The Establishment of an Absorbent Hygiene Product Waste Collection System in Two Informal Settlements in South Africa

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Abstract

Absorbent hygiene products (AHPs), including nappies, sanitary pads, and tampons, have become essential personal hygiene products. In South Africa, most AHP waste is landfilled, however in informal settlements, where waste collection is insufficient, they are frequently dumped within the open environment. The purpose of this study is assess the feasibility of an AHP waste collection system within two informal settlements, Johanna Road and Blackburn Village, in the South African city of Durban. Utilizing a mix methodology case study design incorporating focus groups interviews, household estimations, and an iterative and participatory design process, the study designed, implemented, and tested a pilot AHP waste collection system within the targeted communities. The pilot collections results in a high purity of AHP waste, but with collection volumes which fell short of expectations, suggesting possible overestimations in household numbers or the AHP waste fraction. Moreover, the results indicated that the focus should be shifted from the complexity of bin design for AHP waste segregation to integration into the community. Moreover, it suggests that the aesthetic appeal of bins, as well as community feedback, are crucial factors in the acceptance and success of the project. Skill-appropriate instructions for the staff and a well-decomposed work breakdown structure emerged as key factors for the manufacturing process and staff motivation. Future research should focus on bin distribution's impact on increasing AHP waste collection and the potential for digitalizing data collection to modernize administration and enhance waste management efficiency in informal settlements.

1 Introduction

At the turn of the millennium in 2000, the demographic landscape of South Africa was markedly different, with 43% of the population residing in rural areas. By contrast, in 2016, this percentage had declined to 35%, signaling a significant shift in habitation patterns. Concurrently, the proportion of people living in urban areas rose from 57% in 2000 to 65% in 2016. This period also witnessed an overall population increase in South Africa of 25% (Alexander, 2019). In addition to economic growth, rapid urbanization, and improved living standards, this demographic transition also led to increased waste generation. (Guerrero et al., 2013). However, the effective management of this waste is hindered by limited financial resources and weak institutional and policy frameworks. (Dlamini et al., 2019).

The challenges of solid waste management in South Africa are complex and multifarious. The significant challenge in urban areas remains the efficient collection, processing, transportation, storage, and final disposal of waste. With the expected continuation of urbanization in African nations, there is growing concern regarding whether there will be sufficient infrastructure and suitable land-use strategies to accommodate the escalating demands of urban expansion. (Bello et al., 2016). Waste is not homogenous; it consists of different products, which can have several implications if not correctly disposed of. One that gained attention in several studies (Magadza, 2016; Płotka-Wasylka et al., 2022; Velasco Perez et al., 2021) is absorbent hygiene products.

1.1 Absorbent Hygiene Products

Absorbent hygiene products (AHPs), including nappies, sanitary pads, and tampons, have become essential for ensuring accessible and convenient personal hygiene in daily life (Płotka-Wasylka et al., 2022). AHPs are crafted to efficiently absorb human bodily fluids, serving a crucial role across different stages of life. Typically, these products are structured with four distinct layers: the top sheet, designed for rapid fluid permeation; the acquisition and distribution layer, which effectively spreads the fluid; the absorbent core, responsible for holding the moisture; and the back sheet, ensuring the fluid remains contained. To achieve the functionality of AHP products, a variety of materials are employed, including nonwoven plastics for waterproofing, wood fibers for water absorption, super-absorbent polymers for moisture retention, and plastic tabs to ensure the AHP remains securely positioned.

Managing the disposal of AHP becomes challenging due to feces and other body fluids, especially in the absence of adequate waste management services (Velasco Perez et al., 2021). Feces and other body fluids also hinder the recycling process despite AHPs being rich in cellulose pulp and thermoplastics. However, mechanical recycling of these products faces several challenges: their varied plastic composition, including organic waste, local opposition to recycling facilities due to odor emissions, and the necessity for separate waste collection systems. Despite these hurdles, recycling solutions have been investigated and presented to promote sustainability (Arena et al., 2016). On the other hand, Cabrera et al. calculated that over 25 billion single-use nappies are disposed of via landfilling only in Europe (Cabrera & Garcia, 2019). Landfills of AHP significantly contribute to global warming potential due to methane generation (Velasco Perez et al., 2021).

1.2 Solid Waste Management in South Africa

Most AHP products are disposed of within municipal solid waste (MSW). The amount of waste generated and its composition depends on each country's social, cultural, and economic conditions. In South Africa, municipal waste is traditionally disposed of by landfilling or incineration (Arena et al., 2016). Technology like waste to energy are rare: only one powerplant exists, located in Athlone, Western Cape, processing between 500 and 600 tons of general waste daily (Kudzaishe, 2021)

Managing solid waste effectively is a significant issue for authorities in developing nations, owing to the escalating volumes of waste produced on one hand and limited financial resources on the other. This increase in waste volume is attributed to growing populations, expanding economies, rapid urbanization, and improved living standards in communities. The amount of waste generated is also linked to household size, educational attainment, and monthly household income. In African countries, limited by financial resources and inadequate institutional and policy frameworks, the efficacy of solid waste management is further complicated (Guerrero et al., 2013). A significant issue in urban areas remains the gathering, processing, transporting, storing, and final disposal of waste. As urbanization in African countries is projected to persist, there is growing concern over whether there will be sufficient infrastructure and suitable land use to meet the needs of expanding urban populations (Bello et al., 2016).

In South Africa, the responsibility for delivering solid waste management (SWM) services rests with the local municipalities. These are teetering on the edge of functional failure (Kalina et al., 2020). For example, Kalina et al. (2020) wrote about the breakdown of municipal services in Makhanda, South Africa. Without municipal waste collection, wealthy residents have adapted by managing their waste independently with their financial resources, while those in less affluent areas struggle significantly. This has led to unsafe disposal practices and environmental harm. The case leads to the question of what happens if the government fails to provide essential services and who has to bear the consequences (Kalina, 2021; Kalina et al., 2023).

Urban areas often suffer from inadequate waste collection and processing infrastructure, a situation that is exacerbated by rapid urban expansion. Informal settlements are particularly affected. (Sartorius & Sartorius, 2016). Informal settlements are areas where housing has developed without official approval, often characterized by inadequate infrastructure and poor access to essential services (Huchzermeyer et al., 2014). Recent data suggests that South Africa has around 2.2 million informal residences, making up 13% of the country's households (STAT, 2018). The actual number might be considerably higher due to the fluid nature of land ownership and the frequent movement of residents in these areas. Factors like urban migration, the pursuit of social and economic opportunities, and poverty are key drivers behind the formation of informal settlements, as inhabitants often find themselves unable to afford formal housing options. These settlements are marked by disparities in access to essential services such as energy, water, sanitation, and waste management (SERI, 2018).

For instance, Schenk et al. (2020) conducted a study in 8 informal settlements: None of them received waste management services provided by their municipalities, leaving the residents among those South Africans who must manage their waste independently. A key reason cited by the municipalities for the absence of services is the communities' inability to afford them. Given the absence of service in the municipality, the primary methods for managing AHP waste are dumpsites, burning, and landfills in informal settlements (Schenck et al., 2023).

1.3 Waste Management of Absorbent Hygiene Products in South Africa

The absence of municipal waste collection often results in inadequate AHP waste storage. This can lead to the reproduction of pathogens, including Salmonella, cholera, and protozoan cysts. Consequently, exposure to fecal matter and other bodily fluids from these wastes can cause significant health risks, particularly for those who handle them during collection (Velasco Perez et al., 2021). AHP products frequently end up in water bodies like rivers, either swept in by rainwater or directly disposed of there (Schenck et al., 2023). The absorbent core contaminated with blood and feces pollutes the water, creating environments that facilitate the growth of germs and pathogenic microbes. Sanitary items saturated with blood can harbor viruses like hepatitis and HIV, which have been found to survive in soil for up to six months (Kaur et al., 2018). This situation poses a heightened risk, particularly in informal settlements where nearby rivers or streams are often used as water sources (Sepadi, 2022).

Several studies have been conducted in informal settlements in South Africa concerning waste management and AHP waste management. A literature review by Niyobuhungiro and Schenck highlighted the complexity of waste management and the various factors contributing to indiscriminate dumping. These include inefficient governance, lack of public awareness, education, attitudes, and social disorganization within communities (Niyobuhungiro & Schenck, 2022). Kalina et al. (2022) highlight that many strategies fail to address the current realities, instead, the approaches aim to alter the initial conditions (Kalina et al., 2022). Additionally, Roxburgh et al. (2020) showed that for infrastructure to be truly effective, it is critical to incorporate socio-cultural norms, which may not be immediately clear to all designers. Through a qualitative socio-cultural examination, the study showed women's perspectives on the symbolism and stigma of menstrual blood in Blantyre, Malawi. The study highlights the need for inclusivity and awareness in design processes for feminine hygiene products (Roxburgh et al., 2020).

Finally, Kaur et al. investigated the practices and challenges for the management and waste disposal of menstrual hygiene products in South Africa in the absence of an AHP waste collection system. The study showed the lack of awareness of the environmental and health impacts of discarding menstrual products in open areas or flushing them down toilets. It recommends raising awareness and providing infrastructure such as toilets with dustbins that have secure lids. This measurement can help manage the waste from feminine hygiene products more effectively (Kaur et al., 2018).

The question emerges: How can a system for collecting AHP waste be effectively established to operate within these challenging conditions?

1.4 Previously on the Project

Kimberly Clark funded two AHP waste collection projects as a leading global company that manufactures and markets personal care, consumer tissue, and nappies, including well-known brands such as Huggies and Kleenex. Kimberly Clark is motivated to take Extended Producer Responsibility (EPR). In this concept, manufacturers take responsibility for the environmental effects of their products across the entire product life cycle. In this case, the company is interested in developing a way to dispose of AHP waste safely in low-income and informal communities.

On one hand, a waste collection system for AHP waste was started in Samora Machel, a township in Cape Town, and moved to Langa, Cape Town. Schenck et al. (2023) examined the existing practices in using and disposing of single-use nappies in the township. The insights gained were intended to guide the development and execution of a pilot diaper collection model. It involved 408 questionnaires, community observations, and two focus groups. The study found an increasing popularity of disposable nappies due to convenience and perceived affordability. However, limited infrastructure and services in the area, particularly for backyard- and shack dwellers, make reusable options less feasible. Nappies, often bought from major retailers and paid for by fathers or government grants, are commonly disposed of in bins and then dumped in open spaces, pressuring the waste management system (Schenck et al., 2023). The study revealed designated community dumping spots, viewed as waste management and job creation opportunities. Despite clean-up efforts, these areas remain dumping sites. Community issues include a lack of respect, social cohesion, corruption, and crime, which also affect service delivery. The complexity of Samora Machel's socio-economic, environmental, and political system highlights the challenges in managing disposable nappies. Single solutions are insufficient; a community-involved approach is needed to meet sustainability, equality, and social justice goals. The study underscores the necessity of an engaged, collaborative change process, considering nappies' durability, community dynamics, and service delivery. Embracing complexity, systemic thinking, and transdisciplinary approaches is crucial. (Schenck et al., 2023)

Since such an approach extends the limits of a master's thesis, two studies have previously been undertaken to build the foundation of this work. They were carried out in the same two informal settlements, Johanna Road and Blackburn Village, and their findings support the implementation of an AHP waste collection system.

