Designing a sanitation system for floating communities

Master thesis
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Finch
Floating
Homes

Abstract

An increasing trend of urbanization, land shortages and frequent floodings have created unfavorable living circumstances for Philippine inhabitants. Finch Floating Homes aims to repurpose the permanently flooded ricefields in Hagonoy into flood-proof, typhoon-resilient, affordable housing. The floating neighborhood will serve as storm-resilient living and have an educational purpose on circular living and recovering resources. The pilot floating home is equipped according to current sanitation practices, a septic tank. The septic tanks are usually emptied in drainage fields or surface water. With the aim of circularity in mind, an alternative sanitation had to be designed.

The neighborhood aspects and social implications were analyzed after which a set of eight design criteria were drafted. With the design criteria a framework was set up for selecting a flexible sanitation system that fits a range of desired effluent qualities. The framework offered treatment compartments that can be combined depending upon the location and effluent requirements. Three different treatment scenarios were compared based on the effluent qualities and costs. Scenario 2 containing a UASB-septic tank as primary treatment and a polishing step with water hyacinths, was found to be the most cost-effective. A final effluent concentration of 3 g/L COD, 0,05 mg/L NH_3 and between 53 and 134 mg/L P was reached. And based on the die-off of E.coli, a pathogen removal of 5 log units was achieved.

Next, the conceptualization was laid out. The platforms on which the houses float, were made up from standard modules that were prefabricated and assembled on-site. Rainbarrels in wooden frames provided floating ability. The UASB-septic tank had similar dimensions as the rainbarrels, meaning no specialized treatment platform had to be built since the reactor could take the place of a rainbarrel. The disinfection tubes are placed on top of the platform and could be added at any time if the effluent quality demands a low pathogen level.
The final polishing pond was constructed from locally sourced materials and can be built in any shape that suits the neighborhood as long as the surface area is 17 m².

The treatment system also offered possibilities for resource recovery in the form of biogas, irrigation water, fertilizer and reuse of the plant mass (food, extra COD, fabric raw materials). The residents could benefit from the biogas in the form of a communal kitchen suitable for social gatherings. The fertilizer and irrigation water were applied in communal gardens. Communal areas aided in improving relations between neighbors which created a pleasant environment.

The final treatment design was a scalable, affordable and sustainable treatment system with a range of resource recovery possibilities.

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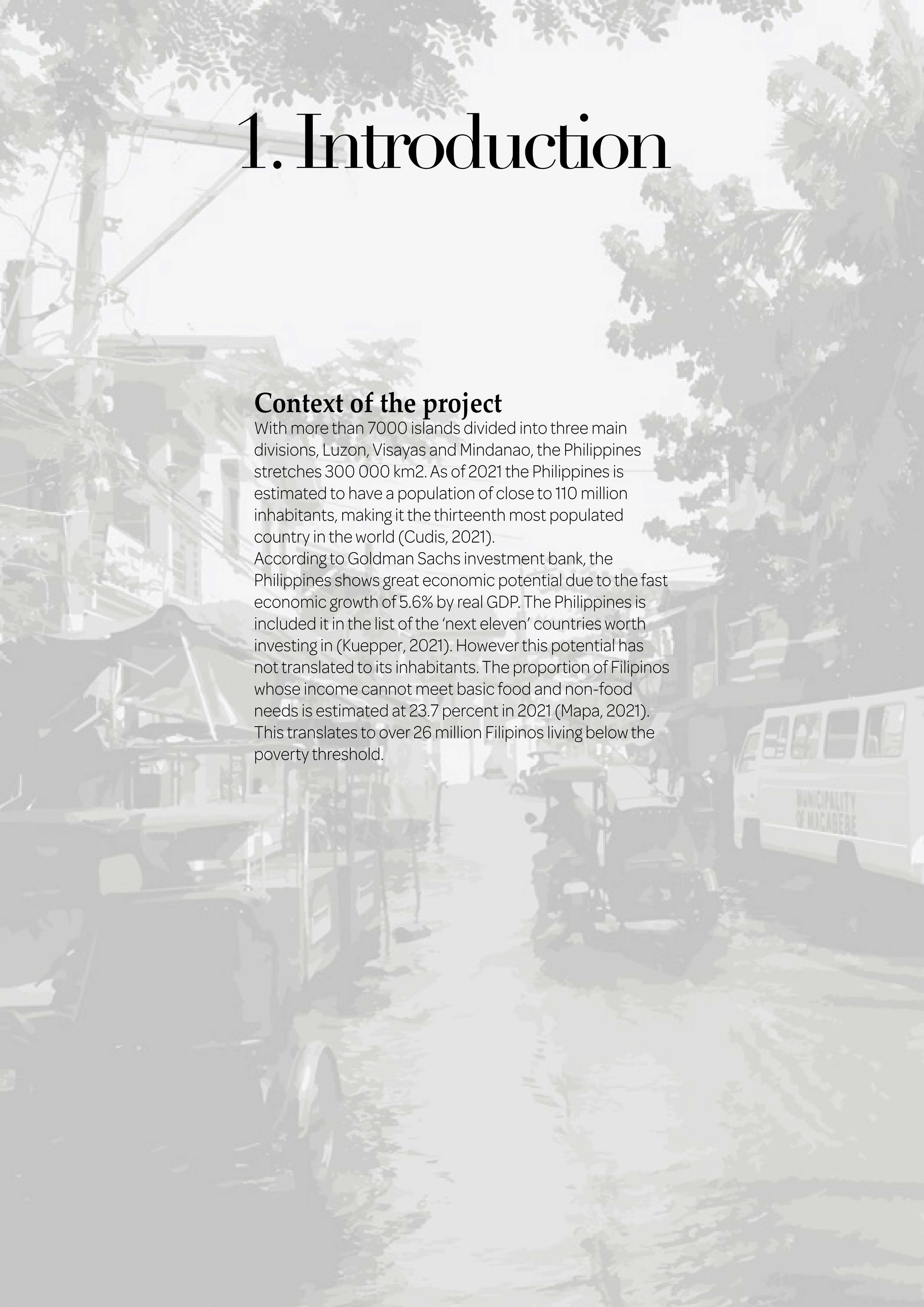
This chapter introduces the challenges faced by the inhabitants of the Philippines. A description of the problem is provided by overviewing the housing situation and water related problems in the Philippines. Next the concept of the floating village from Finch Floating Homes is introduced and the context of the neighborhood for this project is described. This leads to the research objective and research approach.



1. Introduction

Context of the project

With more than 7000 islands divided into three main divisions, Luzon, Visayas and Mindanao, the Philippines stretches 300 000 km2. As of 2021 the Philippines is estimated to have a population of close to 110 million inhabitants, making it the thirteenth most populated country in the world (Cudis, 2021).

According to Goldman Sachs investment bank, the Philippines shows great economic potential due to the fast economic growth of 5.6% by real GDP. The Philippines is included it in the list of the ‘next eleven’ countries worth investing in (Kuepper, 2021). However this potential has not translated to its inhabitants. The proportion of Filipinos whose income cannot meet basic food and non-food needs is estimated at 23.7 percent in 2021 (Mapa, 2021). This translates to over 26 million Filipinos living below the poverty threshold.

Urbanization & housing backlog

Following a worldwide trend, urbanization is increasing in the Philippines. From 2010 to 2015 the population residing in urban bangarays (small districts) had already increased from 45% to 51% (Perez, 2019). This trend is expected to continue in the foreseeable future, meaning the need for housing will also increase.

Currently, the housing backlog in the Philippines is estimated to be around 5.7 million houses due to high demand and lower development rates during the pandemic (Embudo, 2022). Considering the high poverty percentage, the highest demand comes from what the Philippine government calls the economic, socialized and low-cost housing segment (Bellsteros & Raganit, n.d.). From 2000 to 2011 these segments account for almost 70% of the total demand (29%, 27% and 13%, respectively). This includes houses worth up to 3 million PHp or €51.000 (Bellsteros & Raganit, n.d.). Hence, the need for affordable housing is high and only increasing.

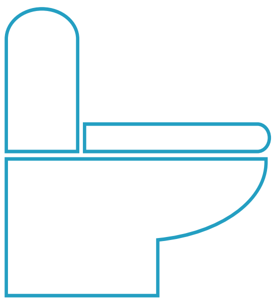
Housing developers name the lack of land availability as the reason for failing to reduce the housing backlog (Embudo, 2022). With a population growth of 1,5% every year since 2000, the available land per person is continuously reduced, meaning the efficiency of the urban areas has to increase to accommodate for the land scarcity (Worldbank, n.d.).

Additionally, rapid urbanization puts pressure on the drinkwater availability. This has led to many illegal deep-water drillings to create wells in the vicinity of urban areas. In the areas of Metro Manila, Guiginto, Bocaue, Marilao, Cavite and Bulacan, the groundwater levels have been identified as 'critical', meaning groundwater extraction has led to longer subsidence times of floods, seawater intrusion into the groundwater and land subsidence (Govph, 2015). The land subsidence causes damages to buildings and infrastructure. Therefore, groundwater extraction is now strictly prohibited in these areas although the damages caused by land subsidence are still prevalent. The Pampanga delta is estimated to subside with a rate of 3-9 cm/year, which is one or two orders of magnitude faster than the 'natural' rate of compression (Rodolfo & Siringan, 2006).

Natural disasters

The geographical location of the Philippines makes it vulnerable to earthquakes, floods, volcanic eruptions and other natural disasters. The countries located on the so-called 'ring of fire' around the pacific ocean suffer many natural disasters due to the shifting of tectonic plates under and around the pacific ocean (CFE-DM, 2021). On top of this, the Philippines is also located in the typhoon belt where one third of the worlds' tropical cyclones form. It is reported that 74% of the population and 85,2% of the country's sources of production are susceptible to natural disasters (CFE-DM, 2021).

The extreme weather events are expected to worsen in the coming decades due to climate change. In 2021 alone, the tropical cyclones have left over $662 million in damages (Cabato, Neff, & Dormido, 2022). Since many homeowners do not have the funds to relocate, they are left on their own to cope with the rising water levels and floods. To flood-proof their homes, the inhabitants, where possible, have implemented a sacrificial ground floor with flood proof furniture and all the utilities on an upper floor.



Sanitation in the Philippines

In the Philippines only 10% of the population is connected to piped sewerage and 84% disposes the wastewater in septic tanks (Baltazar et al., 2021). Septic tanks are containers made from plastic, concrete or fiberglass where solids and organic material settle and are partially treated by anaerobic processes. Usually, the breakdown process cannot keep up with the inflow of wastewater so the septic tanks have to be emptied periodically. However, studies have reported that only 13% of septic tanks have ever been desludged and a high number of on-site systems leak into the groundwater and nearby surface water due to having an unsealed base (IFC, 2016). The groundwater contamination causes serious harm to the environment and human health (Withers et al., 2011). Outside Metro Manila only 5% of the septage waste (sewage stored in a septic tank) is treated due to the insufficient waste and septage management in cities (Baltazar et al., 2021). This leads to people relying on private desludging companies that do not have access to treatment facilities and dispose of the septage in drainage canals or waterbodies (Baltazar et al., 2021).

Finch Floating Homes

The high water levels in the Philippines have permanently flooded much agricultural land in the Hagonoy river delta, leaving lakes of brackish water. The lakes are currently unused after trials with fish farming failed due to the washout of the fish (Ham, 2022). Since these 'lakes' do not serve a purpose currently, Finch Floating Homes aims to repurpose these areas into floating neighborhoods to create flood-proof, typhoon-resilient, affordable housing (Finch Floating Homes, n.d.). This river delta faces the same problems that can be seen nationwide, on a smaller scale. Currently, a pilot floating home has been built and is being tested by several Filipino families. This house is currently connected to a septic tank on land conform the current sanitation practices.

Neighborhood context

The floating neighborhood will provide safe, affordable and comfortable homes in areas that used to be inaccessible for living. The homes will be storm resilient and create amphibious living where people will live with the water instead of being dictated by it. To increase awareness about the roots of the flooding and the decreasing living conditions in the area, the neighborhood will serve an educational purpose on circular living and recovering resources. Current sanitation practices in the Philippines are not only unsustainable and negatively affect the environment, they also form a threat to human health. This is why an alternative solution needs to be found for future floating neighborhoods. The aim of the prefabricated homes from Finch floating homes is to provide a scalable sustainable solution for living on water (Finch Floating Homes, n.d.). This is why a scalable approach for the sanitation is also preferred.

For the purpose of scalability a neighborhood can be divided into clusters of several houses. In this report, a cluster of 4 houses with 4 residents each is assumed. The houses within this cluster may be connected by 'realms', a space between private and public that serves as an extension of the house where neighbors can interact with each other (Jurado, 2021).

Research objective, approach and scope:
Research objective

In order to create sustainable, affordable and scalable floating neighborhoods, a design for a sanitation system is needed that represents these values as well. The design will include the dimensioning of the sanitation system, its implementation and integration into the neighborhood and an evaluation of potential risks associated with this design. With the final concept it will be possible to answer the following questions:

What is a suitable sanitation system for a floating community in the Philippines?

Subquestion part 1: What aspects are important for the design of a sanitation system in the neighborhood of Hagonoy?
Subquestion part 2: What possibilities regarding nutrient and energy recovery, does the treatment system offer?
Subquestion part 3: How can the treatment system be implemented in a scalable and sustainable way, considering the unique neighborhood aspects?
Subquestion part 4: What are the risks when implementing a sanitation system and how can they be minimized?

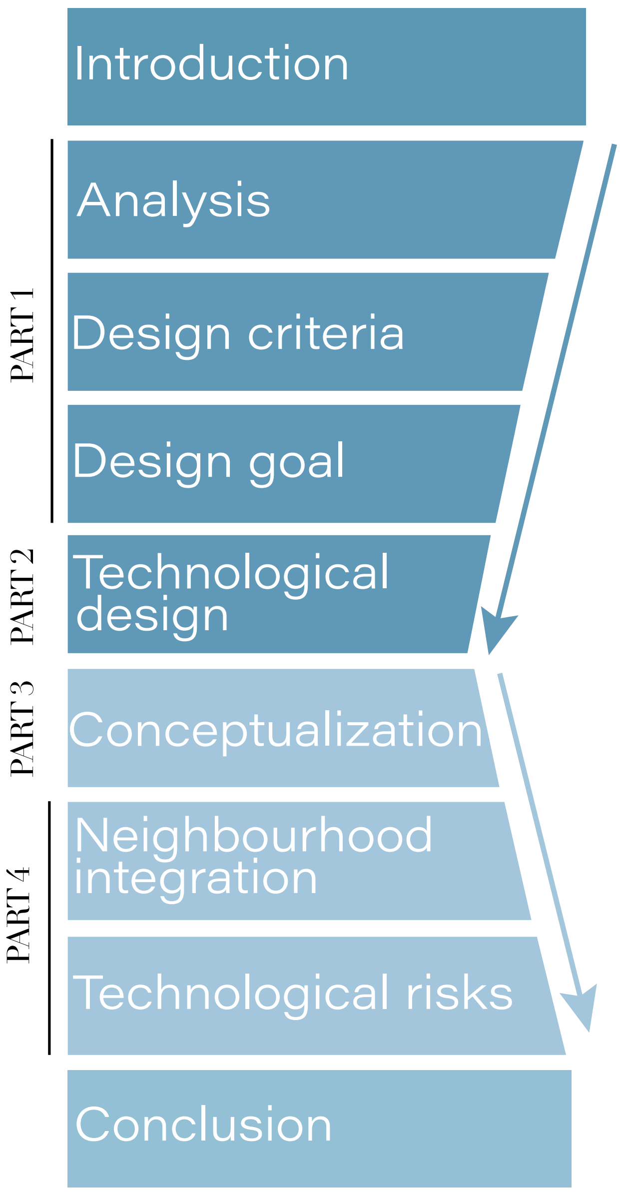


Figure 1. Research approach.

Research approach

Part 1: Context analysis.
To narrow down the sanitation technology, first a set of criteria is devised by analyzing the neighborhood context. Based on these criteria it is argued why the chosen system was selected.

Part 2: Detailed technological design.
Next the technological design of the sanitation system is developed. This is done in the form of a framework with several compartments that can be combined depending on the effluent quality.

Part 3: Conceptualization.
Once the theoretical design is thought out, the next step is to work out the physical design of the system. In this chapter the construction within and on the platform and the materials are laid out.

Part 4: Neighborhood integration and risk analysis.
In part 4 the sanitation system and its relation to the neighborhood is discussed. The location of the system within the community, the aesthetics of certain compartments and resource applications is laid out. Additionally, the interaction with the residents in the form of maintenance of the system is discussed. Lastly, the risks possibly associated with the maintenance or failure of the system are discussed.

Scope of report

In this report, the basis is created for a decision framework for sanitation systems in floating communities. This research fits into a bigger picture to solve the sanitation issues in floating communities. The design process starts with literature research and analysis of neighborhood aspects which leads to an initial design. Next, the design can be discussed with the residents, after which the feedback is incorporated in a new design as a feedback loop. When a satisfactory design is created, a pilot can be build to test the design. Then, the sanitation design can be scaled up to neighborhood level.

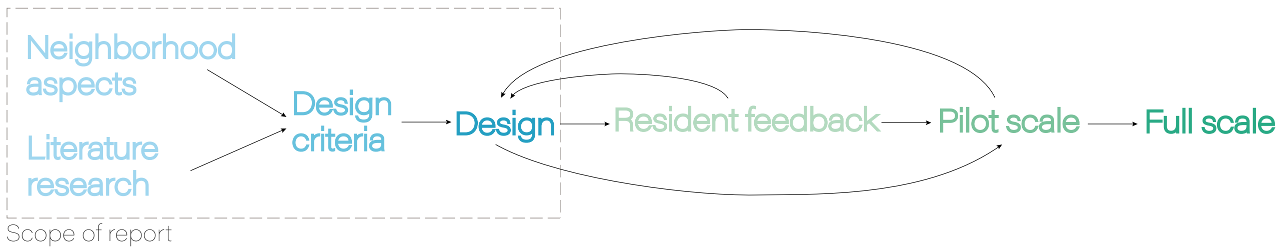


Figure 2. Research scope in context of the floating neighborhood.

