilla – Analysing the amount of biogas produced by the digester under normal conditions with and without the sludge from the SaniSecure

The **desire of facilities with public latrines** to have them emptied with the SaniSecure Service
- Service Group Manager – contact with public facilities about their latrine emptying wishes, setting appointments and having follow up meetings to discuss the experience.

User Level:
To determine the perceived toilet value and inhabitant responsibility for cleanliness and maintenance, data will be collected on:

The **opinion of inhabitants** on the new toilet
- Service Group - through talking with the user, communicating this in a WhatsApp voice message to management

The **intended use versus the true use** of the toilet by users
- Service Group – through inspection and talking with the user, communicating this in a WhatsApp voice message to management

The **desire for the SaniSecure System** among inhabitants
- Service Group – through communicating with inhabitants and community leaders about the desire among inhabitants to own a SaniSecure and communicating this to management

For this pilot set-up, a roadmap has been made for the stakeholders involved, to ensure everyone is aware of their task for implementation, shown in Fig. 5.2.

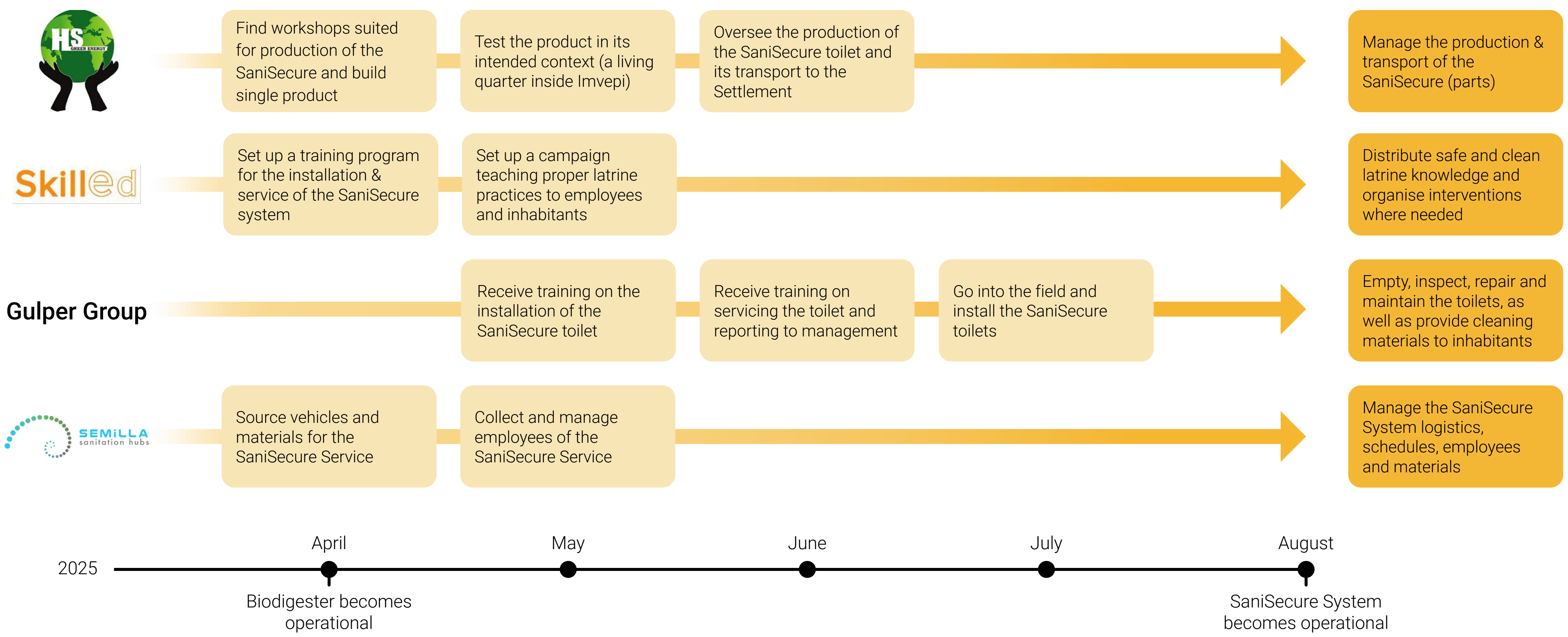


Fig. 5.2 | Stakeholder Roadmap

5.2 Full Scale Set-Up

After the initial 2 years of testing, and simultaneous improvement of the toilet and service, the system is scaled to full size (Fig. 5.3), with 70 SaniSecure Toilets servicing 20% of the biodigester's sludge needs as intended. In this set-up, 1000 people are provided with adequate sanitation.