One study executed by Slekiene et al. (2023) focused on exploring the psychosocial factors and underlying mental health issues associated with the disposal and collection of AHPs among mothers and caregivers. The findings confirmed a connection between poor mental health and unsanitary disposal of AHPs. According to the study, addressing these mental health challenges is crucial for implementing effective and sustainable waste management services in these communities. The anticipated outcome of such interventions includes a cleaner environment and improved health and mental well-being among community members. This can be done by implementing evidence-based behavior change interventions (Slekiene et al., 2023). These interventions were organized and carried out in parallel with the implementation of this AHP waste collection system.

On the other hand, the study by Stutz served as a preliminary step in implementing an AHP waste collection system. The study conducted a solid household waste (SHW) characterization in the two informal settlements in South Africa, sampling 151 households in Johanna Road and 82 in Blackburn Village. The average AHP waste generation rates were 0.52 kg / household / day in Johanna Road and 0.37 kg / household / day in Blackburn. Additionally, the study identified illegal dumpsites in the communities, categorized by size and type of waste (Stutz, 2023).

1.5 Justification and Research Questions

The overall research question of this project is:

How can an AHP waste collection system be practically implemented in an informal settlement?

To answer this question, the following sub-research objectives were identified:

1.5.1 AHP Waste Generation

This section specifies the problem of AHP waste generation in the two informal settlements. Moreover, it gives insights into the caregivers' usage and understanding of the current nappy disposal and usage practices.

- How much AHP waste is generated in liters / week in each settlement?
- How do caregivers use and understand AHPs? Concerning:
    - Nappy consumption
    - Awareness of the health consequences
    - Attitude towards a separation process
- What are current practices in nappy disposal and usage?
- What are the perceived advantages of separating AHP waste for the caregivers?

1.5.2 Bin Design

The following section focuses on the bin design itself. Therefore, the following research questions were answered:

- What characteristics are essential to users of the bin?
- How can the usage of the bin be facilitated from the users' point of view?
- How would the users prevent vandalism and theft?
- What materials and mechanisms can be used to achieve a high percentage of recycled materials?
- How can the community's acceptability be ensured?

1.5.3 AHP Waste Logistics

This part answers the question of how the collection is organized.

- What are potential hotspots for AHP waste generation?
- How can the AHP waste be canalized?
- How high is the purity and the total of the collected AHP waste?
- What is the total volume capacity for a comprehensive AHP waste collection?
- What are the running costs of the collection system?

2 Methods

To answer the identified research questions, I have utilized a mixed-methods case study design, incorporating focus group interviews, household estimations, and an iterative and participatory design process. First, I present the two different locations, followed by the methods for each research objective.

2.1 Site Selection

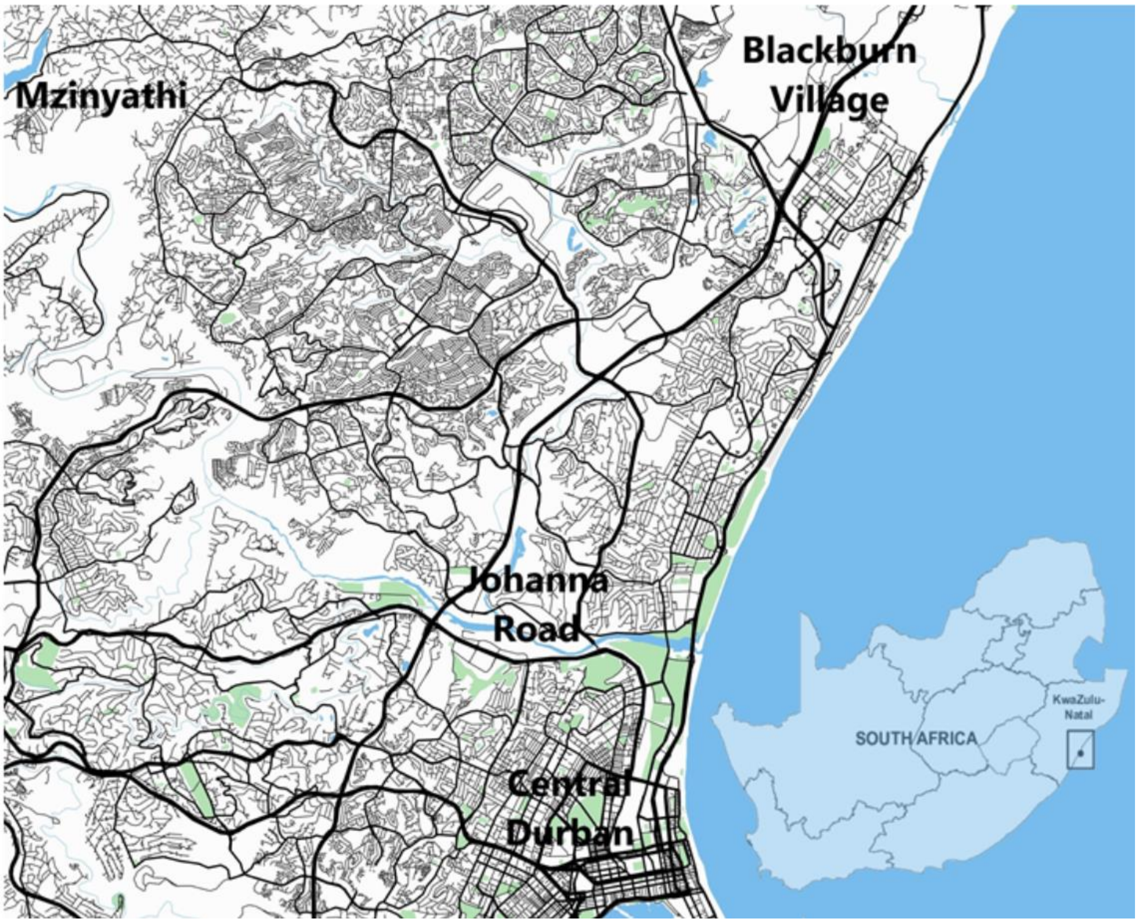

Figure 1: Map of Durban and periphery; Johanna Road and Blackburn depicted in relation to Central Durban (Source: Mappin WMS)

The study occurred in two informal settlements, Johanna Road and Blackburn Village, as indicated in Figure 1. Despite Johanna Road and Blackburn Village having been illegally built on municipal land, they have become established communities. The two locations have already been the focus of the Global Health Engineering (GHE) Chair (Kalina et al., 2022; Slekiene et al., 2023; Stutz, 2023).

For the project, Kimberly-Clark, the project's funder, engaged with the ETH GHE department and Green Corridors. The GHE department contributes academic insight, whereas Green Corridors offers local know-how, connections, and support by providing essential infrastructure and labor. Green Corridors is dedicated to empowering the local low-income community through job creation, focusing on self-employment and skill enhancement, particularly food security, clean water, and sanitation. Additionally, Green Corridors provides the facilities and equipment for the manufacturing site at the Kwamashu Beneficiation Centre (KMBC).

The two settlements were selected for the pilot due to the established connections between Green corridors and the communities.

2.1.1 Johanna Road

Johanna Road is situated in the northern part of Durban, as indicated in Figure 1. It is a densely populated community on a hillside above Sea Cow Lake. The settlement, named after the road it borders, is characterized by precarious housing conditions as residents do not own the land on which their dwellings are built. Despite its informal status, the community has access to some municipal services, including two communal ablution blocks, each with three working toilets, free black refuse bags, and regular waste collection once a week. However, solid waste management remains challenging, as illegal disposal sites are common within the settlement, and collection is centralized and unreliable (Kalina. Over time, residents have built unhygienic and unsafe pit latrines. Johanna Road can be accessed via two roads; one along the Sea Cow Lake may be flooded if heavy rain occurs.

Figure 2: Map of Johanna Road (OpenStreetMap (2024) Johanna Road. Available at https://www.openstreetmap.org/ (Accessed: 16. January *2024*))

2.1.2 Blackburn Village

The informal settlement Blackburn Village is located on Sugar Cane Road near Cornubia Mall and the N2 Freeway. It shares its borders with the Ohlanga River and is surrounded by sugar cane fields, as shown in Figure 3. To the east of the N2 Freeway lies Umhlanga Ridge, an area characterized by high-income residential properties and expansive commercial developments. On the one hand, residents have access there to low-skilled retail and security job opportunities within one to two kilometers of walking distance. On the other hand, the village is surrounded by sugarcane fields, owned and actively farmed by Tongaat Hulett, which is still one crucial employer for the residents (Kemper & McManus, 2019). The village is accessible by a gravel

Figure 3: Maps of Blackburn Village (OpenStreetMap (2024) Blackburn Village. Available at https://www.openstreetmap.org/ (Accessed: 16. January *2024*))

road under dry conditions without requiring a special vehicle. However, the road becomes challenging to use during and after heavy rain. The community has limited access to some infrastructure: Five sanitary blocks are present in the village. However, they were not properly maintained, leading to the fact that there was only one ablution block working during the project. Furthermore, the inhabitants have access to water taps and electricity. Due to the road conditions, municipal services are limited. There is a garbage collection service, but it does not take place regularly. This lack of services has led to numerous illegal disposal sites within the settlement.

2.2 AHP Waste Generation

2.2.1 AHP Waste Volume Flow Estimation

In order to answer the question of the generated AHP waste per week, a household count was carried out. Previous studies (Kalina et al., 2022; Stutz, 2023) estimated the number of Johanna Road at 700 households, which seemed after a personal visit as a overestimation. On the other hand, Blackburn is a relatively large informal settlement home of approximately 3,500 people, according to the Cornubia Social Impact Assessment conducted in 2015 (Kemper & McManus, 2019). A scientific approach for household estimation was carried out to estimate the weekly volume of AHP flow more accurately.

First, the Satellite Imagery Analysis (SIA) method was used; therefore, the contours of building profiles are counted on a satellite picture (OpenStreetMap, n.d.). The contours of shops and other businesses were neglected for the count. The local contractors working on this project and living in the informal settlement ensured that one household per shack could be suggested. So, the number of profiles represents the number of households in the area.

Second, a Household Density Extrapolation (HDE) method was carried out. Therefore, the household density ($\rho_{households}$) for a particular sample area (A_{sample}) was measured. Therefore, a sample area was chosen (A_{sample}), which includes typical housing conditions of the inhabitants. For Johanna Road, a sample area of 4316 m^2 was used, and for Blackburn Village, a sample area of 10295 m^2. After this, the local contractors examined and counted the households in the sample area ($n_{households\ sample}$).

$$\frac{n_{households\ sample}}{A_{sample}} = \rho_{households} \tag{2.1}$$

Afterward, this density was scaled up to the total area of the settlement ($A_{settlement}$) to receive the number of households ($n_{households}$) present in the settlement. The size of the areas was calculated with an online tool (*Map Area Calculator*, 2023).

$$\rho_{households} * A_{settlement} = n_{households} \tag{2.2}$$

The results from the SIA and the HDE are compared and multiplied with the generated mass of AHP waste per household per week and the density of AHP waste (Stutz, 2023) to receive a Volume of AHP waste flow per week (VAHP total) for the whole settlement. The density of the AHP waste was suggested to be 500 kg/m^3 (Stutz, 2023).

$$n_{households} * \frac{m_{AHP}}{\rho_{AHP}} = V_{AHP\ total}$$

(2.3)

Based on this result, the number of bins with the corresponding volume can be calculated.

2.2.2 Caregiver Characteristics and Current Practices of AHP Waste Disposal

To answer the question about the characteristics of the caregivers and current practices, semi-structured interviews with focus groups interviews were carried out. The results gave insights into the attitude towards the project, current disposal and usage practices. Furthermore, the results built the basis for AHP waste logistics. Our local collectors executed the interviews with a questionnaire discussed with three focus groups, each with three caregivers. Caregivers are the main people responsible for a child; in this environment, this role is often assumed by the mother. The semi-structured interview topics are discussed in the following part:

- The number of nappies used per caregiver and baby

This question seeks to understand the average consumption rate of nappies per baby, as reported by caregivers. It helps to estimate the volume of the user collecting bag at home.