PART 1

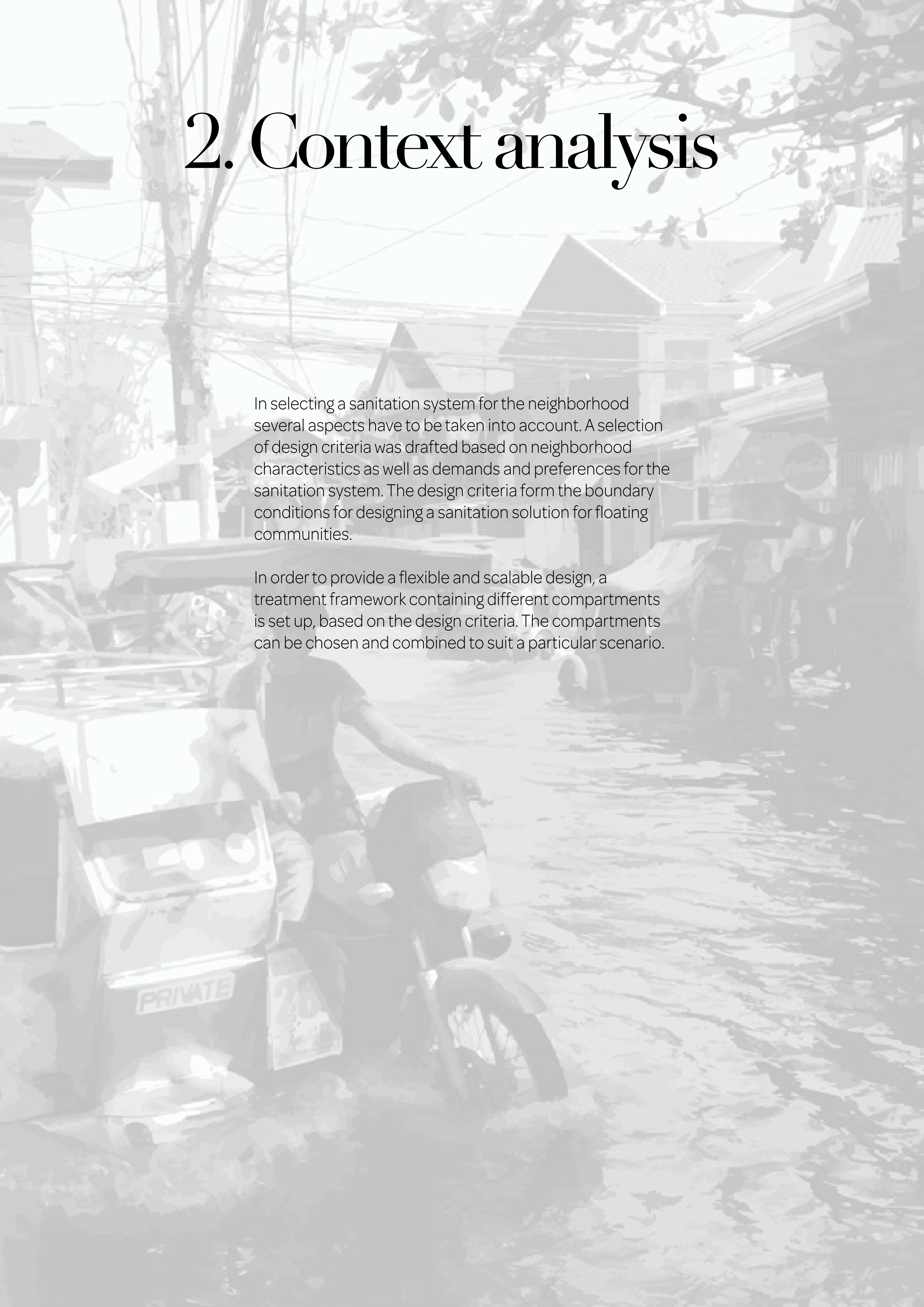
Context analysis

Context analysis:

Land availability and ground quality
Transport logistics
Complexity of the system
Flexibility of the system
Affordability
Weight and floatability
Resource recovery
Circularity
- Logistics resource recovery

Social acceptance
- Wet user interface
- Integration into the neighborhood

In this chapter the context of the neighborhood and the specifics of the area are analyzed. From this analysis eight design criteria were determined that led to the design goal: a framework of treatment compartments that can be combined depending on the desired effluent quality.



2. Context analysis

In selecting a sanitation system for the neighborhood several aspects have to be taken into account. A selection of design criteria was drafted based on neighborhood characteristics as well as demands and preferences for the sanitation system. The design criteria form the boundary conditions for designing a sanitation solution for floating communities.

In order to provide a flexible and scalable design, a treatment framework containing different compartments is set up, based on the design criteria. The compartments can be chosen and combined to suit a particular scenario.

1. Land availability and ground quality

Rapid urbanization and frequent flooding around the Manila bay area have resulted in a scarcity of available land (Bellsteros & Raganit, n.d.). Additionally, the soil is marshy and prone to subsidence due to excessive groundwater extraction which gives difficult circumstances for building houses or other facilities such as treatment plants (Asio et al., 2009; Rodolfo & Siringan, 2006). Consequently, any available land would need extensive processing to build strong foundations for housing a large scale treatment facility in a safe way. Larger treatment facilities not only have a large footprint but are generally constructed with large quantities of heavy materials[*].

Alternatively, a treatment system can be selected that is robust and can withstand land subsidence, circumventing costly foundational constructions. However, land subsidence and land scarcity can be avoided entirely by selecting a designated location 'off-land' and 'on-site' within the floating neighborhood.

In short, the treatment system should occupy a land area as small as possible and preferably not interfere with land available for housing. Furthermore, either the treatment system is able to withstand land subsidence, the land is suitable for processing or the selected location is 'off-land', inside the floating neighborhood.

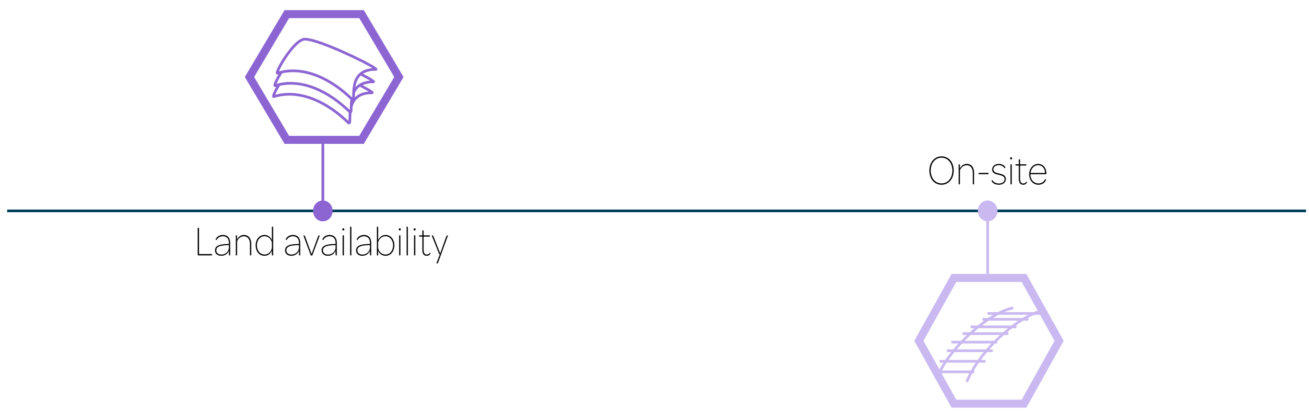
* *In this report, large scale treatment facilities are viewed as everything larger than a full scale Sequence Batch reactor (>20 m2) (EPA, 1999).*

2. Transport logistics

Within the current sanitation systems in the Philippines, septage is collected either by private desludging companies or by vacuum trucks employed by the municipalities depending on the urban area (Baltazar et al., 2021). Collection of septage in a floating home poses challenges since current collection methods are not applicable to water. In the case of off-site treatment, a new collection method on water would need to be devised. For example a boat with a vacuum system to collect the wastewater.

Additionally, depending on the distance between the treatment facility and the neighborhood, the sewage requires transfer to a truck as well, effectively extending the current collection system with collection by boat. Implementing a novel collection method in combination with the existing one not only increases logistical challenges, it also increases transport costs for the boat, equipment and training of new personnel. Since these costs pile on top of costs that are already there in the current system, choosing the collection method combined with the boat has to provide great benefits to the residents to make it an attractive solution. Objectively, one of the largest benefits that can be identified, includes better treatment of wastewater. However, it has to be seen if the residents view this as a benefit since their current sanitation system (septic tanks) doesn't provide this benefit either.

So when selecting a location for a treatment facility, the distance between the collection location and the treatment location should be taken into account as it influences the logistical challenges and costs greatly.



3. Technology level of the system

The Metro Manilla area contains 43 sewage and septage treatment plants serving over a million inhabitants (10% of the regions' population) (Tuddao, 2021). However, in the rest of the country the concentration of the treatment plants is a lot lower, meaning the knowledge about wastewater treatment is mainly concentrated in the Metro Manila area (ARCOWA, 2018).

Treatment techniques used by centralized treatment facilities include many steps of varying complexity ranging from 'simple' sedimentation tanks to complicated techniques such as biological treatment with activated sludge followed by disinfection using chemicals or UV. The more technologically advanced the chosen treatment techniques are, the more skilled personnel is needed for maintenance and operation. Additionally, an increasing complexity of treatment systems often coincides with the presence of more mechanical components and monitoring software. These components, especially the mechanical ones, are prone to failure due to e.g. clogging, power outages, or improper maintenance (Reuters, 2021).

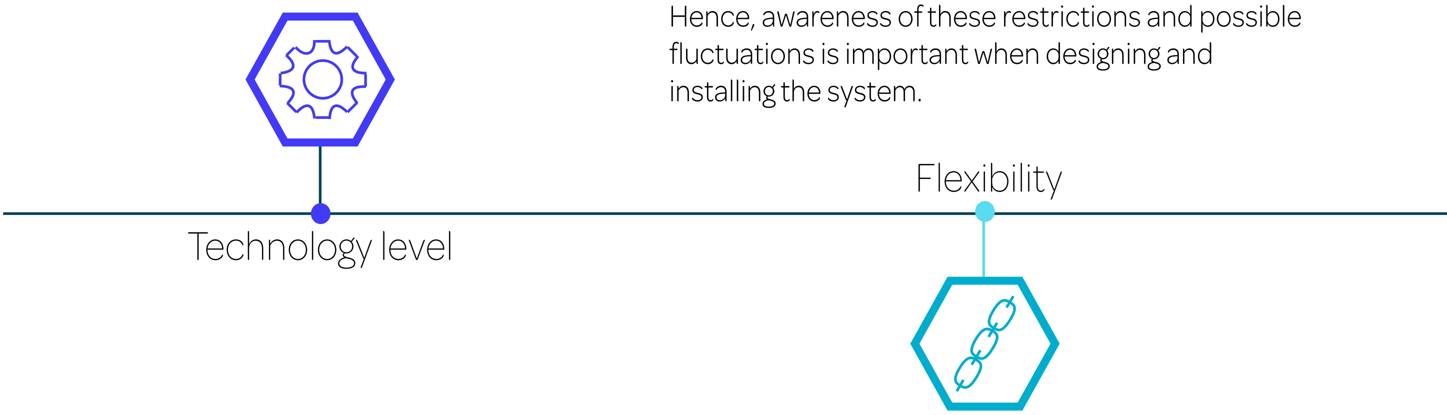
Overall, technologically advanced treatment systems offer lots of possibilities in terms of treatment but also require a higher skill level of personnel and are possibly less robust due to risks of software or mechanical failure. Often, decentralized treatment systems are more low-tech. Amongst the decentralized treatment systems there still is a large range in complexity. Preferably the risk of mechanical failure or clogging is kept as low as possible by choosing a system that can be operated without filters or pumps.

4. Flexibility of the system

By nature of human life, lifestyles, diets and schedules can vary from time to time. Consequently, the wastewater concentrations produced by humans also fluctuate. As for any treatment scenario, the system should be able to handle the fluctuation range of the influent. Some systems, mainly on a smaller scale are sensitive to concentration fluctuations or flow fluctuations due to the lower flux compared to centralized systems. Hence, the flexibility of the system and its ability to adapt to different circumstances play a role in the treatment selection.

An examples of decentralized systems that are sensitive to flow fluctuations is a constructed wetland, a manmade wetland that uses natural functions of vegetation, organisms and soil for the purification of wastewater. In case of a dry spell (very low or absent flow), the vegetation might die without extra irrigation, partly destroying the purifying function of the wetland. An example of sensitivity to concentration fluctuations is biological treatment such as aerobic and anaerobic digestion. Influent characteristics such as ammonia may have an inhibiting effect on the microorganisms in too high concentrations (>3000 mg/L) (Yenigün & Demirel, 2013). In case of anaerobic digestion, the influent concentration also impacts the biogas production. Too high solid concentrations may block the flow through a system without mixing, resulting in clogging. Additionally, the Nitrogen/Carbon (N/C) ratio has to be within a certain range for the microorganisms to be able to produce biogas. Prior to system installment, the influent concentrations can be analyzed. However, this will not guarantee the predictability of the influent fluctuations since it will depend on how the residents use the new system.

Hence, awareness of these restrictions and possible fluctuations is important when designing and installing the system.



5. Affordability

Similarly to system complexity, the installation costs (CAPEX) and operational costs (OPEX) are much higher when the system becomes larger and more complex. The CAPEX costs include everything having to do with the building and implementation of the treatment facility such as, building material, treatment equipment, personnel costs related to installation, software purchases and depending on the location, soil processing and discharge permits. These costs are a onetime investment at the start of the project.

Logically, a large complex system also requires more maintenance and monitoring and in case of system failures, more expensive replacement parts which increases the OPEX costs. OPEX costs include raw materials or chemicals needed for the process, personnel costs for maintenance and monitoring as well as replacement parts and repairment personnel. The OPEX costs are very important for the feasibility of the project since they are recurrent costs that residents have to be able to continuously pay. To be able to estimate the proper OPEX costs, the lifetime of the treatment system has to be determined.

In short, low-tech systems requiring minimal maintenance, have a larger feasibility when affordability is taken into account since these systems will remain operational over time due to lower OPEX costs.

Affordability

6. Weight and floatability

The homes as well as the amphibious foundation they stand on are light structures. Two important physical demands influence the stability of floating structures, the buoyancy force and the weight stability (Ham, 2016).

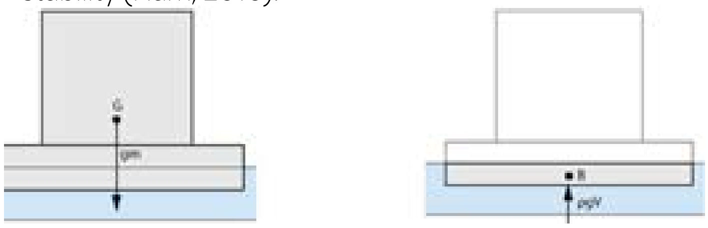


Figure 3. Left: Gravity force. Right: Buoyancy force. (Ham, 2016)

Buoyancy: The vertical stability of the platform increases when the gravity force does not exceed the buoyancy force, meaning the structure on top of the platform should not outweigh the floating force of the platform (Ham, 2016).

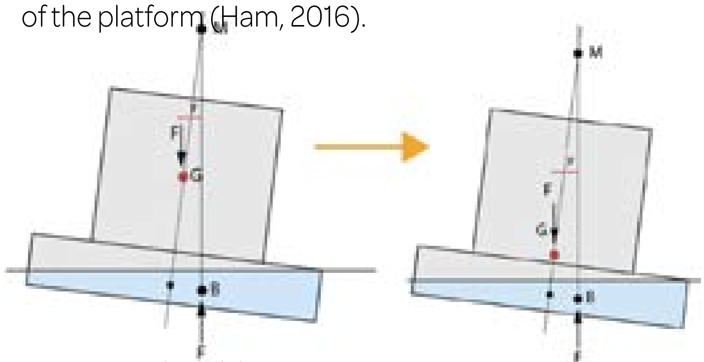


Figure 4. Weight stability. (Ham, 2016)

Weight stability: The weight distribution on the platform (horizontally and vertically) influences the position of the center of gravity (G in Figure 3). The lower the center of gravity, the more stable the entire structure will be (Ham, 2016). Effectively, this means that the positioning of the treatment system -that has a fluctuating weight- on the platform, has limitations.

These physical properties have to be taken into account in selecting potential collection methods or treatment systems. Both the collection tanks and/or treatment systems cannot weigh too much in order to adhere to the buoyancy limitation and they have to be placed in or on the platforms in a manner that adheres to the weight stability limitations.

Weight and floatability

7. Resource recovery

Circularity

Part of the vision for the neighborhood is to educate the residents in the area about circular, sustainable living. The houses and neighborhood facilities are built with as many local materials as possible to reduce the impact on the climate and to support local businesses. The 'living with water' concept however, applies to much more than just floating houses. Households have a water cycle ranging from recovering rainwater to drinkingwater, washwater and wastewater. This offers many possibilities for circularity and sustainable water use which is why the addition of resource recovery in the water cycle of the floating neighborhood is preferred. Resource recovery is most common in the form of clean water, nutrient recovery, or energy recovery.