Business Model

The project proposes a sustainable sanitation system that integrates waste management with biodigester operations. While initial subsidies cover setup costs, the system aims to become **self-sufficient** through a structured service model.

The Gulper Group will receive a fixed salary, providing financial stability, while inhabitants will not be charged due to their low and insecure income. Public latrines will pay a reduced fee compared to traditional cesspool emptying, ensuring affordability and accessibility.

70% of the operational costs comes from biodigester yields.Through the fresh sludge provided by the SaniSecure Toilet, biogas yields are expected to go up. While the exact increase in yields is not yet known, it is expected to increase financial income into the system. Thus further helping towards covering the operational expenditure.

However, it is likely the increase in biogas yields will not fully cover the costs. The humanitarian nature of the SaniSecure System might prompt the Biodigester Group to still adopt it, since total biogas yields will most likely be able to cover the WTCAP costs, as well as the SaniSecure System costs.

Therefore, another strategy has been discovered, where by expansion of the Service Group to empty more public latrines and depositing sludge in other facilities such as the one set up by the Red Cross in Odupi, could create additional income for the system.

Fig. 5.3 | The full scale set-up in Imvepi

5.3 Expansion Strategy

Semilla, together with its local partners, has identified 10 new locations throughout Uganda that lend themselves to the introduction of biodigester systems. Some of them are in rural areas similar to the Imvepi refugee settlement. It is expected that in these locations, the system can be copied with minimal changes. However, it is always necessary to do a feasibility study before committing to a new location. Other locations are slum settings in cities such as Kampala. Here, more extensive studies will be conducted to determine the implementation strategy of the SaniSecure System.

Rural Settings

Through field research it was found that culture, traditions and habits of different tribes spread well across the borders of Uganda. Stories from South-Sudan, DRC, Kenia and others all indicate similarities in living conditions in rural areas.

Therefore, it is expected that the business model can stay roughly the same in expanding into rural areas.

However, it is always advisable to research these areas for the following:

- Current latrine state and products
- Organisational or humanitarian WASH practices
- Water availability
- Current sludge transportation and treatment facilities

These factors could influence the adaptation of the product and the aid or competition on service level.

Urban Settings

Urban Settings come with more challenges, since the context is very different from the one researched for this project. Where rural areas have relatively open space, urban slums are often very tightly packed. Inhabitants of slums are expected to get less of their resources from farming and more from informal 'hustles'. Money plays a more vital role in the acquisition of food.

For these areas, a larger, 50 tonne digester is considered for its higher capacity and efficiency, since distances travelled will be less than in rural areas and more inputs of waste are expected due to high population density.

It is expected that the SaniSecure Toilet as it is designed currently will take up too much space and therefore a smaller version or different concept will be needed.

Tricycles might still be a good option, but motorcycles carrying smaller containers might also be considered.
The Pupu Pump seems to be still be functional in densely populated areas with little space to manoeuvre a vehicle, since the pump can function over a distance of max. 100 metres.

It could become interesting to let users transport their own containers of sludge to the digester in exchange for compensation, since this money could help feed more families in these situations, instead of just paying a select group of transporters for their service.

In conclusion, urban settings require additional research and the rural model will most likely need heavy adaptations before it makes sense in this context.

Scalability of the Business Model

Although the capital expenditure on a biodigester system are high, the system in Imvepi is expected to turn its first profit in 3 years' time. By this point, the SaniSecure System will be tested and optimized. Once the system has proven itself, additional funding from humanitarian aid and government are expected to increase expansion speed to other rural biodigester systems. Through research on urban settings, the biodigester will set up the 50 tonne digester in the slums of Kampala. Which should be optimized and applicable to different urban settings.

Injection Mould for the SaniSecure 2.0

In order to further develop and improve on the SaniSecure design, the results from testing will be incorporated into an injection moulded design. This will make the product much more affordable and quick to produce in future scaling.

50 Tonne Biodigester Set-Up

In densely populated areas such as city slums, it can be advantageous to use a larger digester. Since in these areas, more biowaste can be collected in a small area. This digester is capable of higher efficiency due to its larger size, as long as the supply of waste can meet the demands of the digester. This type of digester can process 50 tonnes of waste per day, a 400% increase over the 10 tonne digester in Imvepi. The SaniSecure System for these digesters is expected to consist of 400 toilets, servicing a total of 6000 people.