- Awareness of the consequences of improper disposal of nappies:

This question assesses the community's knowledge of the environmental and health risks of incorrect nappy disposal. It explores whether caregivers are informed about the potential hazards discussed in chapter 1.3. The responses can help identify gaps in awareness that need to be addressed through educational initiatives alongside the implementation of the collection system.

- Attitude towards a separation process

The aim of this question is to gain an insight into the attitude of the users towards a dedicated AHP waste collection system and how it should be organized within the community. This includes willingness to walk to the next bin, preferences on bin locations, and collection methods. Insights from this question will also support the AHP Waste Logistics section 2.4.

- Current practices usage and disposal of nappies

Here, the focus is on exploring current practices regarding how nappies are used and disposed of within the community. On one hand, it shows who is mainly responsible for changing nappies. On the other hand it uncovers any methods of disposal, such as using municipal bins, informal dumping, or other practices. The results here will identify if dumping is on purpose and if the people are motivated to bring the collected bag of nappies to the bin.

- Advantages for caregivers in the separation of nappies and other waste:

This question explores the caregivers' motivation to separate nappy waste from other household waste. It uncovers potential incentives for caregivers to participate in the separation and collection program. Furthermore, it explores the caregivers' attitudes towards the project and includes them in the process.

Overall, the semi-structured interviews with the focus groups also addressed different aspects of the bin design (see chapter 2.3) and the organization of the AHP collection system (see Chapter 2.4). The insights gained helped develop a system that is effective in managing nappy waste and aligned with the community's preferences and behaviors.

2.3 Bin Design

An iterative and participatory design process was used to examine the important characteristics of the bin for the users. Therefore, the development and evaluation of a new AHP bin design involved three key stages: The first stage was to establish the design criteria with the community. This foundation guided the decision of a prototype, which, upon completion, underwent testing in a real-world environment. This trial phase aimed to identify the design's efficacy and areas for improvement by analyzing its practical performance and user feedback in the setting of an informal settlement. Given the project's short duration, a fast-paced iteration process was essential for learning and development. Therefore, it was decided to implement the first generation of prefabricated modified bins.

2.3.1 Design Criteria

In order to answer the question of the bin's essential characteristics for the users, this question was discussed in the semi-structured interviews with the caregivers and the collectors. The answers were structured and combined with the literature review and the inspection of the facilities at KMBC, where the bin was produced. This leads to the product design considerations as indicated in Figure 4.

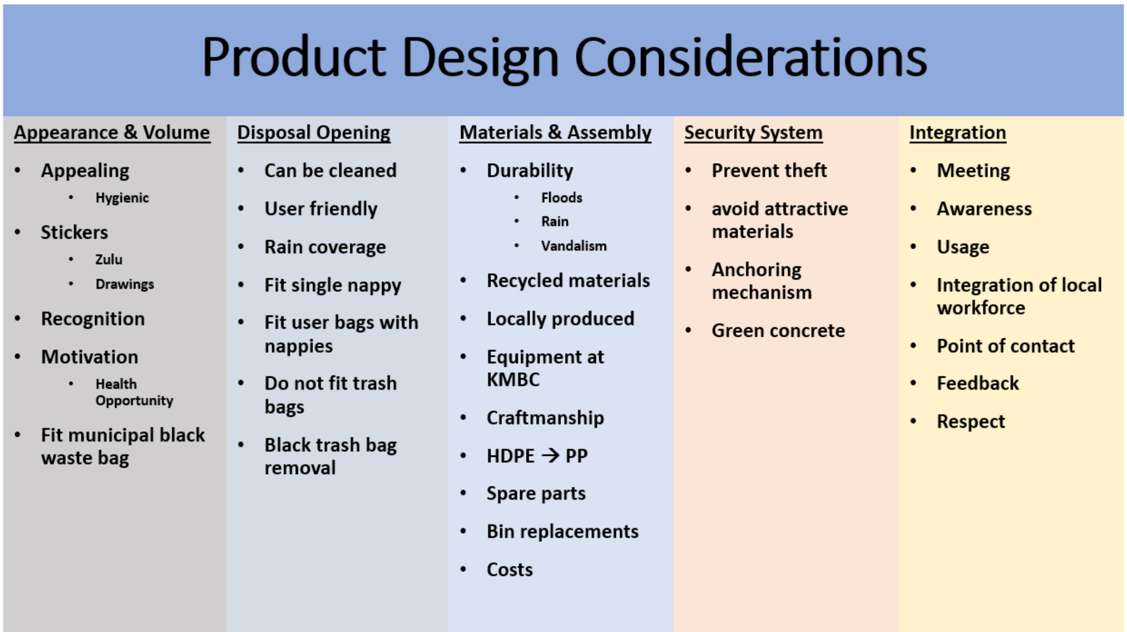

Figure 4: Product design considerations based on the design criteria. The section's color corresponds to the work breakdown structure in Figure 15

The approach that was focused on was to install different bin designs in the informal settlement and see how the infrastructure was used and treated, including feedback from the community. Based on this insight, the next generation of bins could be adjusted and modified if the previous bins have failed. Essentially, the AHP collection system aims for an extensive AHP waste collection with a high AHP purity.

2.3.2 Appearance & Volume

The focus groups pointed out that an aesthetic design combined with an appropriate volume are crucial. Due to the appearance and the attention it gains, the infrastructure tends to be treated with respect and appreciation within the community. This also facilitates the usage and prevents vandalism. So, it was chosen to gain attention with a colorful design. Furthermore, the bin was labeled with the corresponding sticker to make sure what its purpose was. The stickers are written in Zulu, the main language of the inhabitants of the settlements, to make users aware of the facility. Additionally, the stickers had drawings to ensure access for people who were not able to read. This helped to gain recognition and respect in usage. Concerning volume, the bin must fit a municipal plastic bag with a depth of 800 mm and a side length of 650 mm.

2.3.3 Disposal Opening

In order to answer how to facilitate a high AHP waste purity, the disposal opening was discussed. Therefore, it must appear clean and could cleaned. The disposal mechanism is user-friendly and protects the content of the bin from the rain. The first idea was that the opening fits a single nappy and a bag of nappies but did not allow other trash bags to ensure a high AHP waste purity. Moreover, if the bins were collected, the black municipal bag could be removed easily.

2.3.4 Security System

To tackle the research question of preventing vandalism and theft, a security system was developed: Based on the community's feedback, the bin should be as secure as possible. Therefore, an iterative security system optimization approach was used. Therefore, the most secure system was implemented and tested in the environment. The security level was adjusted based on the theft results and the community's opinion.

2.3.5 Materials Selection & Assembly

To answer the research question about the usage of recycled materials, the aim for the durability of the bins was also raised. On one hand, the materials must resist the stress from the environment, like floods and heat, and, on the other, from usage or vandalism. The material should be recycled and locally produced in South Africa. Moreover, the materials should not be attractive for theft. Therefore, expensive materials were avoided or hidden. These bins were manufactured at KMBC and were part of phase III of the implementation. For the implementation phases see chapter 2.4.2.

2.3.6 Integration into the Community

In order to gauge the social acceptability of the prototype bin design, two participatory workshops were held with the community members. This involved the community in the design process and raised project awareness. In these meetings, the health problems associated with incorrectly disposed AHP waste were also discussed. Then, the bin was presented, and its purpose was communicated as well. Then, the different aspects of the bin were explained to the group, such as the usage and the security system. Then, an open discussion was organized where the caregivers could ask questions and give feedback on the current bin. Furthermore, the local collectors were introduced to the caregivers, who are in charge of the collection, and the people were made aware that community members are directly involved in the project. The success of a project depends crucially on the inhabitants' attitude towards the bins, in order not to vandalize or steal the bins. Based on the feedback, the bins were adjusted and then implemented. Last but not least, the community could use the bin mechanisms.

2.4 AHP Waste Logistics

The insights from the AHP waste estimation, semi-structured interviews, and extensive discussions with our local collectors enabled us to work out the AHP waste logistics. Overall, a pilot collection system was implemented in Johanna Road. Based on the insight and feedback, the collection system was replicated and scaled up in Blackburn Village. Therefore, we examined whether we could reproduce the results from Johanna Road.

2.4.1 AHP Waste Hotspots

This part answered the research question for potential AHP waste hotspots, considered "low-hanging fruits." Therefore, these locations could be provided with AHP bins and collected without additional effort from the users. Therefore, the location and number were determined through discussions with the collection assistant in both communities. Moreover, that allowed us to gain a deeper insight into the daily life of the community of the informal settlement. These hotspots were provided with bins in phase II of the implementation.

2.4.2 AHP Waste Canalization

To organize an effective AHP waste canalization, the users were asked about their handling preference. These insights were combined with the results of current practices. Based on the results, a successive participatory implementation of the AHP waste system occurred in 3 phases (phase I, phase II, phase III), each with an adjusted bin type to meet more precisely the desires of the users and collectors and additional locations specified by the community meeting and discussion with the collectors. In order to store the black waste bags from the bins until collection occurs, a storage facility needed to be set up. Johanna Road deals with heavy rain that can cause flooding in Johanna Road from the close Sea Cow Lake. Additionally, bushfires are not rare in this area (Khatija, 2016; Philani, 2022). Therefore, the storage facility must protect the bags from wind, water, and fire to withstand the environment. Additionally, the storage facility must be robust so that it does not get demolished.

2.4.3 Purity and collected AHP waste

To measure the mass of the AHP waste, the black municipal waste bags were weighted by the collectors and stored. After this, the data was entered into a table, and photos were taken. These photos were shared with the group to inform them about the progress. This method was chosen due to mobile phones' simplicity and presence. Moreover, every collection day, another black bag's content was inspected. The bag was opened, and the AHP waste was weighed and entered into the table. With this method, we were able to inspect the purity of different bins. Furthermore, the collection supervisor was provided with data packages to ensure connectivity with the group.

2.4.4 Volume Capacity of a Comprehensive AHP Waste Collection

In order to build a comprehensive AHP waste collection system concerning volume, an iterative process was chosen. First, in phase I, 5 bins were installed, based on the dumping spots where AHP waste was found in the previous study (Stutz, 2023). However, based on the collected weight of the bins, additional bins were placed between the locations. Moreover, the communication with the collectors enables us to understand the structure and routine of the caregivers. Phase I represents only a small fraction of the calculated AHP waste generation, calculated in chapter 3.1.1, but with phases II and III, the total capacity increased.

The bins are labeled and monitored for one week and checked by the collectors. Furthermore, the time was measured for the collectors to collect all bins to estimate the labor force requirements. Based on the gathered data, the bin capacity will be adjusted. To optimize the collection workflow, the caregivers were informed about the project and the motivation behind it. The consequences of an improper disposal of AHP for their health and the environment were communicated. Furthermore, the caregivers were already sensitized due to the Disposal Behavior study carried out in the settlements (Slekiene et al., 2023).

2.4.5 Bottom-Up Cost Estimation

A bottom-up cost analysis was carried out to answer the question about the running costs per week of the project. Bottom-up cost estimation involves a granular approach, where costs are analyzed at the individual component or activity level, allowing for a detailed breakdown of expenses. By dissecting the various cost elements, including labor, equipment, maintenance, and administrative overhead, this methodology enabled a more accurate assessment of the actual economic implications of waste collection. Based on this analysis, the funder of the project could decide if the project could continue or identify the highest cost factors. Moreover, a comprehensive understanding of the costs associated with waste collection is essential for optimizing efficiency, ensuring service quality, and ensuring the project can be financed in the long term.