Recovered water is suitable for non-drinking water purposes such as irrigation or toilet flushing when pathogen levels in the water allow for human contact. Nutrient recovery is most common in fertilizer applications. Lastly, energy recovery is possible in the form of heat produced during treatment or in the form of biogas, which has multiple application options such as cooking and electricity production.

Logistics resource recovery

Resource recovery serves multiple purposes such as creating revenue, educating residents and aiding in climate resilience. For the resource recovery to make sense, a condition has to be met: The location where the resources are recovered should be as close to the application site as possible. This way, the negative aspects associated with the transport of the recovered materials don't cancel out the original benefits. Transport costs could cut into the revenue and hamper profitability.

As for the educational purpose, a faraway recovery location would make it impossible to show residents the use and advantages of the recovery as it does not create ownership over their influence on the environment. And lastly, considering that Filipino society does not run on renewable energy, any transport will add negatively to the environmental impact which arguably, cancels out the potential positive contribution to climate resilience.

Resource recovery

8. Social acceptance

The vast majority of Filipinos use flush toilets connected to septic tanks (ARCOWA, 2018). The general practice is to wash themselves with water and soap after using the bathroom instead of using toilet paper to wipe ("The main purpose of the bucket (or tabo) in Filipino bathrooms," 2011) . They wash themselves making use of something called the 'Tabo'. The Tabo can be best described as a plastic 'bucket-like' tool used for cleansing and bathing as well as flushing the toilet and cleaning the floor in bathrooms (Tan, 2011). Tabo roughly translates to a 'pitcher' or 'water dipper' but this doesn't quite cover the actual meaning according to Michael L. Tan, who writes about Filipino culture. He describes the plastic Tabo as 'an almost indispensable fixture in a Filipino home' (Tan, 2011). The Tabo is such a big part of the Filipino home-culture, some Filipinos even go so far as to bring a Tabo with them when they travel overseas.

Several organizations and NGOs have started to implement ecological sanitation systems (Ecosan) in the Philippines where the use of water is completely brought to zero (Lapid, 2007; Tilley et al., n.d.). In these systems, urine is separated from feces and stored separately to create fertilizers. There is no flush water involved since the feces need to be dry. Hence, it is not possible to wash oneself after using the bathroom. Lapid describes that it takes a lot of convincing, attitude change and training before Ecosan systems can be used since it is a sign of progress and social status to have a flush toilet (Lapid, 2007). The Ecosan system is particularly useful in areas with water scarcity in combination with agricultural land where the fertilizer can be applied. Neither of these is the case in the Hagonoy area, meaning the additional effort going into the social acceptance of Ecosan systems, might not be balanced out by the benefits.

In conclusion, the Tabo, and therefore the use of water, is an integral part of Filipino households and their sanitation rituals. A lot of time has to be invested to train and educate the residents before they accept other user interfaces. Depending on the location of the sanitation system, an assessment had to be made if this investment would reap enough benefits.

Treatment selection

In this section, the selection for the treatment scenarios is laid out based on the design criteria. In order to provide a flexible and scalable treatment solution for a wide range of locations, a framework with different compartments is designed as opposed to a single treatment line. The compartments can be combined to suit a particular location and desired effluent quality.

As mentioned in design criteria 1, 2 and 7, decentralized treatment facilities offer benefits in several areas. Having an on-site treatment system prevents using land suitable for housing and avoids large foundational expenses and unforeseen subsidence circumstances. Additionally, a decentralized system is preferred over centralized systems due to logistical challenges and costs associated with the collection and transport of wastewater. In case of resource recovery, limiting transport costs increases profitability as well as resident involvement due to on-site recovery and application.

Ruling out centralized treatment facilities, a large variety of decentralized systems is left. The systems based on biological treatment are mostly comprised of varieties of anaerobic digestion (Tilley et al., n.d.). Other biological treatments, such as aerobic digestion, require pumps for oxygen circulation. Oxygen pumps require energy and are technologically more complicated than anaerobic digestion. Consequently, aerobic digestion can be discarded since it is not in line with criterium 3.

On-site treatment systems in a floating community, naturally have to be able to float as well. This weight limitation rules out many anaerobic systems according to design criterium 6. Septic tanks, anaerobic filters and anaerobic baffle reactors are large tanks that accumulate a lot of wastewater and sludge over a long time. Commonly, the tanks are constructed from heavy materials such as concrete. Placing these systems on top of a floating platform causes problems in the weight stability and buoyancy requirements of the platform. However, the physical limitations of the floating platform can be circumvented by implementing a different floating mechanism; a treatment system with the ability to float itself. This self-floating ability requires a light construction material such as plastic as well as a high buoyancy acquired by gas production. Biogas production not only provides buoyancy aiding in floatation but also fulfills the design requirement for resource recovery. This leaves anaerobic digesters as possible treatment systems.

Considering the wide range of anaerobic digesters, design criteria 3 and 5 provide reasoning for choosing a low-tech version. By opting for a low-tech anaerobic digester, reactors with mixing mechanisms are excluded, lowering the risk of mechanical failure. Additionally, the system is easier to maintain which favors affordability.

Anaerobic digesters are based on biological treatment in absence of oxygen. Microorganisms are sensitive and perform best under specific circumstances. Criterium 7 dictates that fluctuations in the influent concentrations have to be monitored to prevent reactor failure. Additionally, residents should be educated on the use of the sanitation system.

A few anaerobic digesters fit the aforementioned requirements, meaning they are low-tech, affordable and made from a light material. However, the size and surface area of the treatment line also have to be taken into consideration. For a treatment system serving four households, the area should be kept as small as possible. Hence, the choice was made for a Upflow Anaerobic Sludge Blanket-septic tank (UASB-septic tank). The UASB-septic tank occupies a limited footprint and has a small volume and is therefore ideal for small scale, floating communities.

Anaerobic digestion serves as a primary treatment step where the sludge is stabilized. However, depending on the discharge requirements of the area, post-treatment steps are also considered. The next chapter lays out a framework where several post treatment steps can be combined with the UASB-septic tank.

Figure 5 gives an overview of the design criteria that follow from an analysis of the important neighborhood aspects.

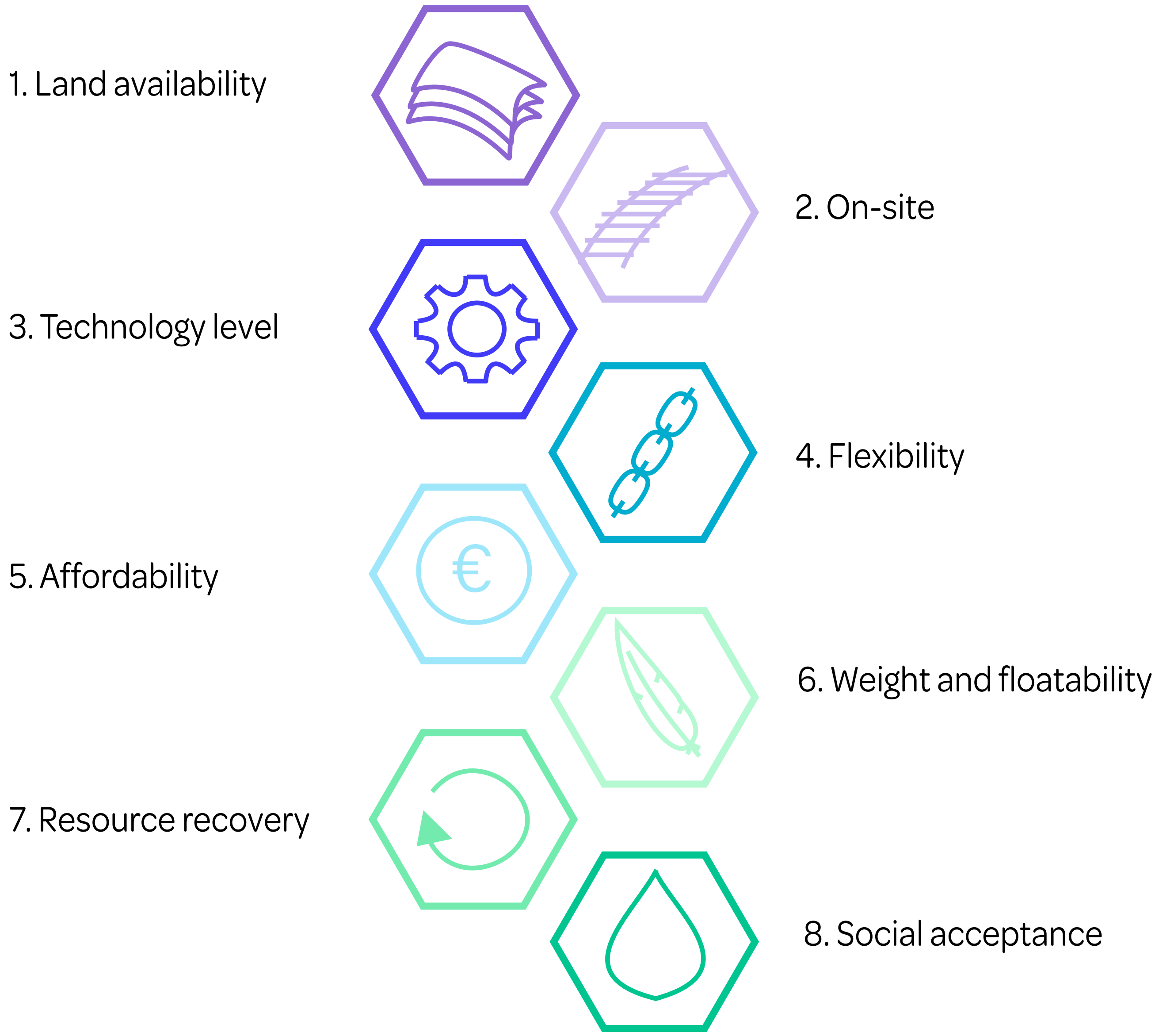
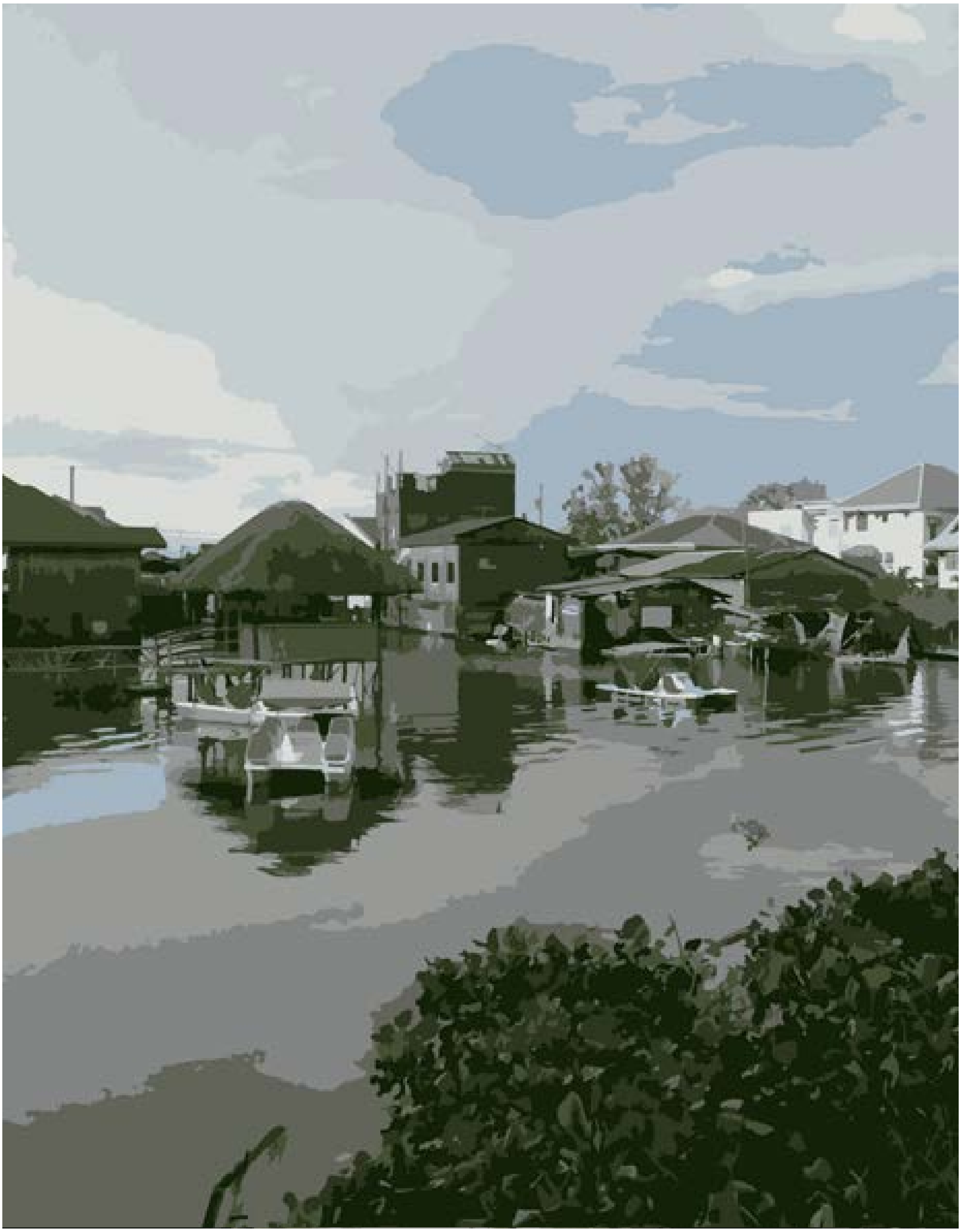


Figure 5. Design criteria for the sanitation system in a floating neighborhood.

PART 2

Technological Design



Technological design:

The following chapter describes in detail the technological aspects of the sanitation scenarios. The dimensions of every compartment in the scenarios are discussed as well as the fluxes everywhere in the system and biogas yields. Next, several scenarios, containing a different combination of treatment steps, are compared based on the effluent quality and costs.

3. Technological design

Overview

Within this concept presentation the focus lies on all technical details relating to the treatment of the wastewater ranging from the user interface, the inflow into the system, to the last polishing step before discharge into the surrounding waterbody or application for other purposes. The treatment options are laid out in several treatment scenarios suitable for different discharge requirements, since the water quality of the receiving waterbody is unknown. The treatment scenarios have modular blocks that can be combined depending on the desired effluent quality. This provides a framework for designing sanitation in floating communities.

Figure 7 shows the framework for the sanitation scenarios and Figure 6 shows the three different scenarios. The compartments are separated in primary treatment, a polishing step and a disinfection step.

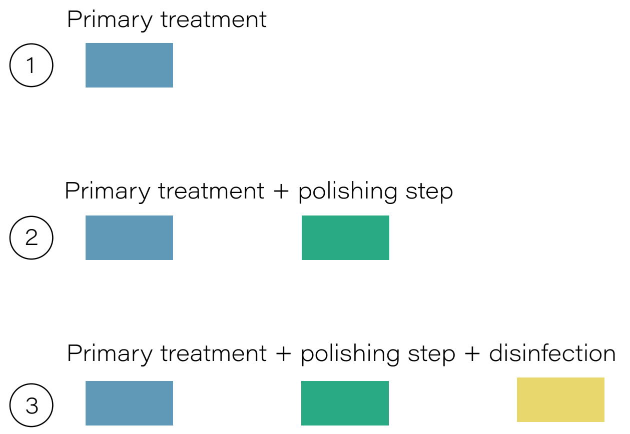


Figure 6. Treatment scenarios based on required effluent quality.

The scenarios that will be discussed in this report are the following:

1. In the first scenario, the water quality of the receiving waterbody is poor and already contains nutrients and pathogens. There is no need for a polishing or disinfection step.
2. The second scenario, the risk of eutrophication of the waterbody demands removal of the nutrients. The removed pathogens are a bonus.
3. In the third scenario, the effluent quality needs to adhere to strict discharge requirements set by the Philippine government. Both a polishing and disinfection step are required.

The different compartments and their technological details are discussed after which the scenarios are compared based on their effluent quality and costs.