The advantage of using a 50 ton digester over a 10 ton digester is that with greater volumes comes greater efficiency and higher yields. Therefore, these systems have the potential to be more profitable, while being able to provide more people with safe and clean sanitation.

The disadvantage of large digester set-ups is that the servicing area is much larger, therefore it is only suitable for densely populated areas. In rural areas such as Imvepi, the area becomes too large and the vehicles for emptying will need too much time and petrol for the system to keep its profitability.
In larger rural situations, multiple 10 tonne digesters are recommended to keep transport manageable.

Validation

06.

This chapter evaluates the effectiveness and feasibility of the SaniSecure System based on research findings, user needs, and system performance. The validation process examines desirability, feasibility, and viability, ensuring that the system aligns with stakeholder requirements and environmental conditions. Through field research, prototyping, and stakeholder collaboration, this chapter assesses how well the system functions within its intended context and the potential challenges it may face during implementation.

6.1 Desirability

This section evaluates how the SaniSecure System meets the needs and preferences of the Settlement Inhabitants. It explains why the human centred research and holistic system design approach facilitate positive and lasting change for inhabitants' wellbeing.

Several governmental and donor-supported efforts to improve the quality of sanitation facilities and processes have taken place in the last years. However, a holistic sustainable solution is yet to be piloted. The uniqueness of the SaniSecure System is that it connects the biodigester to the inhabitants of the settlement and takes into account culture, habits and pain points of its users and operators, while safeguarding environmental wellbeing and organisational effectiveness.
The SaniSecure System utilises a triple approach to substantiate inhabitant wellbeing.

Firstly, sealed containment of fecal sludge prevents groundwater pollution and indirect contamination through water sources such as wells, leading to less contamination of people with fecal particles, causing infection and even epidemics in communities. A topic becoming increasingly more relevant now that the refugee settlements in northwest Uganda are becoming more densely populated.

Secondly, toilet features e.g. the flood proof design and cleanability increase product safety and inhabitant health.

Lastly, the educational role of the system increases collective WASH knowledge amongst inhabitants and consequently boosts good latrine hygiene practices. Therefore making inhabitants more resilient to the dangers of unsanitary toilet practices.
These three levels of intervention provide a solid foundation for improving public health and the system itself can be seen as an innovator and inspiration in fecal waste management systems for low resource settings.

Within the biodigester system, the increased biogas yields through implementation of the SaniSecure System play into the need to preserve the trees in the settlement from being cut down for cooking fuel, by offering inhabitants biogas as an alternative.

Trees are essential in regulating ecosystems and their roots play a vital role in preventing landslides during floods, further emphasizing the importance of their preservation for inhabitant safety.

Within a larger scope, increased biogas yields contribute to the energy transition from fossil fuels to renewable resources and can be seen as an example of sustainable innovation in low resource settings.

Linking User and Client Needs to Product-Service Features

'Safety' and 'cleanliness' are the most important toilet values according to inhabitants (Chapter 2.5), they are emphasized in the toilet's features: flood- and collapse proof design ensures safety, while the Sato products put a barrier between the user and the sludge and make the product easy to clean for users. The values are also reflected in the name of the product to emphasize these product qualities: Sani – sanitary/clean; Secure – safety.

The sitting feature of the SaniSecure Toilet improves the inclusiveness of the design for elderly and disabled users, therefore eliminating the open defecation they are often forced to resort to. The direct added value of this is very apparent: the toilet experience becomes more humane for people with disabilities and directly eliminates health risks for them and their community, but it simultaneously serves a broader social need. People with disabilities are often not able to travel or join social events, because the squatting latrines throughout the settlement are not suitable for them to use. With SaniSecure Toilets spread throughout the area, the members of the community with disabilities gain the freedom to travel beyond their commune and live more social and fulfilled lives.

In ideal conditions for biogas production, sludge needs to be relatively fresh, hence, it is best to be stored in a sealed containment. While this benefits biogas production, it also directly solves the problem of groundwater pollution by preventing leakage.

The SaniSecure Service's main objective is emptying toilets, but the need for increased WASH knowledge (Chapter 2.5) lead them to take up an important educational role as well. In the data they collect on pain points in latrine upkeep and WASH knowledge amongst inhabitants further assists the mapping of problems.