2.5 Ethics

The study research protocol was approved by the Ethics Committee of the ETH Zurich in Switzerland [EK-2022-N-155] and the University of KwaZulu-Natal Research Ethics Committee [REC-040414-040]. The participants were informed of the research objectives and were advised that they had the freedom to refuse participation or withdraw from the study at any time. All study participants provided oral informed consent.

3 Results and Discussion

The following section presents the results, followed directly by the discussion for each sub-research objective. All findings combined allowed a conclusion on the overall research question of how an AHP waste collection system can be practically implemented in an informal settlement.

3.1 AHP Waste Generation

3.1.1 AHP Waste Volume Flow Estimation

The SIA results showed 443 profiles for accommodation for Johanna Road and 1275 profiles for Blackburn village, which correspond to the same number of households, based on the statement of the collection supervisor. On the other hand, the sample size for the Johanna Road for HDE method was 4316 m^2, with 37 households living in this area. The total area of Johanna Road was measured to be 29628 m^2. This led to a total number of 254 households for Johanna Road. Blackburn Village's sample size was 10295 $m^{2,}$ and 114 households were counted. Blackburn, with a total area of 87051 m^2, resulted in 964 households. All the numbers are depicted in Figure 5.

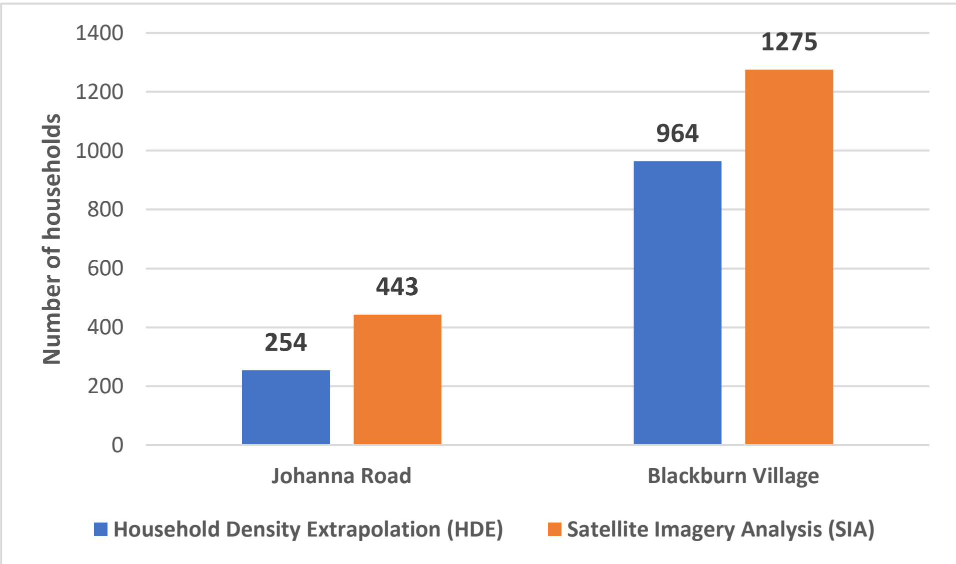

Figure 5:Household estimations with the corresponding approach for Johanna Road and Blackburn Village

The number of households multiplied by the generation of AHP waste per day and per household for Johanna Road with 0.52 kg / day / household (Stutz, 2023) resulted in 931 kg / week for the HDE method and 1624 kg / week for the SIA method. Considering a 500 kg / m^3 density resulted in 1862 liters and 3248 liters AHP waste volume per week for Johanna Road. For Blackburn Village, with an average AHP waste generation of 0.374 kg / day / household (Stutz, 2023), the result showed 5002 liters for the HDE method and 6615 liters for the SIA approach.

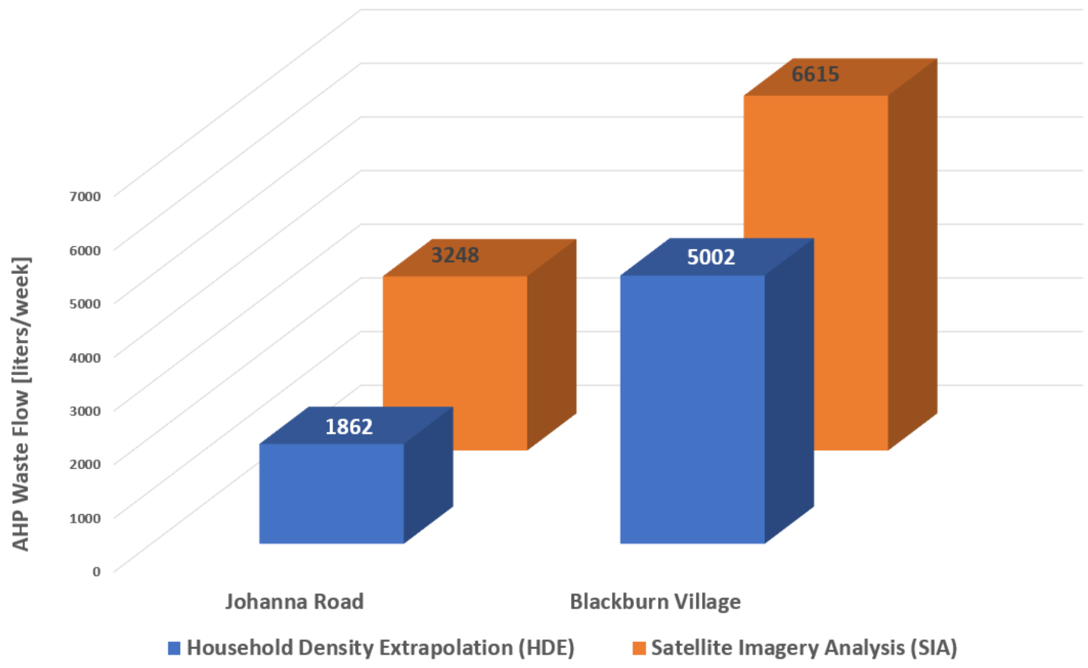

Figure 6: AHP waste volume estimation in Johanna Road and Blackburn Village with the HDE and SIA method

The SIA method showed a 74% higher household count than the HDE method in Johanna Road. This was in comparison to a 32% higher count in Blackburn Village. This might be caused by counting profiles that were not used as houses, but rather for storage or abandoned structures. On the other hand, the sample area of the HDE method in Johanna Road could represent a part of the village with a low density of inhabitants.

The HDE and SIA method results for Johanna Road are significantly lower than the supposed number of 700 in the literature (Kalina et al., 2022; Stutz, 2023) and higher for Blackburn Village (Stutz, 2023). This leads to a lower AHP waste volume flow than suggested for Johanna Road and a higher one for Blackburn Village than the results calculated by Stutz (2023), with 3900 liters / week for Johanna Road and 4700 liters /week for Blackburn Village (Stutz, 2023). Furthermore, the household count for Blackburn Village can fit the estimated 3500 people living in Blackburn (Kemper & McManus, 2019) if an average of 3.63 respectively 2.75 people per household is suggested. The municipality of Ethekwini put forward the average number of members of a household in an informal settlement with 3.93 people (UN-Habitat & Ethekwini Municipality, 2007) therefore the HDE results are more precise than the ones from the SIA.

For further research, the author recommends estimating the total AHP waste flow with 1862 liters per week for Johanna Road and 5002 liters per week for Blackburn Village, according to the HDE approach.

3.1.2 Caregiver Characteristics and Current Practices of AHP Waste Disposal

To answer the sub-research question concerning the caregiver's use and understanding of AHPs, the questions explained in chapter 2.2.2 were discussed in semi-structured focus group meetings with the following results: All nine caregivers used single-use nappies. The consumption was between 2 and 6 nappies per day per child, with an average of 4.11 nappies. Similar values were found by Schenck et al. (2023), with an average diaper consumption in rural areas of 4.47 and 99% single-use nappies (Schenck et al., 2023).

Concerning the awareness of the health implications of improper AHP waste disposal, 6 out of 9 caregivers were aware of the negative consequences. Therefore, it was assumed that 33% of the caregivers could be further educated through community meetings. Overall, the willingness to separate used nappies from general waste was with 100% significantly higher than in Samora Machel, where Schenk et al. showed that only 48% are (Schenck, Chitaka, et al., 2023).

However, most caregivers answered the question about current practices in nappy disposal and usage, stating that the mother is responsible for changing their children's nappies. However, they answered that other female family members, such as daughters or grandmothers, also take this role. Therefore, a broader group of caregivers, not just the mothers, were instructed. Seven caregivers answered that they dispose of their nappies in the local trash bag provided by the municipality, while two others responded that they disposed of them in a hole in the ground.

The discussion about the perceived advantages for the caregiver was very vivid. However, they appreciated the separation due to the smell, the environmental impact, and the additional space in the municipal trash bag. Therefore, they were willing to separate the nappies in an additional bag, which should be provided. Moreover, the caregivers preferred to collect the nappies at home, but they were all willing to walk out of their houses to dispose of them at least once a day. So the associated time effort for the caregiver was examined. The time effort ranged from 1 to 5 minutes of walking with an average of 3.11 min to dispose of their nappies. Since no information on walking speeds in informal settlements is available, results from a study on walking speeds on rough terrains for older people were used (Fossum & Ryeng, 2021). So, an average speed of 1.251 m / s was suggested, leading to an average distance willingness to walk of 234m. Since Johanna Road is built upon a hill with steep terrain, the walking distance was divided by 2 to adjust the distance between the bins, resulting in a 117m radius. This finding was used in the organization of the implementation phase I. The location of the individual bins is shown in Figure 10Figure .

3.2 Bin Design

Since the bin's essential characteristics for the users were already defined and summarized in Figure 4, the bin designs' results section presents the implemented design considerations. The first generation of bins is described, followed by the feedback and adjustments for the next generations.

3.2.1 Appearance & Volume

The first generation of bins had a volume of 45 liters with a yellow lid spring lid and stickers on three walls and the top of the bin. It was appreciated by the community. They liked the design and stickers and thought the bin would be treated with respect. However, if it is more colorful and handmade, the bin would have a higher status and a more appealing appearance. Given this feedback, the team mixed different colors of bottle tops to produce a colorful big sheet, as depicted in Figure 7. The third generations of bins were also assembled by hand at KMBC; therefore, the community's feedback was implemented.