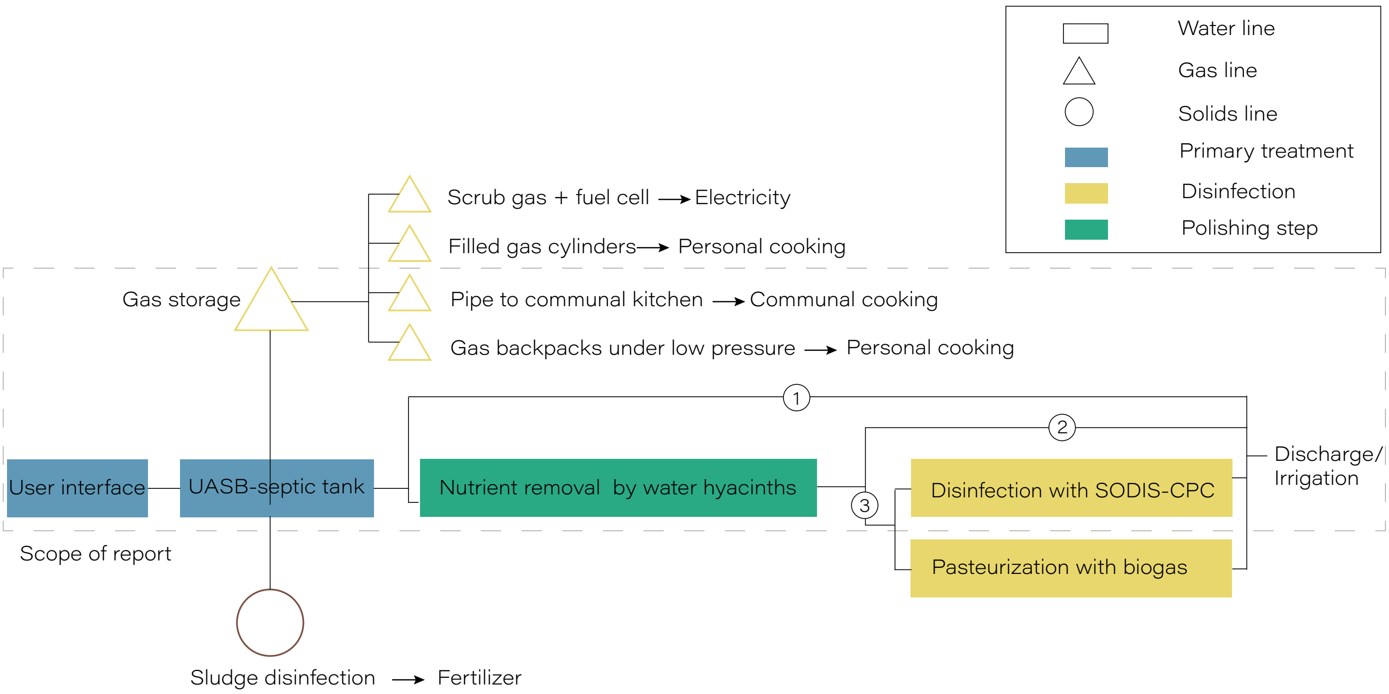
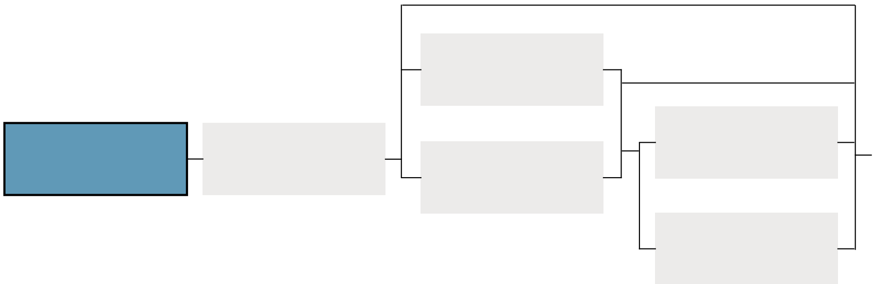


Figure 7. Framework for designing a decentral sanitation system.

User interface



As discussed in the previous chapter, a wet user interface is preferred. This means the urine and feces are flushed with water. This can be done with a mechanical flushing system where 6-12 L is flushed per flush, or by hand where the amount of flush water can be customized by changing the size of the bucket that is used to flush (Kujawa-Roeleveld et al., 2006). In the Philippines, a Tabo is used for flushing, amongst other things (Figure 8) (The Tired Mama PH, 2019) On average, the Tabo has a volume of approximately a liter (Tan, 2011).

Figure 8. Bucket of water ('Timba') with a 'Tabo' (smaller bucket) to scoop the water out of the bucket (The Tired Mama PH, 2019).

Frequency of use

Clare et al. describes that 8 urinations per 24 hours were recorded for a population sample in the US (Clare et al., 2009). However, some studies have reported that children have a 33% reduced urinary output compared to adults (Almeida et al., 1999). Bael et al. report a median number of 6 urinations per 24 hours for children aged 6 to 12 (Bael et al., 2007). It is assumed the houses in the floating neighborhood will be occupied by families consisting of 2 adults and 2 children, hence the average amount of urinations in this design is set to be 7 urinations per 24 hours.

As for the frequency of defecation, it is assumed that one urination per 24h is combined with defecation, flushed with 1L of water. Since no toilet paper is used, wash water has to be taken into account, for which a Tabo is also used. This accumulates to 7L of flush water + 1L of wash water pp per day.

The concentrations of the inflow can be found in appendix 1.

Figure 9. User interface with in- and outflows

Pipes

The toilet is connected to the anaerobic digester via PVC pipes with a diameter of 10 cm (Smith, 2021). According to the regulations regarding horizontal drainage piping in the national plumbing code of the Philippines, the pipes will be installed with a 2^{o} angle (Amosco et al., 2000).

Considering the amphibious nature of the platforms, interaction between the platforms requires a certain flexibility. Both in connections between the platforms and walkways as well as the pipes.

The flexible connections increase storm-resilience since they allow for more movement between pathways and platforms. At connection points, flexible seals are applied to allow for movement in the pipe levels (Figure 10). However, these connections are less durable than rigid PVC pipes and require manual checks after large storm events. The flexible pipe connections are easily replaced in case of breakages. Leakages of pipes or other compartments and the associated risks are discussed in chapter 5.

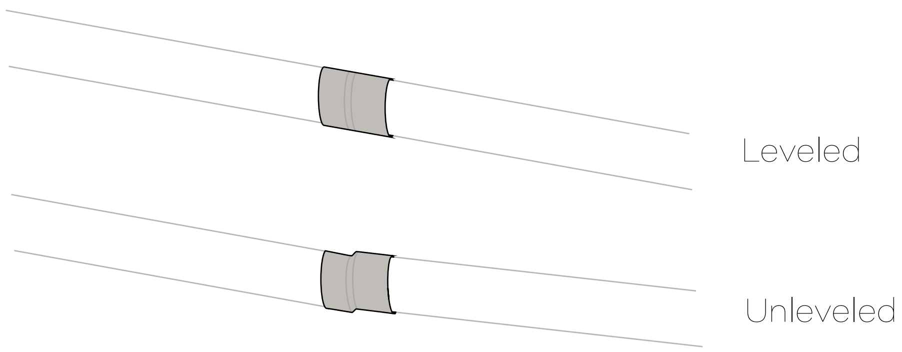
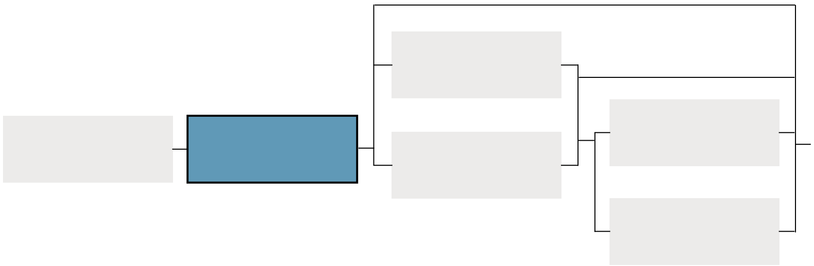


Figure 10. Flexible Pipe connections to accommodate varying water levels that fluctuate the platforms.

Anaerobic digester



Once the wastewater reaches the 'treatment platform', it enters the UASB-septic tank. In this reactor the majority of the treatment takes place. Approximately 80% of the solids is removed and transformed into biogas by methanogens and other microorganisms via the processes described in Figure 12. The anaerobic digester also plays a minor part in pathogen removal in the form of 1-log reduction of coliform forming units (CFU) (Forbis-Stokes et al., 2016). This translates to 90% removal of CFU. However, 90% pathogen removal is not sufficient to adhere to the discharge standards of the receiving waterbody. For a freshwater class C, the discharge standard for fecal coliform levels is 200 MPN/100 ml* (Table 2). After anaerobic digestion, the effluent still contains 4,5 million CFU/100 mL.

The proteins, lipids and carbohydrates are transformed into methane and CO_2 via four phases, hydrolysis, acidogenesis, acetogenesis and methanogenesis.

* *MPN stands for Most Probable Number and is a statistical method for estimating the viable number of bacteria. (Karunasagar et al., 2018)*

The bacteria performing these transformations are naturally present in wastewater. Once the system is running there is no need for inoculating the reactor with new bacteria since the present bacteria will grow and multiply. However, starting up the reactor requires an inoculum from another anaerobic reactor to jumpstart the process. The inoculum comes from a reactor running on wastewater or manure. After inoculation, it takes a few months to establish a good removal efficiency by the reactor with the new wastewater concentrations. During this startup period, the effluent quality cannot be guaranteed.

With an inflow of 152 L/d and a desired Organic Loading Rate (OLR) of 0,48 g COD/L/d, the reactor volume becomes 250 L (Lohani et al., 2015). The OLR is the mass rate of organic substrate addition per unit volume of an anaerobic reactor (Metcalf& Eddy, 2014).

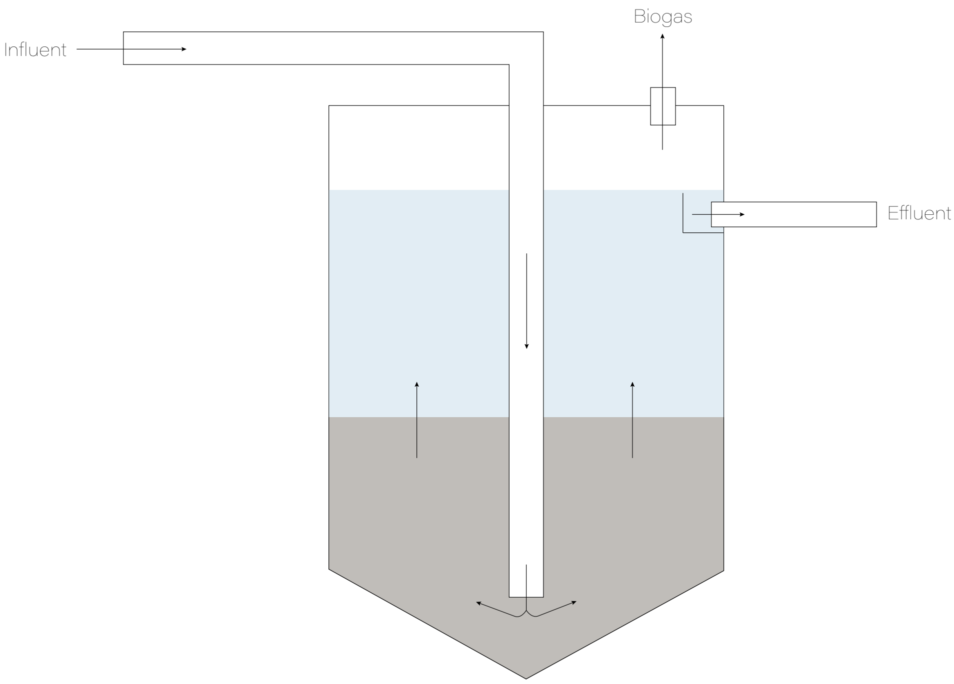


Figure 11. Upflow Anaerobic Sludge Blanket-septic tank. The influent is flowing in at the bottom of the reactor through the sludge layer where the COD is transformed into biogas.

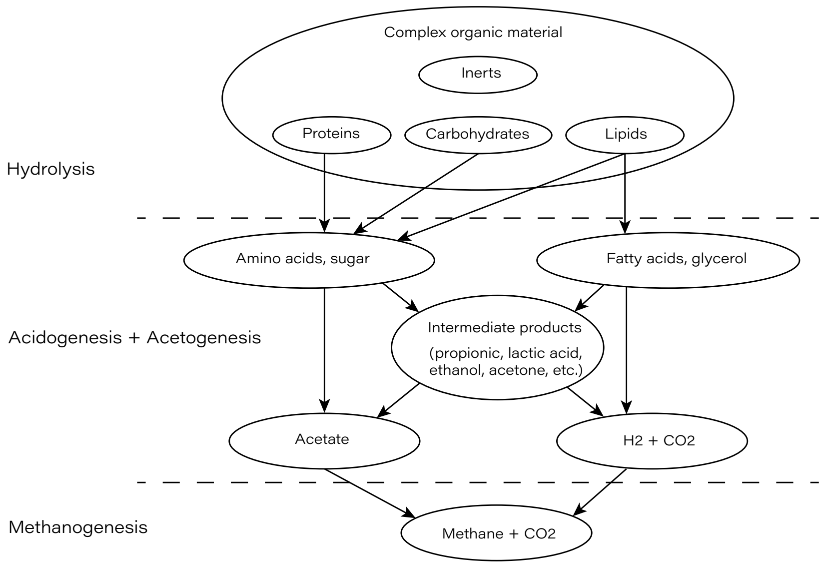


Figure 12.Stages of anaerobic digestion.

Co-digestion

Methane produced by methanogens is converted from available COD in wastewater. Consequently, the amount of biodegradable COD in the water directly influences how much biogas is produced. To boost methane production, the COD concentration can be increased by mixing in food waste (FW) in a process called co-digestion (Mehariya et al., 2018; Shah et al., 2015). Next to an increased biogas yield and therefore more available renewable energy, co-digestion provides a partial solution against food waste. Van Massow et al. estimate that individuals generate up to 85 kg of FW per year (von Massow et al., 2019).

However, to prevent acidifying the reactor, a certain ratio of FW and total solids (TS) in the reactor has to be maintained, meaning not all food waste can be mixed in. In this design an FW:TS ratio of 1:3 is maintained to establish a healthy alkalinity in the reactor, which buffers the acidity (Zhang et al., 2021).

The FW needs to be ground up into smaller particles with a kitchen grinder before it is mixed in with the wastewater in the reactor. A latch in the influent pipe provides an opening through which the FW can be mixed in with the wastewater.
The biogas yield increases from 427-926L/d to 440-943 L/d due to co-digestion, giving the following yields in table 1. The increase gives 2-3 minutes of extra cooking per day.

It must be noted that co-digestion may also have adverse effects depending on the FW composition. The presence of fatty substances causes blocking, mass transfer problems and microbial inhibition. So high-fat FW is not recommended (Hagos et al., 2017). Fibrous substrates can trigger the formation of floating layers in the reactor (Lienen et al., 2013). However, FW generally does not contain as many fibrous substrates as agricultural waste and therefore is not expected to cause a problem.

Table 1. Parameters of the anaerobic digester.

Parameter	Unit	Numerical value
Inflow	L/d	152
Outflow	L/d	152
Hydraulic Retention Time	d	4
Volume of reactor	L	250
Temperature	^{o}C	25
Produced methane (CH_4) at 25 ^{o}C	L/d	286 - 613
Produced biogas	L/d	440 - 943
Energy use stove (Tilley et al., n.d.)	L/h	325
Hours of cooking	h	1,4 - 2,9

Gas production

The produced biogas consists of methane (CH_4), carbon dioxide (CO_2) and the trace gases nitrogen gas (N_2), hydrogen gas (H_2) and hydrogen sulfide (H_2S) (Forbis-Stokes et al., 2016). The higher the methane content of the gas, the more energy the biogas contains. Methane has an energy content of 36522 kJ/m³ (Engineering ToolBox, 2008). CO_2 has no heat of combustion and therefore does not contribute to the energy content of the biogas.

Methane and CO_2 are odorless gasses making biogas an excellent source of energy for cooking. H_2S however, is not odorless and resembles the smell of rotten eggs. It is also extremely toxic and can cause symptoms such as nausea, headaches and dizziness at low concentrations (0,05 mg/m³) and can even be fatal in high concentrations (100 mg/m³) (Tranh, n.d.). Apart from the health concerns, H_2S also corrodes the biogas burners (Forbis-Stokes et al., 2016). Therefore it is important to scrub the H_2S from the biogas.
There are several possibilities for scrubbing H_2S based on oxidation. One of which is creating microaerobic conditions where the H_2S is converted to S^0 or sulfate by the presence of oxygen. The following chemical reactions take place (Wu et al., 2016):

$$H_2S + \frac{1}{2}O_2 \rightarrow S + H_2O$$

$$H_2S + 2\,O_2 \rightarrow SO_4^{2-} + 2\,H^+$$

In these chemical reactions, the H_2S reacts with oxygen to form S^0 and SO_4^{2-} after which it precipitates in the reactor.

The pipe that connects the user interface with the reactor not only transports wastewater but also air. Since the concentration of H_2S is very low, it is expected that the oxygen fraction of air provides enough O_2 to convert the H_2S present in the biogas.

It should be noted that biogas may also contain moisture which has a corroding influence. Moisture content does not have health implications. The moisture content varies per system and should be determined before the choice is made to install a dehumidifier.

Gas Storage

The storage of gas can be done inside the reactor or in a storage container or bag outside the reactor. In case of storage in the reactor, the volume of the reactor should be increased depending on the amount of gas to be stored. In this design, the produced biogas per day is 1,5-3 times the size of the reactor. Even with daily use of the biogas, the reactor cannot be modified to store this amount of biogas. The produced biogas is therefore stored in an external biogas bag. The bag is placed close to the reactor and connected with a pipe to the reactor. A residual 20 millibar of biogas is stored inside the reactor to maintain pressure for the outflow of the effluent.

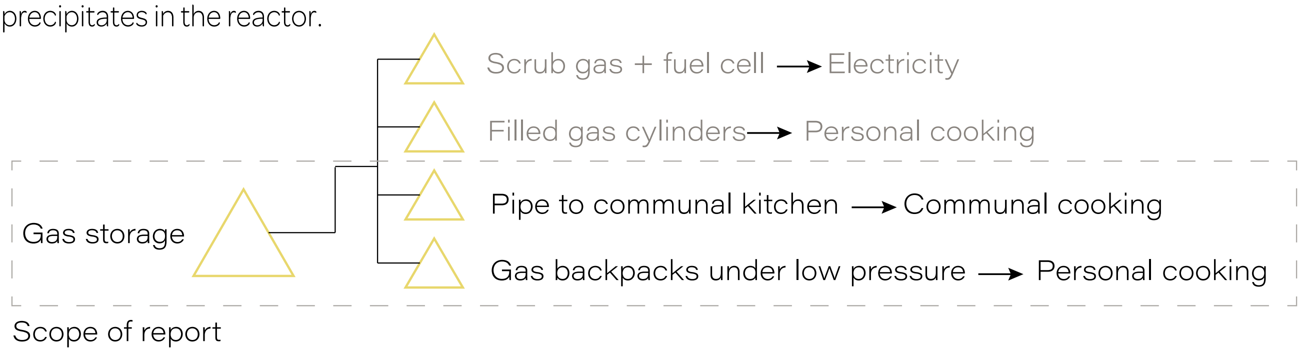


Figure 13. Gas application options. The options outside the scope of the report become feasible when the scale of the project increases.