The safety and health of the Service Group is ensured through use of the Pupu Pump and by fitting fixed tanks on the transport tricycles. The Pupu Pump was chosen considering the Service Group's needs to operate safely and efficiently. The pump can be operated at a distance from the sludge, with built in problem solving features to clear blockades (Chapter 4.2). This puts distance between the employees of the system and the sludge, ensuring their safety from contamination.
The system employees are paid a stable salary, allowing them to take care of their families and community. Their example of what community lead service models can accomplish will serve as an inspiration to other inhabitants in building the local economy. When economic models such as the biodigester system are scaled across the area, this boosts the economy at scale.

Public facilities are also emptied by the Service Group, taking care of the broader sanitary needs of all latrines in the settlement (personal and public), while increasing scalability of the service.

A downside of the employee set-up, is that the amount of employees is limited. In the Gulper Group, more than 30 people are employed using a single tricycle. Through the efficient design of the Service, this system is operational with 10 people and two tricycles. Consequently, up to 50 people are missing out on a salary. Training and employing these people would significantly increase the cost of the system and limit its chances of succesful implementation and financial sustainability. Additionally, the limited number of employees ensures the Service Group employees of a fair salary, which is currently not the case for the Gulper Group (Chapter 2.7).

Sustainable Development Goals (SDG's)

The solution contributes to SDG 6, by improving sanitation, preventing groundwater contamination and ensuring safe waste management; SDG 8, by offering stable incomes for members of the Imvepi community as SaniSecure Service employees and throughout Uganda by creating work in manufacturing; SDG 3 by preventing epidemics caused by fecal sludge contamination; SDG 7 & 13, by producing biogas an affordable and renewable cooking fuel; and SDG 11 by introducing a sustainable and circular fecal waste management system in the Imvepi community; SDG 15, by reducing the cutting down of trees for cooking fuel and contributing to reforestation via the tree nursery set up by the Waste to Clean Air project (Chapter 1.4)

6.2 Feasibility

In this segment the feasibility of the system is evaluated. Feasibility of the project's success can be anticipated by analysing previous projects in the settlement, the organizational support found in the settlement throughout the project and the features of the product service system with the presented implementation plan. Finally, the challenges and limitations of the system are mapped and the mitigating measures introduced by the system are discussed.

SaniSecure as Part of the Biodigester System

Semilla and its partners have laid the foundation for the SaniSecure System with the field research done in the settlement and the construction of the biodigester. The biodigester and the SaniSecure System are codependent: the biodigester needs a constant supply of fresh sludge for optimized biogas production and the SaniSecure System needs funding for capital and operational costs, as well as a sludge dumping site. Since the biodigester is already built, it spearheads the development and rapid implementation of the SaniSecure System, for its beneficial addition to the biodigester system.

Long standing organisational and humanitarian entities such as OPM and UNHCR have been actively supporting the construction of the biodigester and initial testing of the SaniSecure Toilet. They have repeatedly stressed the importance of improving latrine hygiene throughout the project and expressed their operational support (Chapter 2.5) for the implementation of the SaniSecure System.

The Gulper Group has shown that community lead service models can be organised, are effective in their latrine emptying efforts and profitable for its employees. They are also facing challenges as described in Chapter 2.7, which have been guiding in the design of the Service Group. The Service Groups' effectiveness in emptying latrines can therefore be substantiated by the Gulper Groups' example, while the challenges they face regarding health, safety and financial security have been improved to ensure the service's longevity and stability.

Prototyping of the SaniSecure Toilet over multiple iterations in Kampala and testing in both the Imvepi area and

Kampala in collaboration with G-Nex Engineering has ensured that the product can be produced at scale in workshops across the country using available materials, tools, and skills. HS Green Energy's experience in the production and transport sector in Uganda and their commitment to the biodigester and SaniSecure project are invaluable to the production and installation of the toilets in the settlement.

The SaniSecure Toilet itself has demonstrated its ability to meet the requirements when tested in a controlled environment. Giving it adequate substantiation to move to the next phase of development: testing at scale in the settlement. Training local technicians, identifying suitable workshops for production and integrating the solution with existing programs will further drive adoption. The chosen materials (Chapter 3.2) and repairability of the toilet (Chapter 3.6) substantiate the durability and longevity of the toilet once installed.