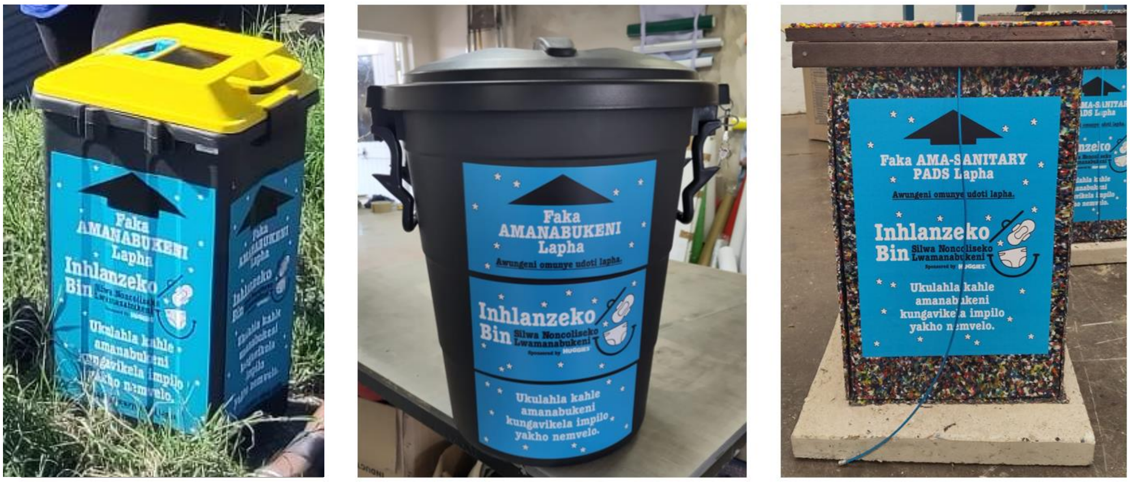

Figure 7: Evolution of bin designs: 45l 1st generation bin (left), 80l bin 2nd generation (middle), and the bin manufactured at KMBC as the 3rd generation bin (right)

Moreover, for the first generation, the volume of the bin was considered too small by the community. Therefore, the 45-liter bin was increased to 80 liters with the second generation of bins. However, the heat press at KMBC only allowed a sheet of size 1300 mm x 650 mm. Therefore, the 3th generation bins were limited to a volume of 70 liters. Concerning volume, the heaviest bag was collected in a creche in Blackburn Village after the Christmas holidays on 03.01.2024. It weighted 20.5 kg, which refers to a volume of 41 liters. Therefore, it is considered that the bins do not need to exceed the size of 50 liters, which exceeds the biggest collected bag by 22%. Furthermore, a higher mass might tear the municipal waste bag.

3.2.2 Disposal Opening

The first generation of bins was equipped with a spring lid that closes automatically. The lid opening is 130 mm x 120 mm. To remove the black waste bag, a locking mechanism enables the collector to open the top of the bin.

The feedback showed that this spring opening, with its limited dimension, hindered the people from putting the user bags full of nappies in it. Moreover, 4 out of 5 of the spring lids were subject to vandalism by the end of February 2024. As a result, rain can now penetrate the inside of the bin. Despite this, the interlock system worked very well. Surprisingly, as discussed in section 3.3.3, the AHP waste collected showed almost 100% purity. Therefore, the user of the bins only disposed of their AHP waste in the bins, which led to the consideration of increasing the size of the disposal opening.

With the second generation of bins, the disposal opening was modified: The opening consisted of a lid loosely connected to the bin by two wire ropes. Due to the backlash of the wire, the lid could now be lifted to dispose of the AHP waste. It was ensured that the lid always fell back onto the garbage can to remain rainproof. The wire on one side could now be removed to remove the black bag, and the lid could be opened completly. First, a lock was used to remove the wires. However, this additional cost was too high, so it was decided to establish a plug connection with the wires. This system especially worked well since the bin was slightly bendable due to its material.

This characteristic was not possible to reproduce with the third bin. Therefore, the disposal opening was replaced by a flap top . This wider disposal opening did not influence the AHP waste purity as the result show in Johanna Road.

From our disposal opening, we can tell that the size does not influence, in our case, the AHP purity. However, it is important to have an opening big enough to facilitate the disposal of AHP waste and the collection of the black bags. Furthermore stability and rain protection must be ensured.

3.2.3 Material Selection & Assembly

The first and second-generation bins were prefabricated and made from high-density polyethylene (HDPE). This sturdy, durable plastic is used for various applications, including outdoor bins, recycling containers, and garbage cans. HDPE is known for its resistance to impacts, chemicals, and moisture (Kanagaraj et al., 2007).

When it came to the production of the bins at KMBC, plastic bottle tops were recycled: Plastic bottle tops are commonly made from Polypropylene (PP). PP is known for its toughness, flexibility, and resistance to fatigue and can withstand various temperatures, which makes it an ideal material for the outdoor bin. The bottle tops are shredded and then put into a frame. These filled frames are then heated up in a heat press. The melting point of PP typically ranges from 130°C to 171°C, depending on the specific type of PP and any additives it may contain. PP is generally considered safe and does not produce toxic gases at temperatures encountered during everyday use or recycling processes. However, when PP is heated to temperatures above its melting point, specifically at temperatures exceeding 300°C to 400°C, it can start to decompose. It may release various compounds, including volatile organic compounds, aldehydes, and other hydrocarbons (Maddah, 2016).

The casted PP sheets were used as the bins' walls, giving the structure additional stability. However, for the frame, another material called lavaplastic was used. Lavaplastic is based on a method of utilizing waste rigid Polyvinylchloride and converting it into a woven lattice for boards, planks, and poles (About Us, 2023.

The assembly of the single sheets and the planks happened at KMBC. Therefore, the bins were manufactured by low-skilled staff with no technical apprenticeship. A work breakdown structure was used to demonstrate the production's different steps, depicted in Figure 8.

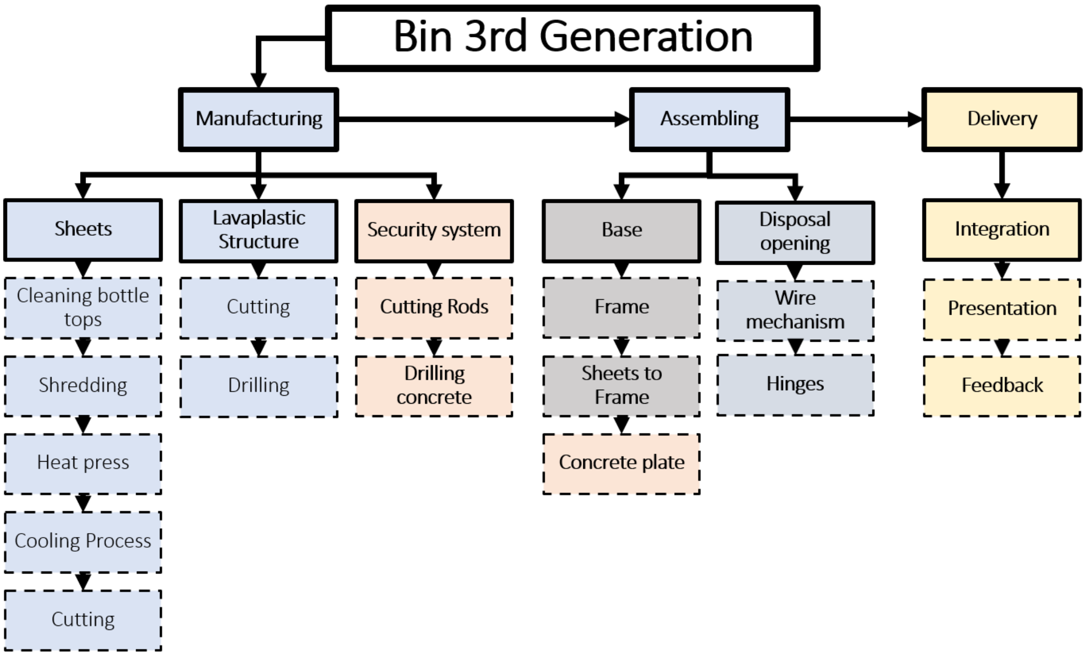

Figure 8:Work-breakdown-structure of manufacturing the bin of the 3rd generation. The colors of the single work packages correspond to the colors of the different design specifications in Figure 4.

It turned out that the PP sheet pressing process required proper training to minimize the staff's risk. Moreover, the central heat flux from the heat presses plates to the sheets caused a non homogenous temperature distribution on the plate. As a result, the edges of the boards showed a coarse granulation at the edges. As a result, the time in the heat press was increased to produce a high-quality sheet with clear edges, ensuring the temperature did not exceed 300°C.

On top of that, it was challenging to maintain the flat nature of the sheets during the cooling process. First, concrete plates were used for additional pressure during the cooling, although it resulted in not having the desired surface structure. Consequently, a hydraulic cold press was fixed where the sheets were placed and could cool off. This resulted in a lower production rate but increased the quality of the boards. Moreover, this additional step required additional craftsmanship skills. Overall, the assembly process was hindered by fluctuations in the staff at KMBC, requiring additional training and organizational effort. However, it has been proven worth using a detailed work breakdown structure and templates for the staff.

First, screws were used with a cordless screwdriver for the assembly, but this process created problems due to the availability of the cordless screwdriver, as well as the skill level of the staff. Consequently, nails and a hammer were used to facilitate the assembly process.

Therefore, a high ratio of recycled elements was achieved with the Lavaplastic elements and the PP sheets. However, the wire, hinges, and nails were not recycled materials, which remain challenging to substitute. Furthermore, no expensive materials were used, which resulted in no stolen parts at the bins.

3.2.4 Security System

The first generation of bins was attached to a concrete base to secure the bin and prevent theft, as shown in. The rough concrete material is produced at KMBC and contains recycled glass, fabrics, and plastic, therefore it is called green concrete. The green concrete is poured in a hole dug at the location. Afterward, four rods with nuts were put into the wet concrete. Then, the concrete dried for approximately one week, depending on the weather conditions. After the concrete had solidified, two Lavaplastic plates, with the bin in between, were assembled to the rods and

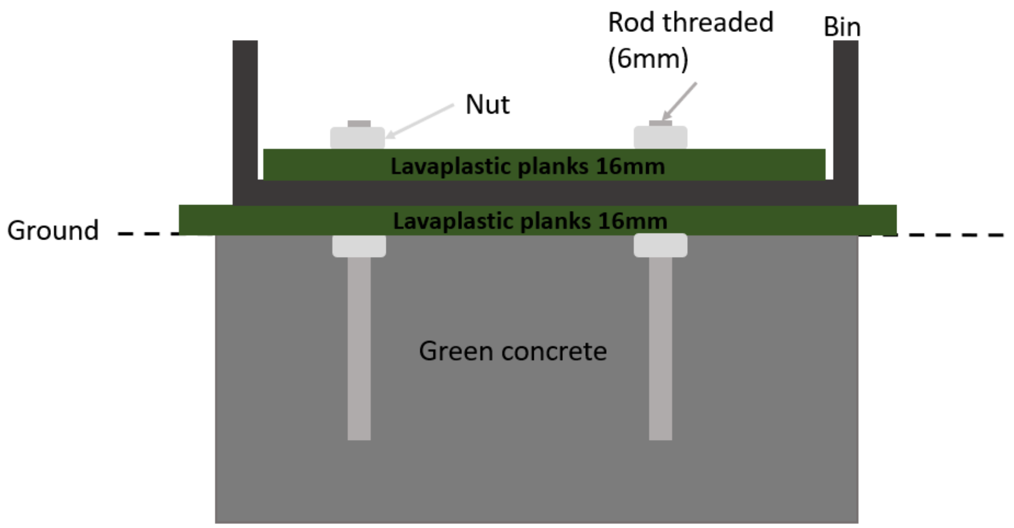

Figure 9: Security system with a concrete foundation

screwed together with an additional nut. Then, the nuts were glued to the rod to add additional security.

However, the concrete dried very slowly due to heavy rain and contained first a too-high ratio of coarse gravel, which led to brittle concrete. Therefore, not all bins of the first generation could be secured with four anchors. Despite this security issue, none of the bins were stolen or demolished. Therefore, the security system was successful. Although the effort for pouring the concrete foundation was enormous, it was considered to attach the bins to a concrete plate manufactured at KMBC, as shown in Figure 7. The weight of the concrete plate is 30 kg, which facilitates the implementation process since the concrete does not need to dry at the settlement. Furthermore, the bins can be moved to another location if they are not used enough.