Extraction of gas

The collected biogas can be applied in several manners. It can either be used for cooking or for electricity generation (Figure 13).

The current method of cooking in the area is by using gas cylinders connected to a stove. Ideally, the transition to using renewable gas for cooking is made as easy as possible. However, transferring the biogas to gas cylinders requires specialized equipment. Due to the dangers associated with the high pressure needed to fill the cylinders, the equipment has to be used by trained personnel. Therefore, this option is left out of the scope of this report (Figure 13). In a larger scale system, this option is worth exploring since it will be more cost-effective.

To produce electricity, biogas is transformed by a fuel cell. In order for this to work, the biogas has to be cleaned and scrubbed to remove all moisture and H_2S to prevent corrosion of the fuel cell. Fuel cells are specialized and expensive equipment, as well as more advanced biogas scrubbers. Hence, this option is only appealing on a larger scale to make it cost-effective.

In case the biogas is used for cooking directly, two options are possible.

The first is to connect a pipe from the biogas storage straight to the stove. It doesn't require a lot of pressure to let the gas flow through a pipe so the pressure buildup in the storage container is enough to transport it over short distances. However, the longer the distance, the higher the pressure drop in the pipes. Hence, the direct connection is ideal in situations where a communal kitchen is used that can be situated close to the gas storage.

When communal kitchens are not preferred by the residents, the biogas can still be used for personal cooking. In this case, the gas needs to be collected by the individual residents in a bag. The pressure in these bags once filled is similar to atmospheric pressure which makes it safe to be handled by anyone(Figure 14) ((B)energy, n.d.).

Figure 14. Biogas backpacks image edited from ((B)energy, n.d,).

Polishing pond

Depending on the water quality of the receiving waterbody, discharging the effluent might increase eutrophication of the receiving waterbody. To prevent this, scenario 2 and 3 include a polishing step where the nutrients N and P are removed via water hyacinths (*Pontederia Crassipes*) (Figure 15). Water hyacinths have a high removal efficiency of ammonia and phosphate (0,6 g/m²/d and 0,15 g/m²/d respectively) (Sooknah & Wilkie, 2004). Other aquatic macrophytes that are capable of nutrient removal also reach removal efficiencies in the same range and are just as invasive for the local ecosystem as the water hyacinth. The reason that water hyacinths were chosen over water lettuce or pennywort, is that water hyacinths exhibit a sturdier growth in waters with a higher salinity (Sooknah & Wilkie, 2004). As mentioned before, the water in the area is brackish which is why water hyacinths are preferred.

During anaerobic digestion,hardly any nutrients are removed (apart from nutrients needed for biomass growth). So the nutrient concentrations to be removed are approximately equal to the concentrations in the influent (Table 3).

Water hyacinths have a very high removal efficiency under optimal conditions (Table 3). The pond is designed in a way that the effluent is diluted with a 1:1 ratio to create favorable conditions for the water hyacinths. This dilution is taken into account with the final nutrient concentration. Considering the nitrogen concentration, only ammonia removal is taken into account since the nitrate fraction of the nitrogen output is negligible compared to the ammonia fraction.

The nutrient discharge standards for different water classes are displayed in table 2.

Figure 15. Flowering Water hyacinth plant. (Osmond & Petro-eschevsky, 2013)

Table 2. Discharge standards for nutrient levels in the Philippines (Department of Environment and Natural Resources, 2016).

Waterbody classification		Unit	Ammonia as NH3-N	Phosphate
AA	Public water supply Class I; Protected water area, only disinfection required before use as drinking water	mg/L	0,05	<0,003
A	Public water supply Class II; Use as drinkwater after conventional treatment (coagulation, sedimentation, filtration, disinfection)	mg/L	0,05	0,5
B	Recreational Class I; bathing, swimming	mg/L	0,05	0,5
C	Recreational Class II; fishing, boating, agriculture	mg/L	0,05	0,5
D	Navigable waters	mg/L	0,75	5
SA	Protected waters such as reserves, marine parks and sanctuaries. Fishery water class I; shellfish harvesting for direct human consumption	mg/L	0,04	0,1
SB	Ecotourism Fishery water class II; spawning area milkfish-like species Recreational water class I; bathing, swimming	mg/L	0,05	0,5
SC	Fishery water class III; propagation and growth of aquatic resources for commercial and sustenance fishing Recreational water class II; boating, fishing Marshy/mangrove area declared as wildlife sanctuary	mg/L	0,05	0,5
SD	Navigable waters	mg/L	0,75	5

Table 3. Hyacinth pond parameters and removal rates of COD, ammonia and phosphate (Sooknah & Wilkie, 2004).

Parameter		Unit	Numerical value
Retention time		Days	31
Pond measurements	Depth	m	1,5
	Inflow	L	152
Influent concentrations	NH3-N	g/L	0,04 - 0,14
	P	g/L	0,14 - 0,30
	COD	g/L	0,85 - 1,82
	Pathogens	CFU/100mL	$4,4 * 10^6$
Removal rates	NH3-N	$g/m^2/d$	0,62
	TP	$g/m^2/d$	0,15
	COD	$g/m^2/d$	7,96
Decay rate day 1-7	Pathogens	d^{-1}	0,50
Decay rate day 7-end	Pathogens	d^{-1}	0,27
Required surface area to reach discharge standards	NH3-N	m^2	5,5 - 17
	P	m^2	72 - 157

Nutrient removal

The removal rates for ammonia and phosphate are 0,62 $g/m^2/d$ and 0,15 $g/m^2/d$ respectively. Considering these removal rates, the area of the pond can be adjusted to adhere to the discharge standards set by the Philippine government (Table 2). The removal rate for ammonia is higher and the influent concentration is lower than for phosphate, giving a required surface area between 5 and 17 m^2. However, this does not suffice for phosphate. With a removal rate of 0,15 g $P/m^2/d$, the required area of the pond is between 75 and 157 m^2.

Ideally, the treatment system occupies a land area as small as possible to create more space for housing. Hence, the treatment platform containing the UASB-septic tank is kept as small as possible (~1/4 of a housing platform*). However, the polishing pond also serves an aesthetic purpose aside from its functionality so arguably, the size can be larger than the treatment platform. One treatment platform and polishing pond serve four households. As a rule of thumb, the treatment platform and polishing pond combined should occupy an area equal to maximum of one housing platform (23 m^2). This way, not too much space is taken away from housing. Keeping this restriction in mind, the polishing pond will have a surface area of maximum 17 m^2, enough for reaching the ammonia discharge standards.

With a surface area of 17 m2, the polishing pond reaches a phosphate effluent concentration of 53-135 mg/L which does not reach the effluent requirements (0,5 mg/L). However, during the retention time of 31 days, the water hyacinths still remove 77 grams of phosphate from the effluent. Even though the phosphate discharge requirements are not met, the effects on eutrophication are greatly reduced by implementing the polishing step.

Using water hyacinths as a polishing step after anaerobic digestion, gives promising results in the context of a floating neighborhood since the discharge requirements for ammonia can be met while also removing 11-23 % of the phosphate.

**In scenarios 1 and 2. Scenario 3 has a treatment platform of ~1/2 the size of a housing platform.*

Pathogen removal

Human feces contain many bacteria coming from the intestinal flora. These bacteria include non-harmful species that aid in processing food in the intestines as well as bacteria and viruses that can be harmful upon contact with humans. The percentage of viable cells in the bacterial mass of feces is reported to be around 49% by Ben-Amor et al., meaning 49% of bacteria and viruses can potentially cause harm and have to be removed depending on the guidelines (Ben-Amor et al., 2005).

Removal Anaerobic Digestion

As previously mentioned, the anaerobic digester provides a 1-log removal of CFU, meaning 90% of the viable bacteria are removed in the reactor. Ben-Amor et al. (2005) report a mean total cell count per g feces wet weight of 8,6 $*10^{10}$ CFU/g out of which 49% are viable cells, leaving 4,2 $*10^{10}$ CFU/g feces (4,5 $*10^{6}$ CFU/ 100 mL) that need to be removed if the discharged standards have to be adhered.

Guidelines

The discharge guidelines in the Philippines depend on the water class of the receiving waterbody (Table 4). Due to the slightly brackish water and the changing user purposes of the lakes, it is unsure under which category the receiving waterbody falls.

Since the lakes have been previously used for cultivating fish, it is assumed that the waterbody falls in the freshwater classification C which states the following uses :

1. Fishery water for the propagation and growth of fish and other aquatic resources.
2. Recreational water class II – for boating, fishing, or similar activities
3. For agriculture, irrigation and livestock watering.

The pathogen discharge standard for freshwater class C is 200 MPN/100 mL.

Table 4 Discharge standards for pathogen levels in the Philippines (Department of Environment and Natural Resources, 2016). AA until D are freshwater sources. SA until SD are salt water sources.

Waterbody classification	Unit	Fecal coliforms
AA	MPN/100mL	<1,1
A	MPN/100mL	<1,1
B	MPN/100mL	100
C	MPN/100mL	200
D	MPN/100mL	400
SA	MPN/100mL	<1,1
SB	MPN/100mL	100
SC	MPN/100mL	200
SD	MPN/100mL	400

Pathogen decay

Pathogens are living organisms which means they die after a while. The rate by which this happens is the decay rate. The water in the polishing pond has a retention time of 31 days during which the nutrients are removed. Simultaneously, the retention of the water has the added benefit of providing time for the pathogens to die.

Microorganisms each have a different decay rate, making it difficult to predict how many pathogens will die during the 31 days. Using the indicator microorganism, *Escherichia coli*, an estimation can be made. Easton et al. (2005) report a difference in decay rate in the first 7 days and the time after day 7 for *E.coli* in water of 23 ºC.

Decay rate day 1-7: 0,50 d^{-1}
Decay rate day 7-end: 0,27 d^{-1}
(Easton et al., 2005)

The decay of microorganisms can be calculated based on this decay rate (kd) according to the following formula:

$$X = X_0 * e^{-kd*t}$$

X represents the biomass over time, X0 the starting biomass, kd the decay rate and t represents time.

The water exits the UASB-septic tank with a pathogen concentration of 4,5 *10^6 CFU/ 100 mL (Table 5). With a decay rate of 0,50 d^{-1}, the pathogen concentration at day 7 equals 1,3*10^5 CFU/100mL. After day 7 the decay equals 0,27 d^{-1}, meaning the discharge standard of 200 MPN/100 mL is reached after day 31, with a log removal of 4,3 (Table 5).

It must be noted that *E.coli* is often used as an indicator organism for fecal pathogens but it shows a higher decay rate than many other microorganisms often present in feces such as Enterococci or helminth eggs. This means that other harmful fecal pathogens might still be present in the water after 31 days. So even though *E.coli* is a commonly used indicator for fecal pathogens, it does not properly represent the die-off of more persistent microorganisms.

Depending on the application of the effluent, the choice can be made to build in an extra safety step to ensure safe pathogen levels in the effluent. This can be done with a disinfection step.

Table 5. Pathogen level in the polishing pond based on the decay factor of E. coli.

Day	Unit	Numerical value
1	CFU/100mL	4,4 * 10^6
7	CFU/100mL	1,3 * 10^5
14	CFU/100mL	2,0 * 10^4
21	CFU/100mL	3,0 * 10^3
27	CFU/100mL	465
31	CFU/100mL	208

Effluent application

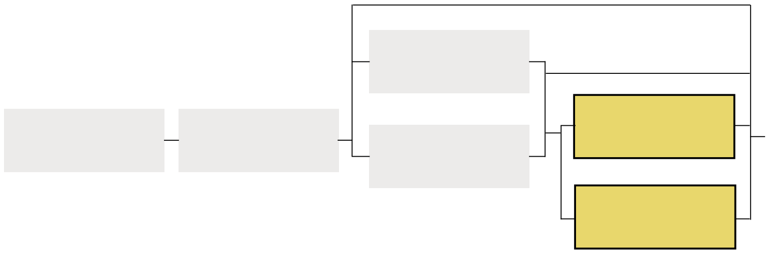
Effluent can be used for irrigation purposes under specific circumstances. The regulations from WHO, based on health-based targets, state that for drip irrigation use, the log reduction of pathogen levels is 2 and 4 for high-growing and low-growing crops, respectively (WHO, 1989). With the decay rates of *E.coli*, these log removals are reached by the polishing pond, meaning the effluent is theoretically suitable for drip irrigation. The specific irrigation application will be described in chapter 5.

Plant growth

Under ideal conditions (slow-moving fresh water), water hyacinths will double in mass every 5 days (Osmond & Petroeschevsky, 2013). Even though the conditions won't be ideal since salinity is an inhibiting factor, regular removal of plant mass will be required. The removed plant mass is very rich in nutrients and fiber, making it suitable for many reuse applications.

The nutrient richness makes the plants suitable to repurpose into fertilizer or as extra biomass in the UASB-septic tank. The leaves are also edible, not only for animals but for people too. In Thailand, the stalks and leaves are added to soups and the fibers may even serve as raw material for fabrics (Chanana et al., n.d.). The applications will be further discussed in the chapter 5.

Disinfection



Depending on the requirements set by the government or the application purposes of the effluent, the choice can be made to build an extra security step into the treatment system. Adding a disinfection step after the polishing pond will ensure a low pathogen level in the effluent.

Figure 16. Solar Disinfection tube combined with a Compound Parabolic Collector (Ubomba-Jaswa et al., 2010). The tube holds 25 L.

Removal Disinfection

Pathogens can be removed from wastewater in many ways, one of which is Solar Disinfection. To keep a net 'energy-producing' system, the choice was made to use solar energy instead of the other available energy source, biogas. Since solar radiation is variable which gives uncertainty, pasteurization with biogas is kept as a backup option. In this case, the biogas cannot be used for cooking anymore. Instead, the gas is burned to heat up the water to pasteurization temperatures, causing the pathogens to die.

The solar energy is harvested in an enhanced version of SODIS (SOlar DISenfection) combined with a CPC (Compound Parabolic Collector) based on the design by Umbomba-Jaswa et al. (Figure 16) (Ubomba-Jaswa et al., 2010).

SODIS performs optimally in direct sunlight and it uses the thermal properties of the sun's energy as well as the chemical properties of UV irradiance. The thermal properties ensure an increase in the water temperature which kills bacteria and viruses that can't withstand heat. The UV irradiance disinfects based on chemically altering the DNA in micro-organisms after which they are unable to live.

The disinfection step can be implemented after the polishing pond. SODIS is highly influenced by the turbidity of the water. Having a polishing pond before the disinfection step means more organics are removed and solids have time to settle, increasing the effectivity of SODIS. The water is pumped from the pond by a small pump into the tube where it remains for 6 hours for optimal disinfection.

The SODIS-CPC system is placed in a 14 ⁰ incline, equal to the latitude of Hagonoy to recover maximum UV A irradiance throughout the year (Ubomba-Jaswa et al., 2010). This means the water has to be elevated to 23 cm above the platform level (Figure 18). To overcome this height difference, a small pump is used, powered by a solar panel.

The water is pumped from the polishing pond into the tubes. The inlet of the pump is placed halfway the depth of the pond to prevent sucking up plants or settled solids. This means the pump has to overcome 23 cm + 75 cm of height (Figure 18).

$$\frac{\Delta m}{\Delta t} = \frac{P}{g \cdot h} = \frac{10\ W}{9{,}81 \frac{m}{s^2} \cdot 0{,}98\ m} = 1{,}0 \frac{L}{s}$$

With a small water pump of 10 Watts, one reactor tube is filled under a minute. The storage barrel is filled up during the day and the night so all tubes can be filled up in the morning. With a timer, the pump is turned on in the morning.
With a sensor on the inlet valves of the tubes, it is measured when the tube is filled up after which the pump fills up the next tube. The outlet valves have a time sensor to let the water flow out after 6 hours, the required time for disinfection. The water then flows into the water hyacinth pond via a pipe with holes to cool the water before it enters the pond.

It takes 2 minutes to fill up 3 tube reactors. The energy required for pumping the water is 1800 Joules per day and is provided by a solar panel.

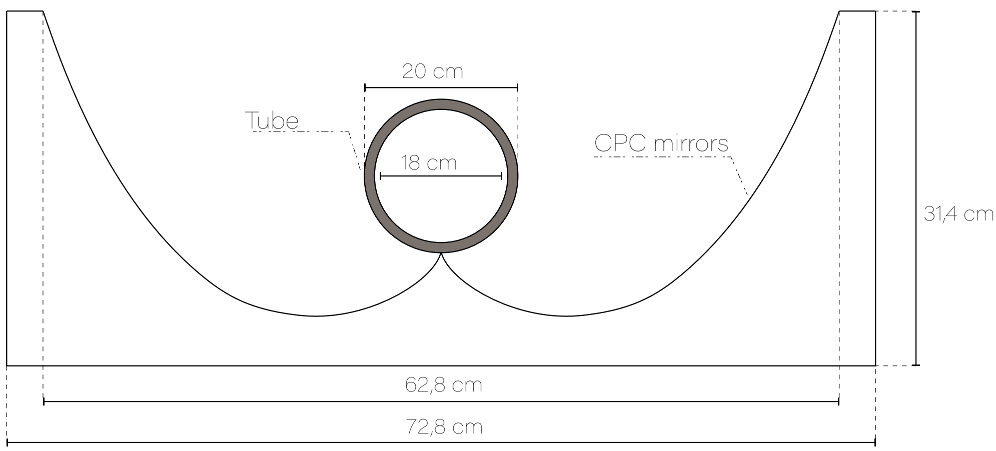


Figure 17. SODIS-CPC intersection. The CPC mirrors concentrate the solar energy on the tube. Adjusted from (Ubomba-Jaswa et al., 2010).