The Pupu Pump has been deployed in informal settlements in Kenya (Practica foundation, 2024), where similar conditions to the Imvepi settlement are found. Here it has proven to be functional in its emptying capacities while ensuring the safety of the operators. The pump's small dimensions and low weight relative to alternative pumps (Chapter 4.2) make it suitable for transport on the tricycles, which have a limited carrying capacity. The developers of the Pupu Pump, Practica, have aided and consulted during the project's development and are closely involved in its future implementation.

The transport tricycles are a proven transport vehicle within the settlement. They are capable of transporting the required amount of sludge and can be operated by their drivers, as has been proven by the Gulper Group. This means that no adaptation or training is needed by the inhabitants and the vehicle is readily available to use.

Challenges & Limitations

Though the SaniSecure System is a seemingly simple product, the implementation into the system proves why this is a complex solution. The feasibility of the SaniSecure System faces several challenges and limitations that could impact its successful implementation. These include financial dependencies, logistical constraints, and material durability concerns.

One of the primary challenges is the project's reliance on external funding sources such as grants and donations. The speed of implementation is highly dependent on securing these funds, making financial sustainability a potential bottleneck. Without consistent funding, the roll-out of the system may be delayed or remain incomplete, limiting its impact.

Additionally, a limiting factor of the system's impact is the scale at which the system operates. Out of the 67.000 Imvepi inhabitants, only 1.200 are serviced by the SaniSecure System, limiting the system's impact on groundwater quality at scale in the short term. The long term scaling strategy presented in combination other fecal waste management strategies are needed to improve groundwater quality at scale in the long term.

Material availability is another key challenge. The construction of the SaniSecure Toilet relies on specific materials and semi-finished products that are not readily available in the Imvepi area. As a result, these materials and products must be sourced from Kampala, requiring bulk transportation to minimize costs. This logistical constraint increases the complexity of the supply chain and raises the overall expenses of the project. HS Green Energy is conducting a feasibility study on material availability and manufacturing to gain insight into the effect of these logistical constraints.

The quality of work in local workshops is crucial to ensuring the durability and structural integrity of the SaniSecure Toilet. Flood-proofing and safe structural design depend on qualitative manufacturing and assembly. If production standards are not maintained and guaranteed, the system's effectiveness and longevity could be compromised. Prototype development in Kampala in collaboration with G-Nex Engineering has provided insight into the capabilities of workshops and ensured that toilets can be constructed with available expertise and skill.

Hygienic WASH practices dictate that the toilet should be cleaned regularly with soap/detergent, in order to kill fecal microorganisms causing illness. The biogas producing quality of fecal sludge however, is dependent on the presence and abundance of microorganisms. This poses a conflict of interest, where the need for public health negatively impacts biogas yields and profit, limiting the financial sustainability of the system. The impact of soap and detergent on the biogas producing quality of fecal sludge requires further research and mitigating measures.

Structural damage presents another

limitation. Breaks in the toilet's frame are difficult, costly, and time-consuming to repair. Since repair infrastructure is limited in the settlement, extensive damages could render some toilets unusable, leading to gaps in the system posing health and safety risks.

Additionally, emptying equipment failures pose a significant risk to operational efficiency. Pupu Pump or tricycles break downs severely effect the Service Group's ability to empty latrines. In the worst-case scenario, full latrines without an alternative solution could lead to unsanitary conditions and a decline in overall community hygiene.

Mitigating the foreseeable risks and assessing the system's flexibility to deal with unforeseen challenges is the main focal point within the test set-up. It is expected that with 40 toilets, the severity of challenges faced by the system will be manageable within its limits, in order for the system to remain operational at all times.

6.3 Viability

The long-term viability of the SaniSecure System depends on its financial sustainability and organizational framework. Key aspects include production and operational costs, educational efforts, and scaling strategies.

Financial dependency on grants and external funding presents a viability challenge during the project's implementation stage. While initial implementation requires significant financial input, the operational system's revenue model is designed to become self-sustainable.

Self Sustainability

This sustainable business model is defining for the financial viability of the SaniSecure System. The production of biogas at scale is what funds the largest part of the system's operational costs. This ensures that long-term operational costs, such as toilet maintenance and sludge collection, can be covered without continuous external aid. Public facilities are also emptied by the Service Group, partially funding the system's cost, while collecting higher quantities of sludge to produce biogas at scale.