All three bins of the 3rd generation were still in place at the end of February 2024. Therefore, the security level of the 3rd bin is considered as appropriate. However, one bin that was placed along a road at a turn was hit by a car. This showed that the bin should be placed in a clear location.

3.2.5 Integration into the Community

The community meetings were held to integrate the first and the 3rd generation of bins with all three collectors. The audience seemed familiar with the subject in the first meeting due to the studies already carried out in the settlement (Slekiene et al., 2023). However, they appreciated the effort and now received a product. However, the community did not participate in the discussion as planned; they instead seemed intimidated. The reason can only be suggested; it might be a cultural gap that hindered their participation. It also might be the language since most do not speak English as their mother tongue. Therefore, it was decided to translate the discussion to Zulu and let a female collector from the community lead the feedback discussions. The community expressed the suspicion that the bin could be stolen. Therefore, the concrete foundation was worked out as explained in chapter 2.4.5. The community was still surprised that none of the bins from the first generation were stolen. Concerning the 3rd generation of bins, they appreciate the colorful appearance and the fact that it was produced and assembled locally. Moreover, according to the community meeting, the materials' weight and thickness give the bin a higher quality.

3.3 AHP Waste Logistics

3.3.1 AHP Waste Hotspots

The answers of the semi-structured interviews with the focus groups showed that, indeed, a few AHP hotspots exist in informal settlements. The caregivers pointed out that for female hygiene bins should be provided to the sanitary blocks. Moreover it was determined that three creches in Johanna Road and in Blackburn Village exist. The caregivers bring their children for half or a full day there, where also the baby's nappies are changed. Additionally, the bins can be placed there without security since the creches kept the bins inside and were closed at night. Overall, the sanitary blocks and creches were revealed as hotspots.

3.3.2 AHP Waste Canalization

To answer how the AHP waste flow is canalized, Figure 10 gives an overview. On top of that, caregivers collect the nappies at home in a transparent plastic bag and bring them to the bins. Some caregivers bring their babies to the creches, where a bin is also placed. Last but not least, the toilet facilities are equipped with bins to dispose of feminine hygiene products. The collectors go to all bins three times a week to collect the black bags and bring them to the container, where the weight is measured, the AHP waste purity is examined, and the values are documented. The AHP waste is stored in the container until the municipal waste service collects it and brings it to the landfill.

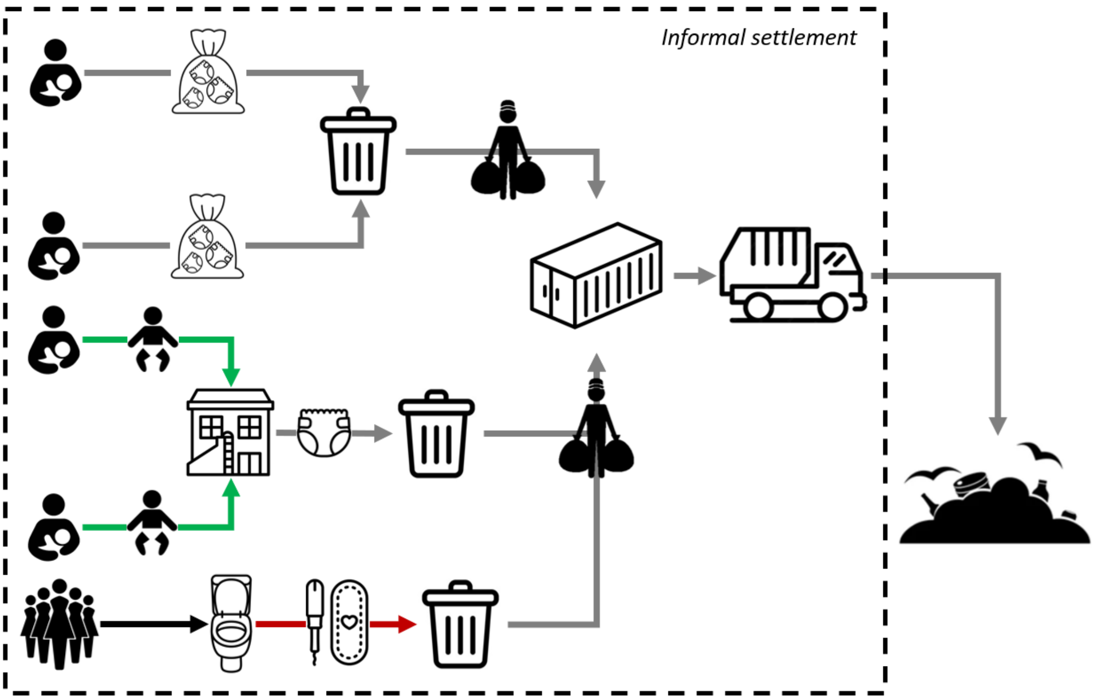

Figure 10: Organization of the AHP waste collection system: Grey arrows indicate direct nappy waste flow, and the green arrow points to the creche. The black arrow points to the sanitary facility, and the red arrow corresponds to a female hygiene product waste flow

As shown in chapter 3.1.2, the caregivers preferred to collect the nappies at home with a provided bag. It showed that transparent plastic bags facilitated the examination of the AHP waste purity at a later stage. The provision of this additional bag is also based on the results by Slekiene et al. that 34.3 % of the caregivers would be motivated to bring the nappies to the collection point if they were provided with plastic bags (Slekiene et al., 2023).

To ensure the bins were not overloaded, a collection frequency of three times a week was chosen. Additionally, the collectors informed us that a strong smell was reported after three days, which led us to the decision to collect the bins on Monday, Wednesday, and Friday.

The implementation of the AHP collection system was carried out first in Johanna Road and consisted of 3 phases. First phase I was implemented in Johanna Road with five first-generation bins, depicted in Figure 711, with a total capacity of 225 liters. Although it represents 18% of the average AHP waste per week in Johanna Road, it is the start of the implementation process. After the first week, all bins were still in place in Johanne Road. Moreover, none of them was damaged. Therefore, it was assumed that tolerance and respect were paid to the project.

The time effort was measured for the collection on Johanna Road: it showed that the walk up and down the hill is the most time-consuming part. Especially considering that the collectors carry two black bin bags and therefore have no hands free to support themselves. In addition, the weather conditions are often unfavorable, and the paths are muddy. The time that was measured to collect five bins of the first generation was 47 minutes with good conditions, meaning dry ground. Since the collectors are paid on a daily base, the number of bins could be increased without higher expenses for collecting.

In phase II, all three of the creches were equipped with the 2th generation of bins. Moreover, to collect used female hygiene products, the two sanitary blocks in Johanna Road were equipped with 25-liter bins with a spring lid, referred to as sanitary bins in Figure 11. Due to the given environment, it was decided to use a 10-foot shipping container as a storage facility due to its water and wind tightness. The containers are indicated with red rectangles. Furthermore, the container offers a storage volume of 15950 liters. Therefore, the storage facility provides enough volume for the municipality's long absence of waste collection. To ensure air circulation, a wind turbine fan was installed on the container's roof in Johanna Road. Phase II was carried out in the 3rd week after the first implementation, and a capacity of 515 liters was installed.

As a last step, Phase III was realized: Therefore, bins manufactured at Green Corridors (3rd generation) were implemented within the settlement. Due to time and labor limitations, only three bins, each with a volume of 60 liters, were installed within the settlement and are indicated with red circles in Figure 11. Currently, the waste collection capacity in Johanna Road is 1725 liters and, therefore, 92.6% of the AHP waste flow calculation of the HDE. The measured time effort for collection and weighing was reported to be 4 hours.

Figure 11: Location of bins in Johanna Road

After the first collection was successful, the locations in Blackburn Village were analyzed and chosen. Therefore, the local contractors were involved in determining suitable spots. The radius for Blackburn Village was calculated at 234m, corresponding to the average willingness to walk. The locations are indicated in Figure 2.

After Phase II was completed in Johanna Road, the infrastructure for Blackburn Village was provided. Based on the feedback of the community, the 2nd generation bin with a capacity of 80 liters was implemented. Due to the higher household numbers and the larger area, the implementation started with seven bins on the main roads and a bin for each of the three creches. Furthermore, one location could not be equipped with a bin because the foundation broke apart. Therefore, it is crossed in Figure 2. After two weeks of collection, bin number two was hit by a car and could not be used anymore. This was a single case, possibly due to its location at a turn. Initially, it was planned to provide bins to the sanitary blocks, but none of them was working. Therefore, the bins were given to the responsible person, and as soon as the sanitary blocks were fixed, the bins were placed there.

Overall the collection volume in Blackburn Village, with collection three times a week, represents with 635 liters, 12.6% of the calculated AHP volume generation calculated with the HDE. Due to the more considerable distances for the collectors, two 10-foot containers were implemented on both sides of the village without any air circulation system.

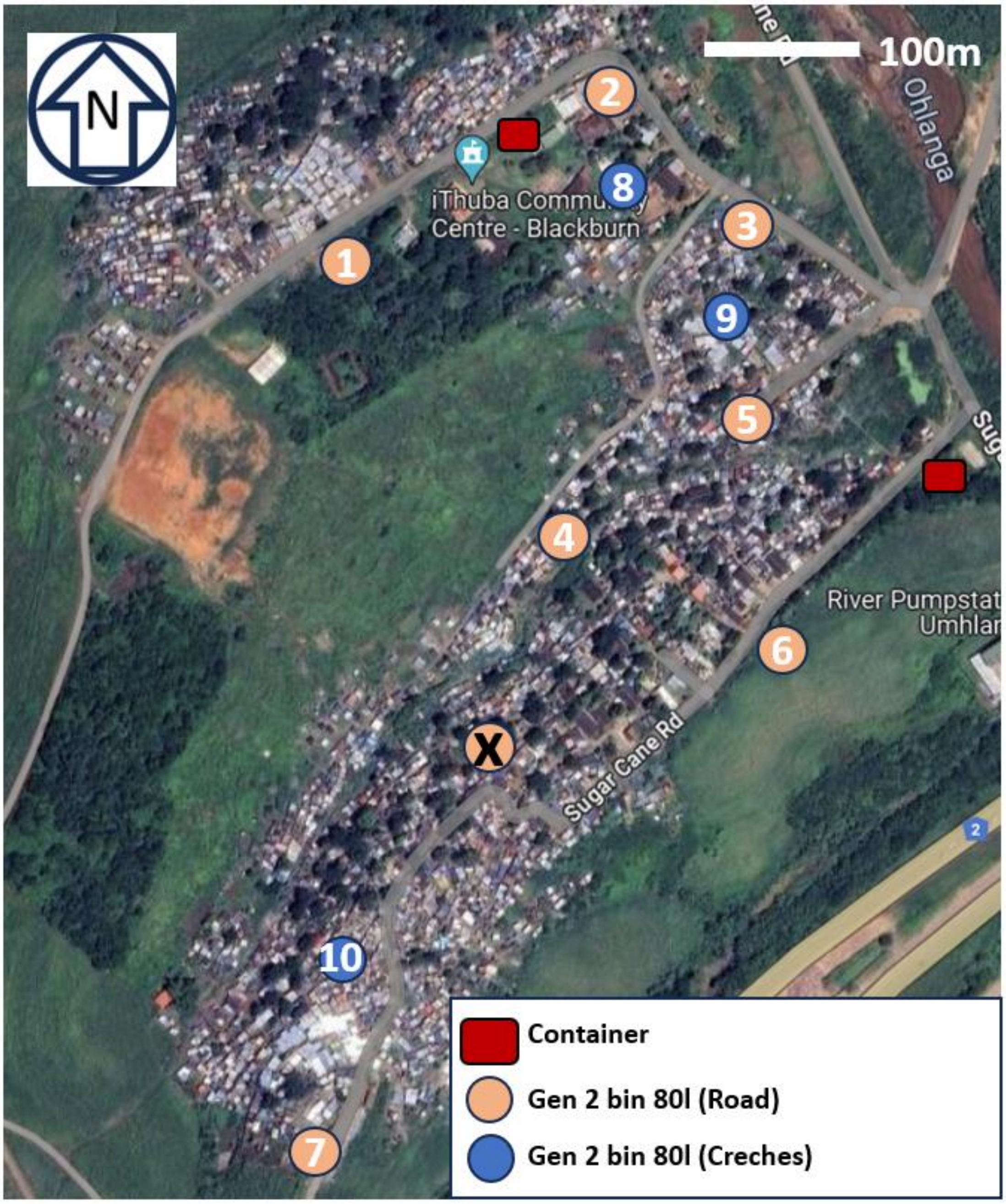

Figure 12: Location of bins in Blackburn Village

3.3.3 Purity and Collected AHP Waste

After the rollout of phase I, the first data was collected for the 5 bins in Johanna Road: Figure 3 shows that not all bins in Johanna Road were used. In fact, on the first collection date, only three bins collected AHP waste. Nevertheless, only in the following collection, the second bin was used as well. Furthermore, all the used bins increased the collected weight. This showed how fast awareness of the facilities was created among the community. In order to draw attention to the fifth bin, the grass was cut around it. Another interesting result was that almost 100% of AHP waste was collected in all the bins in these two collections under the supervision of the author of this study. However the five bins represented 18% of the calculated AHP waste volume, therefore phase II and III were rolled out to increase the capacity.