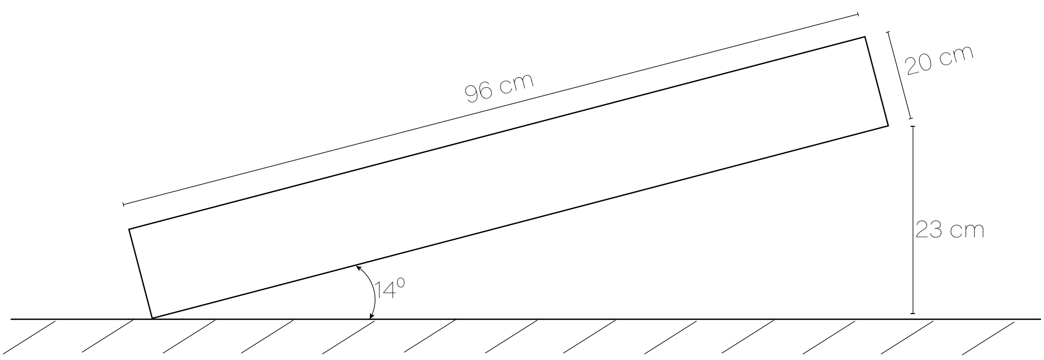


Figure 18. SODIS-CPC sideview. The tube is elevated in a 14 ⁰ angle to recover maximum UV A.

Weather patterns

The climate in Hagonoy follows a wet season and dry season pattern. The wet season is usually longer than the dry season and coincides with more cloudiness and less direct sunlight. Hence, the SODIS was enhanced with a CPS (Figure 16). The CPC ensures that more diffuse light is caught and directed at the SODIS capsule due to its parabolic shape (Figure 17). This system was tested in Almeria, Spain where they obtained inactivation of bacteria to the detection limit (<1 CFU/mL) in clear sky conditions, in less than 6 hours of contact time (Ubomba-Jaswa et al., 2010). In cloudy conditions a residual 2-log concentration of bacteria remained. It is expected that The SODIS-CPC system performs similarly, or even better, in clear sky conditions in Hagonoy seeing that the shortwave irradiance in Hagonoy, on average, is higher throughout the year in these conditions (Figure 19 c). As for the other weather conditions, Hagonoy has a significantly higher UV A irradiance and shortwave irradiance during the 'lower' months indicating that the inactivation will be higher in Hagonoy with the use of this system (Figure 19 a, b).

Bacterial concentrations and turbidity

Due to the inactivation happening during anaerobic digestion and the bacterial decay in the polishing pond, it is expected that the pathogen concentration is already low before it enters the SODIS tube. The UASB-septic tank provides 1 log removal and the polishing pond approximately 4 log removal. This means that the negative influence of cloudy conditions on the final bacterial concentration is less influential since the concentration is already low.

As mentioned before, the polishing pond has a retention time of 31 days. The flow in the pond is very low, providing optimal conditions for any solids still present to settle. The pump entrance is strategically placed, far enough below the water surface to prevent any plant mass from blocking the entrance and far enough away from the bottom to prevent any solids from being stirred up. These measures ensure that a negative influence by turbidity is avoided.

In short, the SODIS-CPC serves as an appropriate disinfection step when extra security has to be built into the treatment system.

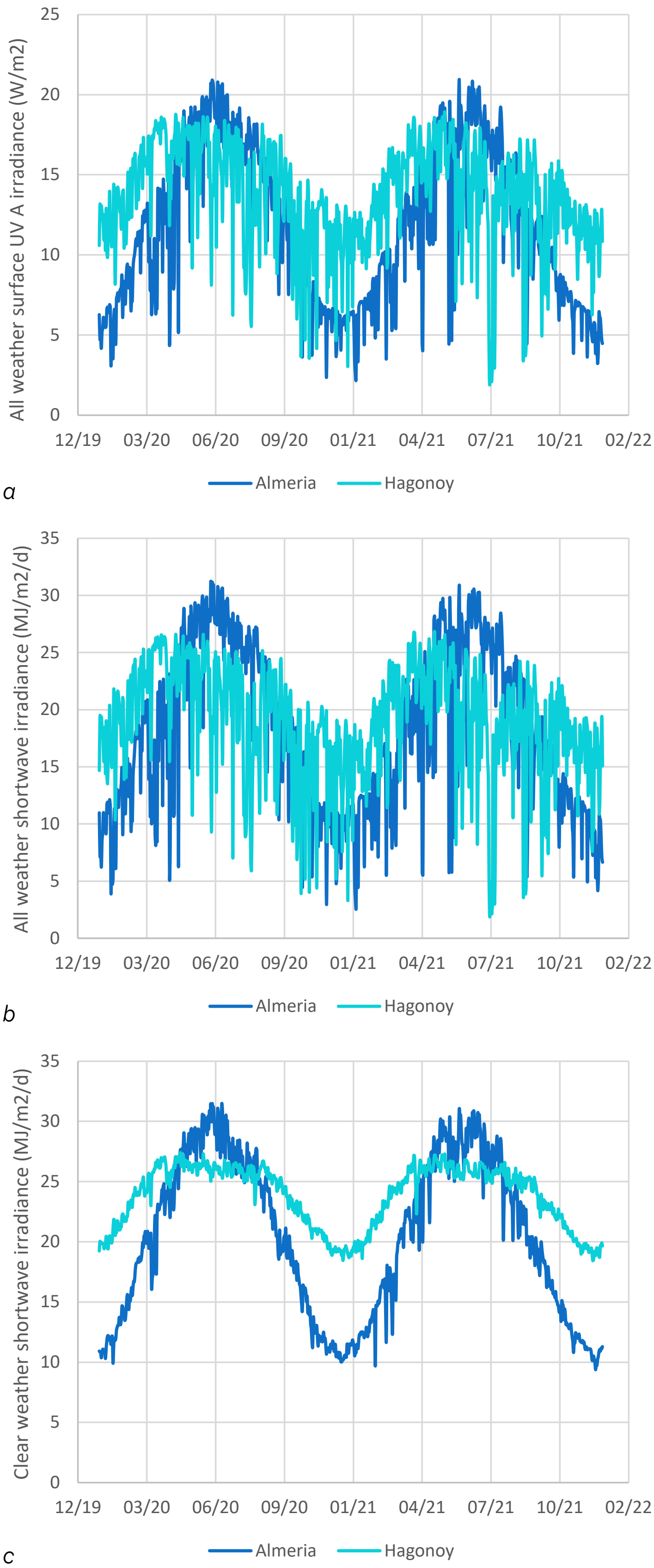


Figure 19. Weather conditions in Almeria and Hagonoy over a two-year period. (a) UV A irradiance for all weather conditions. (b) Short-wave irradiance for all weather conditions. (c) Shortwave irradiance for clear sky conditions.

Scenario comparison

Treating wastewater with the goal of discharging the effluent into a surface waterbody has to be done with the effluent quality in mind. To create the most cost-effective treatment system, the effluent quality should be similar to the quality of the receiving waterbody. Discharging effluent with a higher quality than the receiving water, effectively dilutes the existing pollution.
Therefore, it is important to adjust the treatment according to the required effluent quality to have a cost-effective treatment system.

In order to facilitate varying effluent qualities, a framework has been presented in this report where modules can be chosen and combined to reach the desired quality for specific parameters. Three scenarios following from this framework will be compared based on their effluent qualities and on the corresponding costs associated with the scenarios (Table 6).

The parameters of importance are the COD concentration, pathogen levels, phosphate concentration and ammonia concentration. Potential application purposes are laid out as well.

Table 6. Scenario comparison based on effluent parameters.

	No treatment	Scenario 1	Scenario 2	Scenario 3
Primary treatment				
Polishing				
Disinfection				
	No treatment	Scenario 1	Scenario 2	Scenario 3
COD concentration (g/L)	5,6 - 12,0	0,9 - 1,8	0,04 - 0,09	0 - 3,3
Pathogen concentration (CFU/100 mL)	$4,5 \cdot 10^7$ (4,5*10⁷)	$4,5 \cdot 10^6$	~200	<200
P concentration (mg/L)	$(1,4 - 3,0) *10^{-2}$	$(1,4 - 3,0) *10^{-2}$	$53 - 1,3 *10^{2}$ *	$53 - 1,3 *10^{2}$ *
NH_3 concentration (mg/L)	$(0,4 - 1,4) *10^{2}$	$(0,4 - 1,4) *10^{2}$	0-0,05 *	0-0,05 *

* *The P and NH3 concentrations correspond with a polishing pond of 17 m2.*

Cost comparison

The costs associated with the different scenarios can be divided into two categories: capital costs and operational costs. Capital costs (CAPEX) include one-time costs such as building materials and installation costs. Operational costs (OPEX) include costs that have to be paid continuously such as maintenance costs, cleaning supplies, replacement parts and electricity. A list of all compartments and their costs can be found in appendix 2.

All scenarios share the base investment costs associated with the primary treatment step: Toilets, UASB-septic tank, gas storage and the platform in which the UASB-septic tank is located. This adds up to a base CAPEX cost of roughly €4400. For scenario 2 the CAPEX costs are slightly higher due to the construction costs of the water hyacinth enclosure (€5000). Adding a disinfection step increases the CAPEX costs to around €6500 due to the construction of the SODIS-CPC tubes and the fact that the platform needs to increase in size to accommodate the SODIS tubes. The investment costs are for a treatment system serving 4 households with 16 people total.

On the long term however, the OPEX costs increase the differences between the scenarios even more. For scenario 1 the operational costs largely consist of replacement parts for compartments like the gas storage bag and the kitchen grinder. Per year the costs add up to €150/y (€38/y per household).

The operational costs for scenario 2 also include the replacement of weeding equipment, pond plastic and bamboo fencing which adds up to roughly €200/y (€50/y per household). Lastly, scenario 3 has the same operational costs as scenario 2 combined with the costs associated with the disinfection step with SODIS-CPC. The operational time of the SODIS-CPC tubes is expected to be around 10 years, meaning replacement is required. Additionally, the pump and solar panel required to fill the tubes are fragile and have to be replaced when they break. On average the operational costs for scenario 3 add up to €340/y (€85/y per household).

Usually, operational costs also include personnel wages. In these scenarios, the wages are not included since maintenance is performed by the residents.

Including a disinfection step in the treatment line increases the operational costs by 124% and 64% compared to scenario 1 and scenario 2, respectively. The addition of the polishing pond in scenario 2 compared to scenario 1 increases the operational costs by 37%. Figure 20 shows the effect of the higher operational costs on the long run.

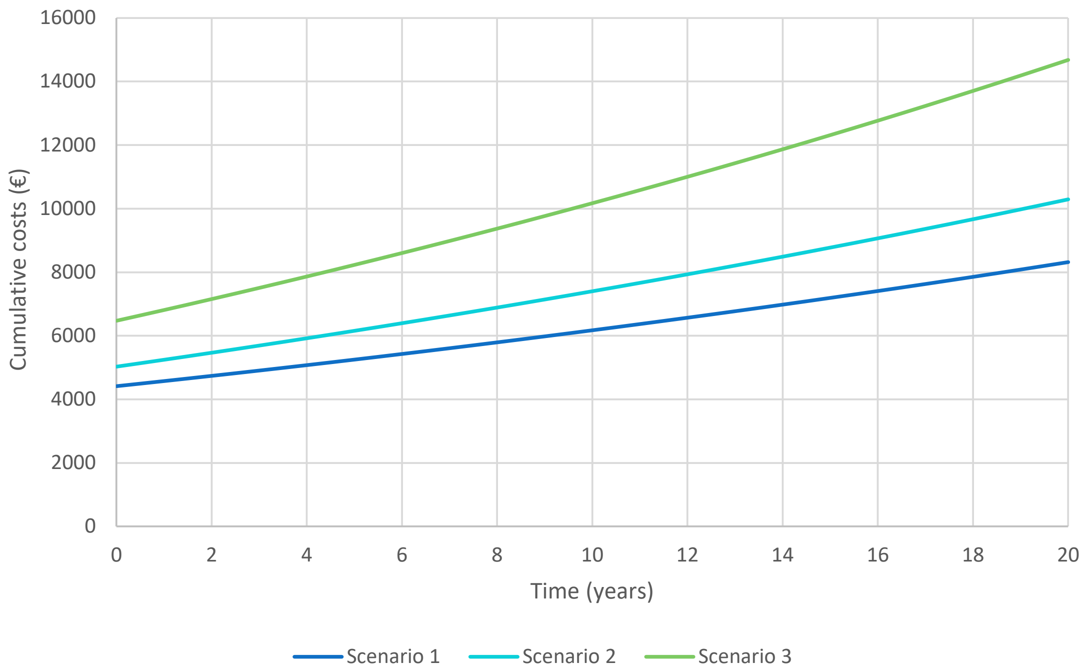
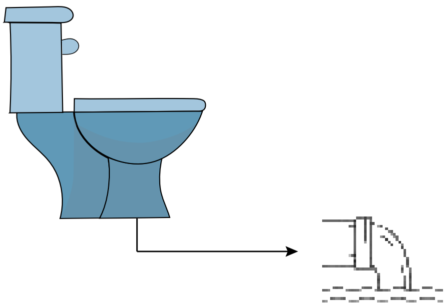


Figure 20. Cumulative cost overview of CAPEX and OPEX costs for 3 treatment scenarios with an inflation of 2% per year over the OPEX.

No treatment



When wastewater is not treated and directly discharged, the COD and nutrient concentrations provide excellent conditions for growth of unwanted microorganisms in the receiving surface water. A high COD level depletes oxygen in the water which impacts the ecology and results in unfavorable conditions for plants and other organisms living in the water. Similar damage to the ecology is done by the high phosphate and ammonia concentrations which cause algal growth. Next to the ecological damage of the untreated water, pathogen levels make it dangerous for human interaction since they can contract bacterial infections or viruses from the water. However, this is the cheapest scenario with virtually no costs associated due to the lack of treatment.

Removal:

No COD
No pathogens
No NH_3
No P

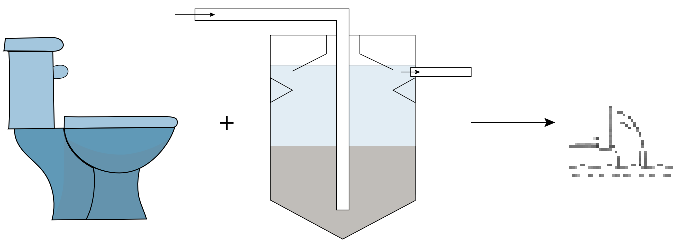
Application purposes:

No biogas
No irrigation
No fertilizer

Costs:

CAPEX: ~€0
OPEX: ~€0/y

Scenario 1



With primary treatment, 85 % of the COD is removed as well as 90% of the pathogens while also producing energy in the form of biogas. This scenario is applicable to a situation where the receiving waterbody already has high nutrient levels and the pathogen levels pose no danger to humans. The capital costs of this system are relatively high due to the fact that an extra treatment platform has to be built to house the UASB-septic tank. However, the operational costs consist only of estimated costs of replacement parts and are expected to be around €38/y per household.

Removal:

85% COD
1 log pathogens
No NH_3
No P

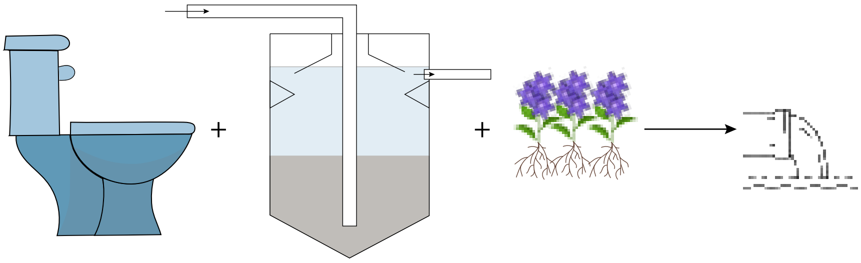
Application purposes:

Biogas for cooking

Costs:

CAPEX: ~€4400
OPEX: ~€150/y

Scenario 2



Primary treatment with an UASB-septic tank combined with a polishing step by water hyacinths removes COD, pathogens, ammonia and phosphate. The effluent leaving the polishing pond has a final COD concentration of 3 g/L due to removal by the UASB-septic tank and uptake by the water hyacinths. Per day 135 g of COD is prevented from ending up in the water compared to no treatment.

As for ammonia, with a pond of 17m², the discharge requirements for ammonia are met (0,05 mg/L NH_3). For phosphate, up to 2,5 g of P is removed per day and prevented from ending up in the receiving waterbody. However, the final concentration of 53-134 mg/L P does not meet the discharge requirements set by the Philippine government.

The addition of the polishing pond results in a total of 5 log removal of pathogens based on the decay rate of *E.coli*, making the effluent much safer for human contact than the effluent of scenario 1. Since the log removal of the polishing pond is based on the die-off of microorganisms, more persistent pathogens will remain in the water in this scenario.

Aside from the removal efficiencies associated with this scenario, there are also many possibilities regarding resource recovery. The addition of the polishing pond provides plant mass that can be transformed into fertilizer, raw fiber for fabric, or extra COD for the UASB-septic tank. The leaves and stems can even be used as food.