The cost of producing, transporting, and installing a locally made SaniSecure Toilet for the scale of the Imvepi project is approximately €350 per unit (Appendix J). However, the implementation of injection moulding techniques could reduce this cost to €300 per unit or less, improving affordability and scalability. Coverage of costs is not dependant on user payments, but instead is financed by biogas sales and public latrine emptying (Chapter 4.5), the system does not have to rely on the (instable) financial state of settlement households. Instead, each refugee household is responsible for digging its own pit before installation (Chapter 3.5), which reduces labour costs and fosters community involvement and product ownership.

Educational initiatives are another significant financial factor. Training the Service Group and community members on proper sanitation practices incurs costs, but sanitary and safe working conditions are key requirements of Semilla, emphasized throughout the project. Educational efforts are expected to yield long-term public health benefits. By equipping local technicians with the necessary skills, repair and maintenance costs can also be reduced over time.

From an economic perspective, the SaniSecure System at full scale (70 toilets, 2 tricycles, and 1 Pupu Pump) requires an estimated capital expenditure of €55,000, excluding research and development (Appendix J). Operational expenses are predominantly labour-related, with fair wages set at €1,800 per year per employee, which is 4.5 times the Ugandan minimum wage, and currently unheard of in the settlement. This could consequently be a strong financial incentive for the inhabitants to want to sustain the proposed system.

Scalability & Business Model

The scalability of the SaniSecure System depends on regional adaptations. In rural areas, where living conditions and cultural practices are similar across different settlements, minimal modifications to the business model are expected. However, urban settings pose additional challenges due to limited space and different economic structures. It is expected that adjustments such as compact toilet designs, alternative transport methods, and localized sludge collection strategies are required for urban areas.

Despite these challenges, the business model's long-term outlook is promising. The biodigester system in Imvepi is expected to achieve profitability within three years (Semilla Sanitation, personal communication, 2024), demonstrating its potential for replication.

Once the business model becomes self sustaining, the system is ready to be scaled across multiple context. To accelerate the scaling process, future expansion is envisioned through additional funding sources, government partnerships, and humanitarian aid programs, ensuring that the benefits of the SaniSecure System extend beyond Imvepi to other refugee settlements and underserved communities.

By prioritizing financial sustainability, efficient resource allocation, and strategic scaling, the SaniSecure System aims to provide a long-term, impactful solution to sanitation challenges in low resource settings throughout eastern Africa.

Project Evaluation & Personal Reflection

07.

This chapter reflects on the project's overall development, key learnings, and areas for improvement. It provides an evaluation of the project's objectives, research methodology, and design approach, alongside a personal reflection on the learning experience. By examining the successes, setbacks, and insights gained throughout the process, this chapter highlights the impact of human-centered design in sanitation solutions and the importance of cross-disciplinary collaboration. The final section discusses recommendations for future iterations and broader application of the SaniSecure System.

7.1 Project Evaluation

This chapter evaluates the SaniSecure project based on its initial goals and the final outcomes achieved. The evaluation considers the depth of contextual understanding gained, the simplicity and feasibility of the design, the effectiveness of collaborations, and the overall progress toward implementation. Additionally, it reflects on the impact on the inhabitants and how the goals have translated into tangible results.

Project Goals

The project was set up with several key objectives:

- Immerse in the foreign design context and understand cultural, habitual, and belief-driven factors to create a contextually appropriate solution.
- Identify context-specific pain points related to sanitation and waste management.
- Develop a simple yet effective product that could realistically progress to implementation.
- Design a system that integrates with the existing biodigester infrastructure.
- Approach the project holistically, considering the full ecosystem of the settlement.
- Collaborate closely with local stakeholders for research and development.

Project Outcomes

The fieldwork in Uganda was essential in achieving these objectives. Spending nine weeks in the local environment provided direct insights into cultural habits and practical challenges. The inhabitants were open and willing to engage in discussions, which provided valuable information. However, cultural dynamics meant that responses in interviews were not always reliable, requiring additional verification through observations.

The integration of the design with the biodigester system was a fundamental requirement. The toilet design was developed to ensure compatibility with existing infrastructure, allowing for efficient sludge collection and management. The approach taken focused on ensuring that the product remains simple, effective, and feasible for long-term use within the settlement.

Collaboration was crucial in refining the design and implementation strategy. The expertise of the Gulper Group helped shape the service model, while Design Without Borders contributed insights into the cultural context and design process. Joseph at G-Nex played a critical role in prototyping and manufacturing, ensuring the feasibility of production.