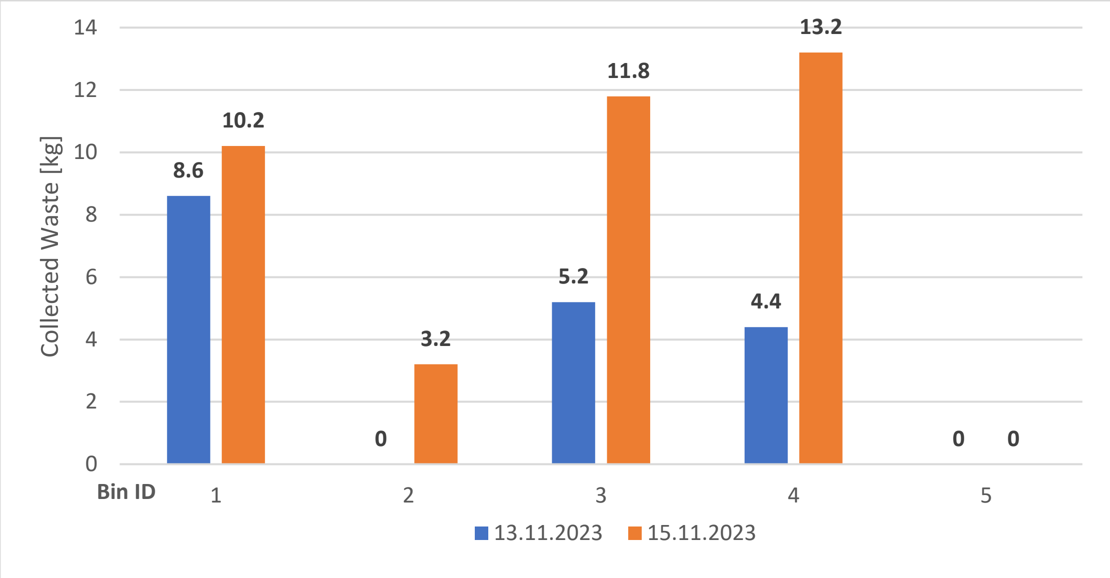

Figure 13: First two waste collection, blue on the 13.11.23 and orange on the 15.11.23 with the collected weight for each bin

Due to the absence of scales in the informal settlements the regular data collection started with the end of Phase III in Johanna Road. The results are presented in Figure 4: The collection in Johanna Road reached its 10th week at the end of January 2024, when the latest data was analyzed. The data was collected in the first and the third week with scales under the supervision of the author of this study. From the 6th week on, the collectors continued data collection on their own with scales that were provided to them. Every collected bag was weighed, and on every collection day, another bin content was inspected. In all cases, almost 100% AHP waste was found. Therefore, it is assumed that the collected waste contains as well pure AHP waste.

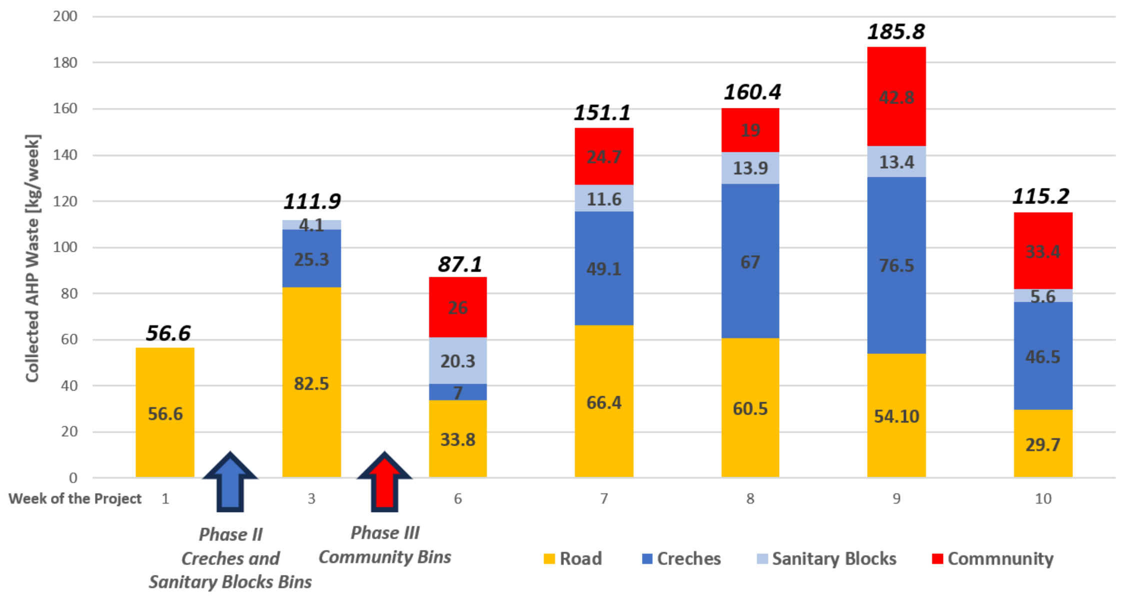

Figure 14: Collection progress in Johanna Road with the two implementation steps. The colors refer to the locations in Figure 11.

The data shown in Figure indicates that the collected AHP waste increased till the 9th week and then suddenly decreased in the 10th week.

All AHP waste facilities were used. The creches have contributed the highest mass of AHP waste to the bins after the 7th week. Overall the creches contributed 33% of the AHP waste collection. Furthermore, it seems that the bins placed on the road decrease the AHP waste contribution with the project's progression. This might be due to the poor condition of the spring lids. Another explanation could be the usage of the community bins from the 3rd generation. The sanitary block bins are regularly used, which is surprising since menstrual practices still face significant barriers in the path of menstrual hygiene management (Kaur et al., 2018; Roxburgh et al., 2020). Moreover, it is very interesting that every inspected black bag contained only AHP waste. The author of this study assures the results from the first and the third week. However, it is interesting that almost 100% AHP waste was still found in all bags as the project proceeds. Further steps might be to review the current practices to ensure the collection of pure AHP waste.

Overall, the most collected AHP waste in week 9 represents 20% of the conservatively calculated AHP waste generation see, therefore, chapter 3.1.1. This might be attributed to an overestimation of households or an overestimated fraction of AHP waste in municipal solid waste. Another cause could be the caregiver's disposal of nappies in black municipal trash bags. Concerning the air quality in the container, the collector’s feedback was that the wind turbine ventilator provided fresh air to the container, ensuring a comfortable workspace.

The infrastructure in Blackburn was implemented completely on 29.11.2024, which also represents the start of data collection:

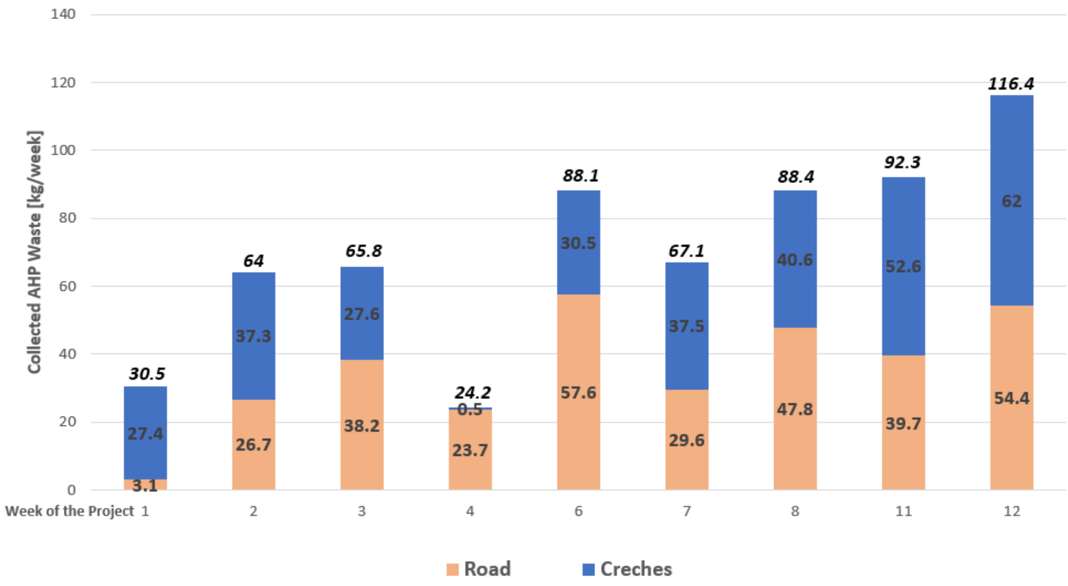

Figure 15: Collection progress in Blackburn Village The colors refer to the colors of Figure 11.

Overall, the collected AHP waste was increasing and peaked in the most recent 12th week of the project, with exceptions in weeks 4 and 7. The data for weeks 5 and 9 is missing due to holidays and a missing data table. In general, the creches have a very high contribution to the total amount of collected AHP waste. Based on the data displayed in Figure 15, the creches contributed with 316 kg 49,6% to the total collected AHP waste. However, Blackburn Village only shows with the latest collection of 116.4 kg / week, only 4.66% of the calculated AHP waste estimation from the HDE method. However, the results could not be identically reproduced from Johanna Road due to the circumstances of Blackburn Village, like missing bins in the sanitary blocks. However, they have in common that the collected AHP waste is increasing, with exceptions. The higher installed capacity in Johanna Road may lead to a higher total collected AHP waste, therefore the capacity in Blackburn Village needs to be increased for a larger AHP waste collection. This thesis would be interesting to test with further implementation of bins and their integration in the community.

3.3.4 Cost Estimation

Table 1 compiles a comprehensive cost calculation table to show the financial aspects of the waste collection management system. This bottom-up analysis provides a transparent breakdown of weekly expenditures for the operating cost and does not include the investment cost.