Effluent:

3 g/L COD
5 log pathogens removed
0,05 mg/L NH_3
53-134 mg/L P

Application purposes:

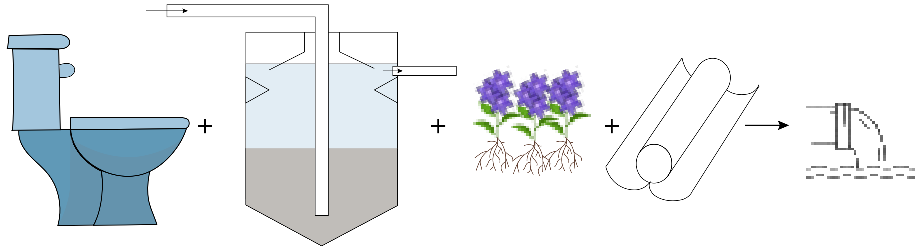
Biogas for cooking
Fertilizer
Raw fiber material for fabric
Food for humans and animals
Extra COD for UASB

Costs:

CAPEX: ~€5000
OPEX: ~€200/y

The capital costs of this system are only 14% higher than scenario 1, making the polishing pond an attractive, cost-effective addition to the primary treatment. The operational costs of the polishing pond consist of replacement parts of the fencing and the pond plastic, as well as weeding equipment. The OPEX adds up to €52/y per household, 37% more than scenario 1.

Scenario 3



When the effluent is required to adhere to the pathogen discharge standards set by the Philippine government, an extra safety step can be added in the form of SODIS-CPC.

This scenario aids in pathogen removal but does not add extra nutrient or COD removal. However, the effluent leaving the SODIS tubes is suitable for irrigation according to WHO guidelines (WHO, 1989). Compared to scenarios 2 and 1, this scenario has the most possibilities regarding resource recovery.

The extra safety this scenario provides, comes at a cost. Not only do the SODIS-CPC tubes have to be constructed, the treatment platform also has to double in size to accommodate for the tubes. This gives almost 50% increase in capital costs compared to scenario 1. As for the operational costs, the pump and sensors needed to operate the SODIS-CPC system, require electricity which is provided by a solar panel. This disinfection step has a lot of fragile compartments, increasing the risk of breakages. The OPEX costs add up to €84/y per household, a 124% more than the OPEX of scenario 1.

Effluent:

3 g/L COD
< 200 CFU/100mL pathogens
0,05 mg/L NH_3
53-134 mg/L P

Application purposes:

Biogas for cooking
Fertilizer
Raw fiber material for fabric
Food for humans and animals
Extra COD for UASB
Irrigation water

Costs:

CAPEX: ~€6500
OPEX: ~€340/y

Conclusion scenario comparison

Which scenario suits the neighborhood best, depends on several factors: The level of involvement of the local government, the water quality of the receiving waterbody, the wishes of the residents regarding reuse possibilities and the budget.

If the local government gets involved and the discharge standards have to be met, scenario 3 will most likely be chosen. However, the cost increase for this scenario compared to the others makes this scenario unattractive for the residents. In terms of budget, water quality and reuse possibilities scenario 2 is advised. The effluent quality is nearly the same as scenario 3 and the reuse possibilities are identical apart from irrigation water. It is unsure whether residents would even be open to using the effluent for irrigation.

In short, the added benefits of scenario 3 do not outweigh the steep increase in costs. Therefore, scenario 2 is advised since it is considerably the most cost-effective of the three scenarios.

PART 3

Conceptualization

Conceptualization:

How to build
- Construction platform
- Floating abilitiy platform
- Construction reactor
- Construction SODIS-CPC
- Construction polishing pond

Hydraulic line scheme

Concept overview

In this chapter, the theoretical design is translated into physical considerations. The construction of the specific compartments is discussed as well as the platform around or underneath them. The energy level throughout the entire system is displayed in a hydraulic line scheme.

4. Conceptualization

After the desired effluent quality is determined and the corresponding treatment blocks are selected, the sanitation system has to be built and integrated with the community and its residents.

The reactor is integrated into the platform in a way that allows it to float. This affects the floating ability of the platform. The polishing pond is located next to the 'treatment platform' to allow for easy maintenance and short transport distances and the disinfection tubes are placed on top of the platform to collect maximum solar energy.

How to build

The platforms on which the houses are built, consist of a wooden frame that holds recycled rainbarrels that provide the floating ability to the platform. The rainbarrels can be oriented in two different ways depending on the amount of weight that has to be carried (Figure 21). The horizontal placement requires fewer barrels but is also able to carry less weight and may therefore be more susceptible to the movements of the water.

The reactor has a vertical orientation with respect to the platform. A vertical orientation of the barrels offers more security for the placement of the reactor since it offers fewer movement possibilities.

The reactor is secured in such a way that it can float individually and doesn't influence the leveling of the platform. The securement below the bottom of the reactor makes it impossible for it to sink below a certain level to reduce the risk of failing pipe connections. The stilt on which the securement is attached should be the same material as the stilts that secure the house since they are selected for minimal wood rot caused by water.

Construction platform

The platform is constructed from locally sourced materials. The foundation modules are prefabricated in a local factory and connected on-site. The modules consist of a wooden frame that holds sixteen rainbarrels in place (Figure 22) (Finch Floating Homes, n.d.). The rainbarrels are made out of HDPE (High density polyethylene) and have a volume of 200 L. The barrels have standardized dimensions and are widely available due to a surplus of disregarded barrels in the area (Ham, 2016).

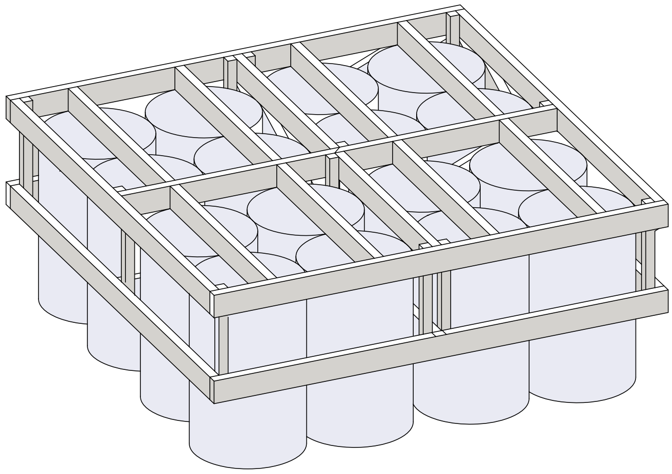


Figure 22. Platform construction (Finch Floating Homes, n.d). The timber cage holds sixteen rain-barrels.

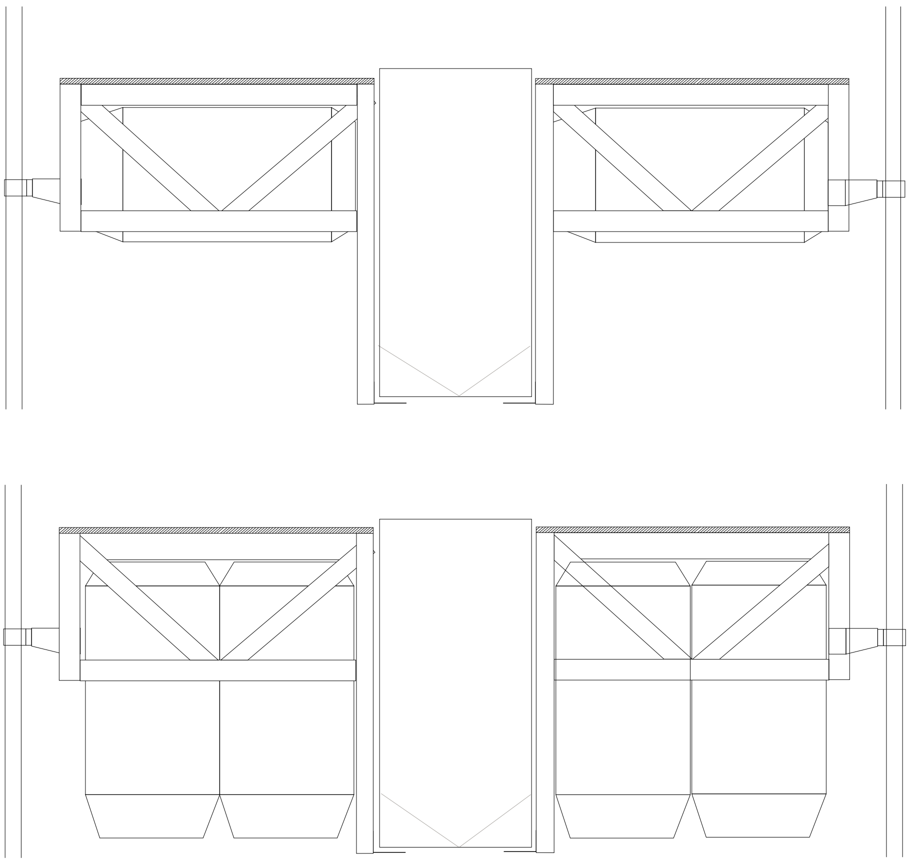


Figure 21. Orientation of rainbarrels in the platform.

Floating ability platform

Since the rainbarrels provide the floating ability to the platform, replacing a rainbarrel with a UASB-septic tank influences this ability.

The floating ability of a platform with or without the reactor can be compared. Since the reactor requires maintenance, the platform has to be able to handle an extra load of people too. Two scenarios are compared: A platform without a reactor and a platform with a reactor filled with water and the weight of four people (one household).

A platform of 2,5 x 2,5 m2 containing 16 rainbarrels has a sinking depth of ~11 cm. Having the same platform carrying 4 people and a reactor filled with 270 L of water, has a sinking depth of ~19 cm. This is a difference of roughly 8 cm. In this scenario, it is assumed that the platform carries the entire weight of the reactor but in reality, the reactor has a floating ability of its own. This means the effect on the sinking depth is less in reality.

Construction reactor

UASB-septic tanks can be constructed with several materials. On land, the most common construction materials for these reactors are concrete or polyethylene. Due to the weight requirements, concrete is not an option but polyethylene is lightweight and has been proven to withstand the local water environment in the pilot home. The rainbarrels in the platform are made from polyethylene as well.

The reactor itself has to be purchased at a specialized wastewater treatment shop and cannot be constructed locally. The reactor has to be airtight to guarantee the effluent and biogas don't leak into the environment and the air, respectively.
The reactor has a similar diameter to the surrounding rainbarrels, meaning no special platform design is required and the reactor can be located anywhere in the platform.

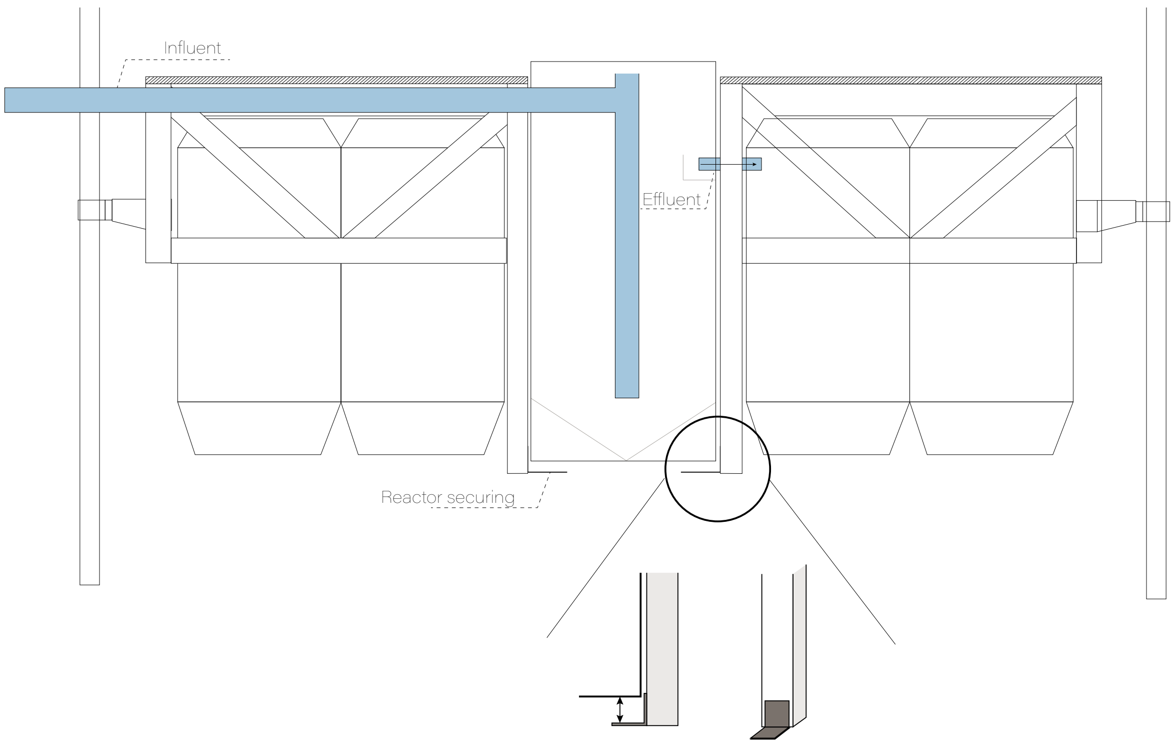


Figure 23. Integration of reactor in the platform. The inflow pipe is situated right below the floor and the outflow pipe flows into the polishing pond. The reactor securing prevents the reactor from sinking too deep.

Construction SODIS-CPC

The SODIS-CPC consists of a tube that holds the water, mirrors that concentrate the solar energy and a frame that holds the mirrors. The tube is made from methacrylate (plastic) with an inlet port with a valve at one end and an outlet valve at the other end. The tube is placed along the linear focus of a CPC mirror with a north-south orientation at 14° to collect as much UV A irradiance as possible throughout the year. The bottom and top plates are secured with a rubber seal and secured with screws (Figure 24).

The CPC reflectors are made from reflective anodized aluminum sheet which has a concentration factor CF = 1 *. The aluminum reflects 87% of UV A and 90% of visible and infrared irradiance. The supporting material for the mirrors is made from locally sourced, durable timber.

* *[MIROSUN® Aluminium GmbH, Ennepetal, Germany]*

The first tube is filled up by the pump entirely after which the valve closes. After this, the second tube is filled up and then the third. The pump turns on in the morning for 5 minutes, during which 3 tubes are filled. The excess water flows back into the polishing pond. After six hours the tubes are emptied and filled again. Twelve hours of sunlight allow for two batches. The outlet valves have a time sensor that opens after 6 hours. The water flows to the next tube via a V-notch after the tube is full (Figure 25).

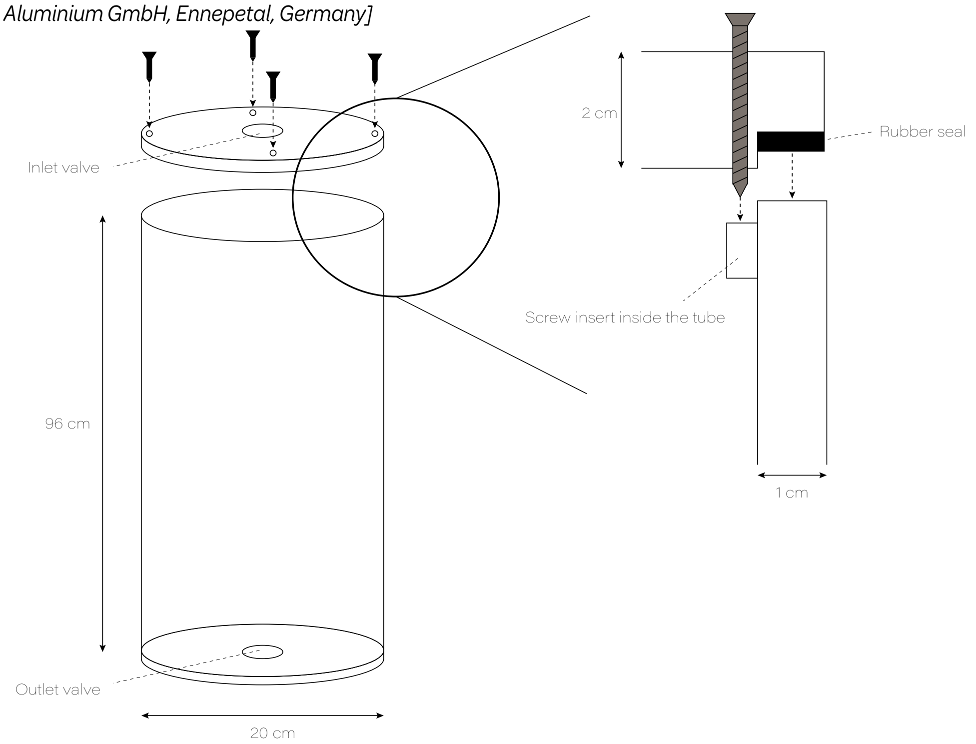


Figure 24. Seal of the SODIS-CPC tube.

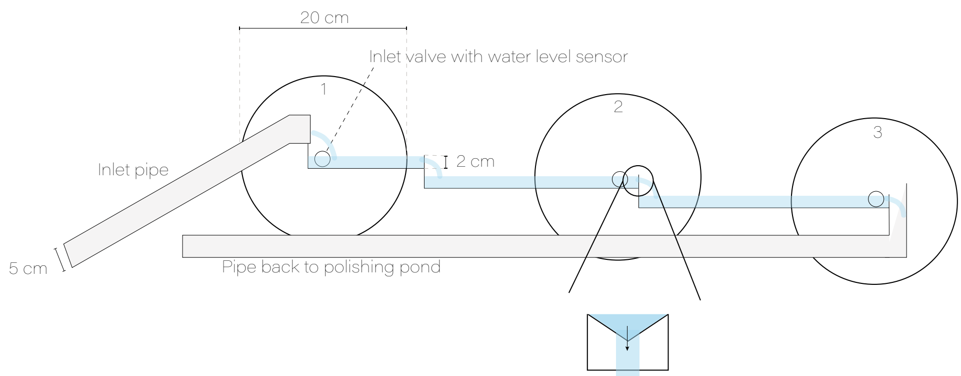


Figure 25. Distribution of the water over the tubes. The water flows to the next tube via a V-notch.