Challenges & Setbacks

Several setbacks were encountered throughout the project:

- Interview Reliability: Respondents often provided answers even if they were unsure, leading to some inconsistencies in collected data.
- Navigating Foreign Hurdles: Dealing with administrative processes such as travel and fund applications slowed down certain aspects of research and development.
- Working with unknown materials and tools: the manufacturing industry in Uganda was unfamiliar to me and welding and grinding was not yet in my skillset, requiring additional learning.

Final Recommendations

To ensure the successful continuation of the project, the following recommendations are made:

- Building and testing the transport tricycles by conducting water runs through the settlement to evaluate their capacity and functionality.
- Test runs with water to determine if the tricycles can fully fill the containers and assess the efficiency of transport logistics.
- Optimizing the service through ride-alongs with the Transport Group to identify areas for improvement, which could influence both the toilet design and service model.
- Identifying an alternative pump that is safer than the gulpers and more cost-effective than the Pupu Pump, ensuring system redundancy in case of failure.
- Conducting research on urban areas such as the slums of Kampala to explore the adaptability of the system to different environments.
- Finding an additional sludge disposal site and expanding the Service Group to create more financial input into the system by emptying public latrines, ensuring long-term sustainability.
- Adding a fill-level indicator in the toilet to signal when it is approaching 1000L capacity, improving the efficiency of sludge collection and service scheduling.

By implementing these recommendations, the SaniSecure project can refine its approach and enhance the overall effectiveness of both the toilet design and service model.

7.2 Personal Reflection

The SaniSecure project has been an incredibly enriching learning experience, both professionally and personally.

Personal Learning Goals & Growth

At the outset, I set several learning objectives for myself:

- Design for a foreign culture with a deep **understanding** of local needs.
- Develop new **prototyping skills**.
- Learn to **collaborate** more, rather than handling everything independently.
- Create a **simple and effective design** instead of an overly complex, multi-purpose solution.
- Improve **academic writing skills** to structure a well-researched and articulated report.

Looking back, I can confidently say that I have made significant progress in each of these areas.

The design process reinforced the importance of truly immersing myself in a cultural context. The final product is not just a technical solution but one that respects and integrates with the community's values, habits, and infrastructure. This understanding would have been impossible to achieve without direct interaction with the community.

Prototyping was another rewarding aspect of the project. Learning welding and grinding was a completely new experience, and I enjoyed the hands-on process of building something physical. Beyond the technical skills, working with local manufacturers and seeing the design come to life in a real-world setting was immensely gratifying.

One of the most significant personal challenges was letting go of the need to manage every aspect of the project myself. By involving experts in various fields—manufacturers, designers, sanitation professionals—the project became much stronger than it would have if I had attempted to control everything on my own. This realization has been a major step in my development as a designer.

Simplicity & Impact

Throughout my studies, I have struggled with over-designing solutions—creating complex, multi-functional products that did many things decently but nothing exceptionally well. With this project, I intentionally pursued simplicity, and I am proud of the outcome. The final design may seem straightforward—a frame and a container—but beneath this simplicity lies the complexity of the problem it addresses. The fact that this 'simple' product reached a stage where it is ready for implementation is something I consider a major achievement.

Reflections on Academic Writing

Writing this thesis was one of the most daunting aspects of the project. I have always been more inclined toward visual and hands-on design work, often contributing in roles such as 3D modeling and user testing. However, with the invaluable help of my girlfriend Maria Sofia, who critically reviewed my work multiple times, I gradually became more comfortable with academic writing. The final report is something I am genuinely proud of, marking a significant milestone in my academic journey.

Final Thoughts

This project has been a transformative experience. It has challenged me in several ways. The foreign context was difficult to design for, but the willingness to help and share culture of Ugandans greatly assisted me to understand. The journey of designing and testing the SaniSecure System in a real-world context has reinforced my belief in the power of human-centered design and collaboration. While the project is nearing completion, I see it as the beginning of my broader exploration of how design can create meaningful impact in low-resource settings.

The biggest lesson I take away from the project is that help is always there if you ask for it. The foreign context was daunting to even begin trying to understand, but by putting myself out there and asking for help where I felt I could not go alone has resulted in a very succesful outcome in my eyes.

I am deeply grateful to everyone who contributed to this project—particularly the people in Uganda who welcomed me into their communities, shared their insights, and helped shape the final design. Special thanks to everyone involved in making the project a reality. It would not have been the same without these collaborations.

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