Table 1: Bottom-up cost calculation per week

Activity	Quantity [Units/Week]	Unit Cost [Rand/Unit]	Total Cost [Rand/Week]

Labor			***2200***
Collection Assistant 1	3	200	600
Collection Assistant 2	3	200	600
Collection Supervisor	2	500	1000
Equipment			***225***
Gloves	1	20	20
Transparent user bags	500	0.2	100
Black waste bags	40	2	80
Internet for data collection	1	25	25
Maintenance			***158.32***
Cleaning tools	0.1	120	12
Soap	0.1	35	3.5
Bin Replacement	0.1	928.2	92.82
Administration Overhead	0.1	500	50
Total Cost per Week			**2583.32**

Under the "Labor" category, salaries for the workforce, including Collection Assistants and Supervisors, were documented. The total labor cost is 2200 Rand per week. This detailed breakdown underscores the critical role played by personnel in maintaining efficient waste collection operations. The collectors and the supervisor work on a daily basis with a daily salary. The time effort for them to collect all the bins in Johanna Road was reported to be 4 hours with all three employees. Additional time expenses are associated with data collection and caregiver meetings.

The "Equipment" section pointed out expenses associated with essential tools and resources necessary for operations. This comprised the costs of gloves, transparent user bags, black waste bags, and internet connectivity for data collection, resulting in a cumulative equipment cost of 225 Rand per week.

In the "Maintenance" category, expenses related to the upkeep of the infrastructure, with a particular focus on bin replacement. Based on the fact that the bins are, after two months, still in good condition, it was assumed to replace one bin every ten weeks. A detailed calculation for the bins manufactured at KMBC is shown in the appendix. Additionally, maintenance costs accounted for cleaning the bins with soap and tools. Moreover, administerial overhead cost was included. The total maintenance costs amount to a weekly cost of 158.32 Rand.

Table 1 reveals a total weekly cost of 2583 Rand for one settlement. Overall, 85% of the cost is based on the labor cost of the contractors, and only 8% is allocated to the equipment and 5% to the maintenance, as indicated in Figure 16. Labor is a crucial factor, especially in the environment of informal settlements. Integration of the project within the community has been made possible primarily through the involvement of local employees. This has contributed significantly to the respect for the installed infrastructure, exemplified by the continued presence of all the bins in Johanna Road. Furthermore, the employees play a crucial role in facilitating communication with local caregivers. This task would be challenging without their presence, given the relatively tight-knit nature of the community. Additionally, the contractors are very grateful for the job opportunity since the unemployment rate in informal settlements is high. For example, Nkonki-Madleni et al. (2021) reported an unemployment rate of 61.6% in eZakheleni, another informal settlement close to Durban (Nkonki-Mandleni et al., 2021).

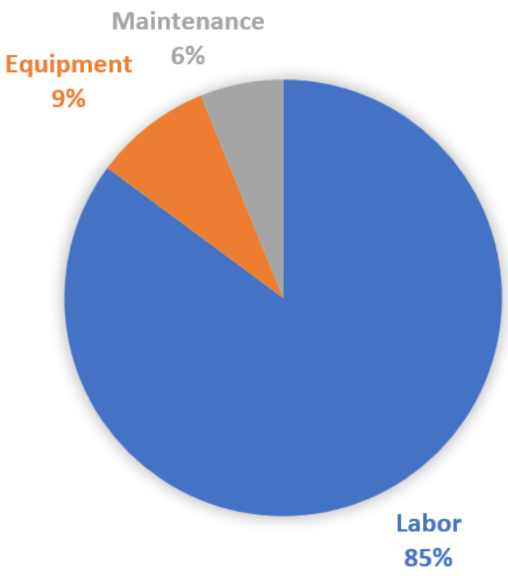

Figure 16:Cost allocation concerning running costs of the project

Furthermore, the cost for the different bin designs was calculated: It showed that the 2nd generation bin only costs 603 Rand, while the bin produced at KMBC costs 928 Rand and is, therefore, 35% more expensive. This is mainly due to the effort required to fabricate the PP sheets and the time-consuming assembly, as indicated in the appendix.

4 Conclusions and Recommendations

This study tested the feasibility of a successful AHP waste collection system in an informal settlement and illuminated our limited understanding of these communities. Informal settlements are often perceived as unstructured by those unfamiliar with them. But they actually consist of highly structured communities, each distinguished by its own organizational system. The primary challenge is effectively transferring and applying this knowledge to improve waste management practices.

For the AHP waste collection system to be successful, it is essential to work and communicate closely with a person of trust representing the community. Moreover, critical components are understanding the community members' attitudes towards the project and explaining the environmental and health issues arising from improper AHP waste disposal. Moreover, active engagement with the community, utilizing tools such as focus group interviews and local employees, and integrating community feedback into the bin design highlighted the importance of direct communication and local support. Open discussions, especially those facilitated by individuals fluent in the local languages, support trust between the community and researchers. Communication and understanding are crucial for minimizing infrastructure damage and enhancing awareness of waste management issues.

For answering the research questions of the total generated AHP waste, the HDE approach proved to be more precise than the SIA method compared with numbers found in the literature (Kemper & McManus, 2019). Moreover, the caregiver's understanding of their AHP waste disposal was examined with semi-structured interviews, revealing that the improper disposal of nappies is not intentional. More often, they are placed in municipal plastic bags, which are not collected by local services. These bags then rupture, leading to environmental contamination.

Furthermore, the bin's characteristics were investigated and implemented with an iterative and participatory design process. The findings suggest that the bin design does not need a special mechanism, allowing only the disposal of AHP, as long as community awareness around proper disposal is empowered. Moreover, extensive security measures for the bins may not be necessary if the project fosters a sense of respect and community engagement. However, the aesthetics of the infrastructure must align with local perspectives, such as handmade and colorful designs. Concerning manufacturing, clear instructions and hands-on demonstrations are necessary due to the staff's lack of skills, which promotes inclusion and motivation among the team.

A successive participatory implementation was carried out to implement a comprehensive AHP waste collection system. Despite the purity of AHP waste being 100%, the project observed that at most 20% of the calculated AHP waste was collected. This discrepancy may be associated with overestimating the number of households or an inaccurately high assumption of the AHP fraction in municipal solid waste, as suggested by Stutz's study (Stutz, 2023). Another contributing factor could be caregivers disposing of nappies in black municipal trash bags, which municipal services do not collect regularly. Nevertheless, the collected AHP waste increased as the project progressed. Therefore, the collection systems' organization shown in Figure 17 has proved its worth.

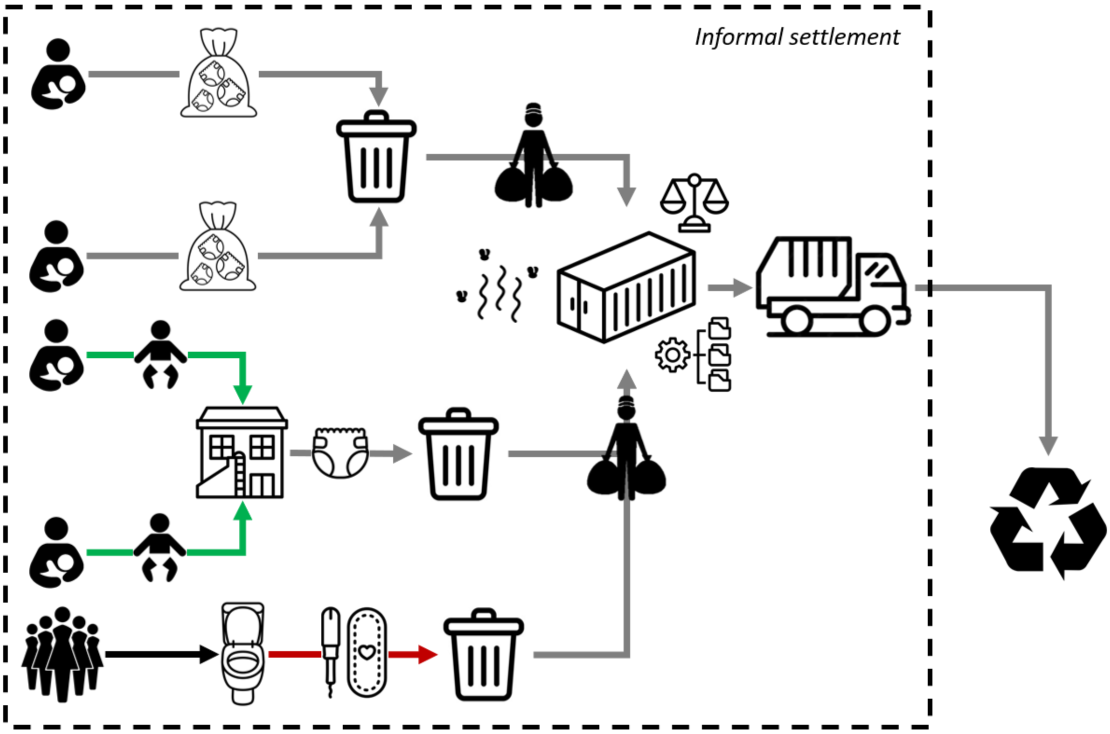

Figure 17: AHP waste canalization with further improvements

As the project progresses, the effectiveness of the taken measurements can be validated in the long term. Further studies need to be carried out, like examining if the distribution of bins could increase the collection of AHP waste and verifying if the quantity of improperly disposed AHP waste decreases. Moreover, the result that 100% AHP waste was found in the bins should be reviewed critically, as indicated by the scale in Figure 17. As a further step, the digitalization of the data-gathering system could be organized, resulting in a lower administrative overhead effort. More data would open opportunities for further research into whether the strategic distribution of bins can enhance waste collection and efficiency. Moreover, the container's air quality in Blackburn Village must be monitored, as indicated in Figure 17. This requires scientific measurement of the air conditions, and based on the findings, relevant actions should be implemented.

Furthermore, if the AHP waste purity is ensured, further utilization at the end of the AHP waste flow in Figure 17 could be considered like Arena et al. (2016) did (Arena et al., 2016). Therefore, a process combines a pressure vessel and a sorting machine to sterilize waste and segregate its cellulosic and plastic components. It recycles the plastics and uses the cellulose to generate steam for sterilization. For this step, a feasibility study could be carried out by Kimberly-Clark with the Global Health Engineering department.

Last but not least, the project depends on the local supervisor; therefore, if the financial resources are cut back, it is essential to sustain funding for this labor expense.

5 Appendix

Table 2: Cost calculation bin 2nd Generation

Bin 2nd Generation	Quantity	Unit Cost [Rand/Unit]	Total Cost [Rand/Week]
Material			***428.25***
Concrete Block	1	40	40
Rod threaded (1m)	1	45	45
Nut	8	4	32
Wire rope (1m)	1	30	30
Wire ferrules	4	7	28
Lavaplastic Plank (2m)	0.25	61	15.25
Prefabricated bin	1	250	250
Labor			***175***
Assembly (hour)	0.5	350	175
Total Cost per bin			**603.25**

Table 3:Cost calculation bin 3nd Generation

Bin 3rd Generation	Quantity	Unit Cost [Rand/Unit]	Total Cost [Rand/Week]
Material			***403.2***
Bottle tops (kg)	1	4	4
Concrete Block	1	40	40
Rod threaded (1m)	1	45	45
Nut	8	4	32
Hinge	2	14.5	29
Wire rope (1m)	1	30	30
Wire ferrules	4	7	28
Lavaplastic Plank (2m)	3.2	61	195.2
Labor			***525***
Sheet production (hour)	1	350	350
Assembly (hour)	0.5	350	175
Total Cost per bin			**928.2**

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