Construction Water Hyacinth pond

The polishing pond has a surface area of 17 m2. The orientation and length of the sides can be decided upon depending on the neighborhood specifics and the orientation of the houses. Since the flow in the pond is very low, the shape of the pond is less important due to the low risk of flow dead zones. Requirements for the pond are: accessibility for maintenance and impermeability of the enclosure for water hyacinth seeds. The latter is very important to restrict the water hyacinths from spreading out over the entire waterbody.

The enclosure wall consists of a plastic layer supported by a thin bamboo wall. The wall itself is attached to similar piles as the ones supporting the platforms (Figure 26). The plastic has to be able to withstand the water environment. Pond foil made from PVC is able to withstand the environment and is used to cover the bamboo wall.

The outlet pipe of the pond is covered by a cloth filter to keep the water hyacinth seeds or dead plants from spreading to the surrounding water.

Hydraulic line scheme

From the toilet to the UASB-septic tank, the water flows due to gravity. The pressure in the reactor ensures the effluent flows from the reactor to the polishing pond. The pressure in the reactor can increase up to 20 mbar to store extra biogas (Figure 27). A higher pressure would result in biogas escaping through the effluent pipe.

With an extra disinfection step, the water has to be pumped from the polishing pond into the tubes. The disinfection tubes are located on top of the platform with the inlet valve 23 cm above the platform level. To overcome the height difference, a small pump is required to pump the water into the tubes.

The system is gravity driven except for the disinfection tubes. So scenarios 1 and 2 are completely gravity driven whereas scenario 3 requires a small pump connected to a PV cell to provide the required electricity.

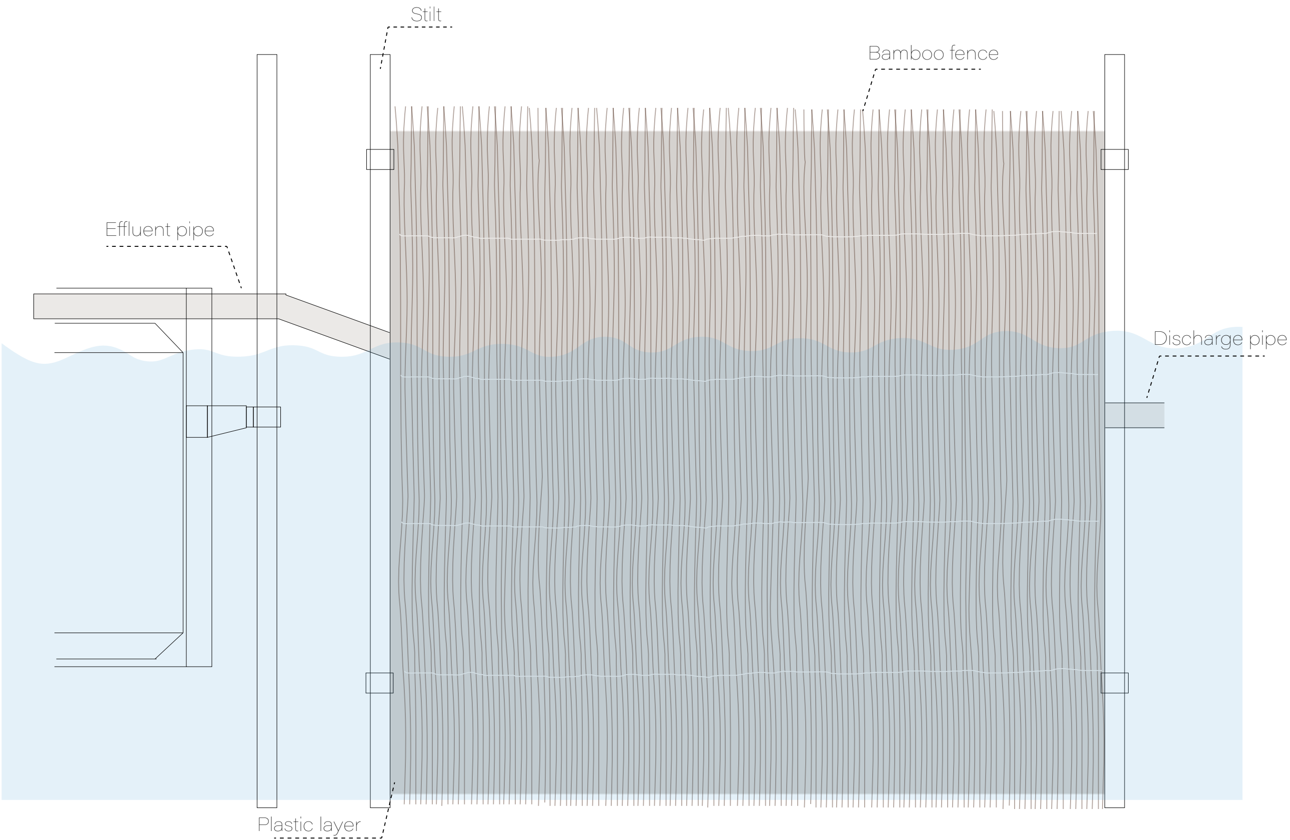


Figure 26. Polishing pond construction.

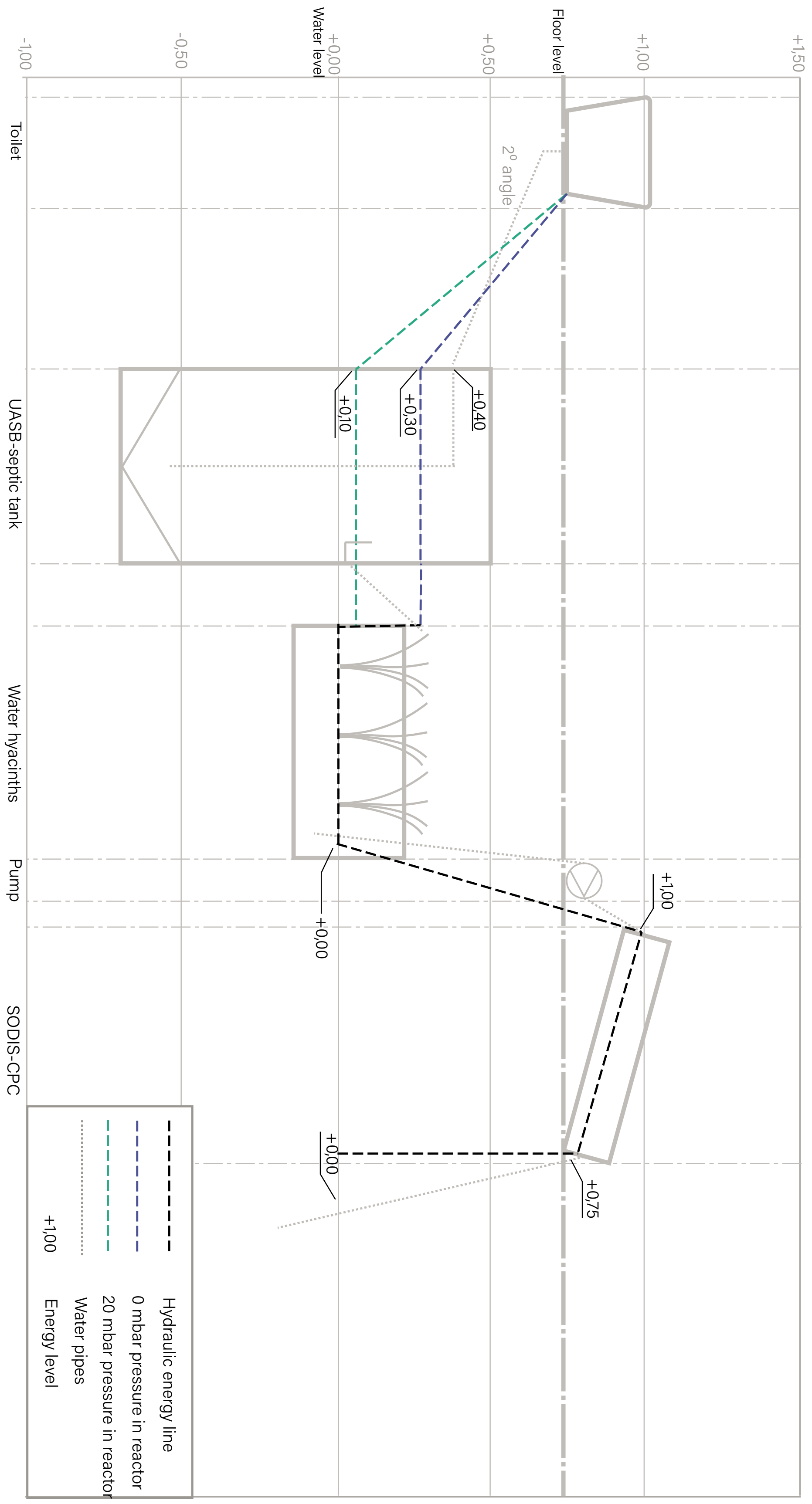


Figure 27. Hydraulic line scheme. The blue line corresponds to 0 mbar pressure. The green line corresponds to 20 mbar pressure.

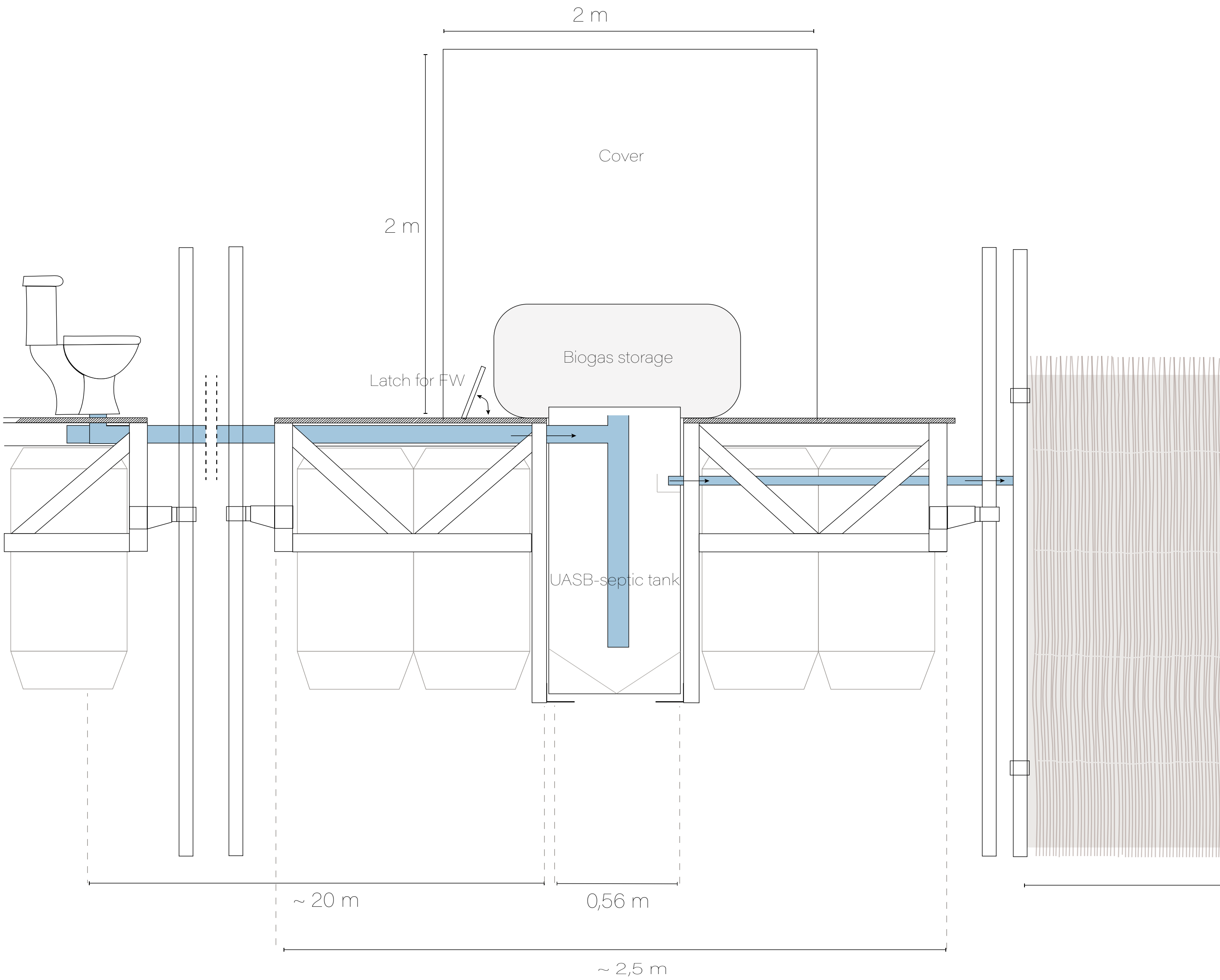


Figure 28. Total overview of the treatment scenario containing all treatment steps.

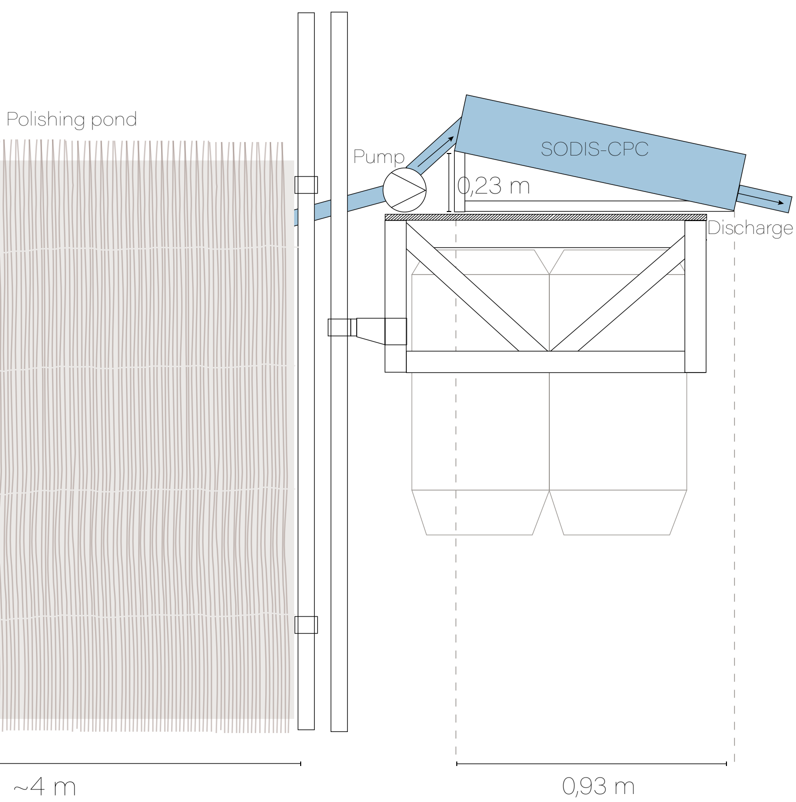
Concept overview

Combining all treatment compartments in scenario 3 leads to the total overview displayed in Figures 28 and 29. The toilet is located inside the residents' houses. The pipe exiting from the toilet leads to the treatment platform via walking paths. The pipe is integrated into the floor of the paths. On the treatment platform, the pipe contains a latch that can be opened manually, where food waste can be mixed in with the wastewater. The effluent of the UASB-septic tank flows to the polishing pond due to gravity. The reactor and gas storage are covered by a shed for protection from heavy weather. After the polishing pond, the water is pumped into the SODIS-CPC tubes twice a day.

The height of the cover is 2 meters. The layout of the platform is such that the shadow of the cover does not cover the disinfection tubes during the morning. Hagonoy is situated at N 14° 00', E 120° 00', meaning the sun casts a shadow in the morning and evening. With the azimuth angle of the sun over time, the shadow length can be calculated with the following formula:

$$\frac{Height\ building}{\tan\theta} = Length\ shadow$$

The shadow lengths for October 12th are presented in Figure 30. The shadow reaches lengths over 10 meters in the morning and evenings which hinders the solar energy capture for disinfection.
So to prevent any shadows from falling on the disinfection tubes, the platforms are oriented in such a way that the cover is situated north of the tubes and the shadows fall on the north side of the building during the day (Figure 31).



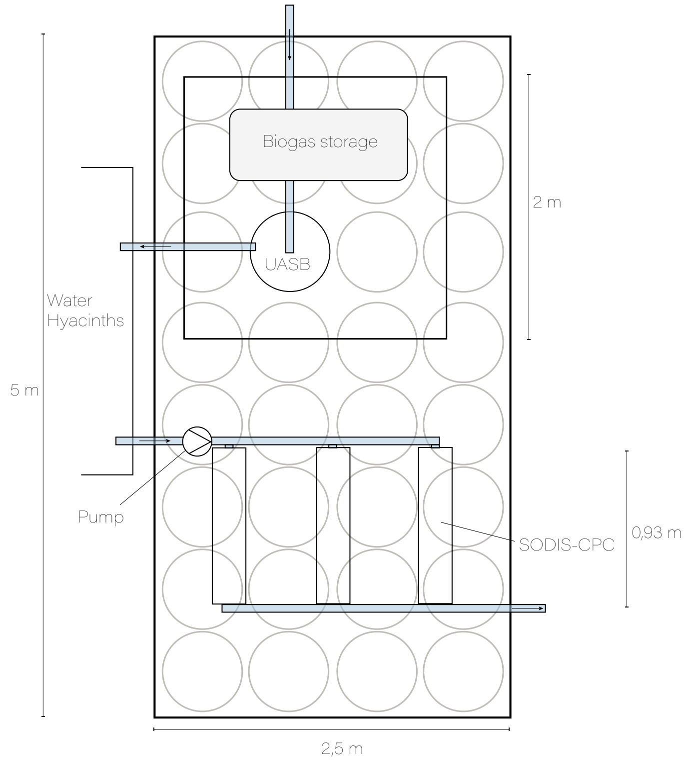


Figure 29. Top view treatment platform.

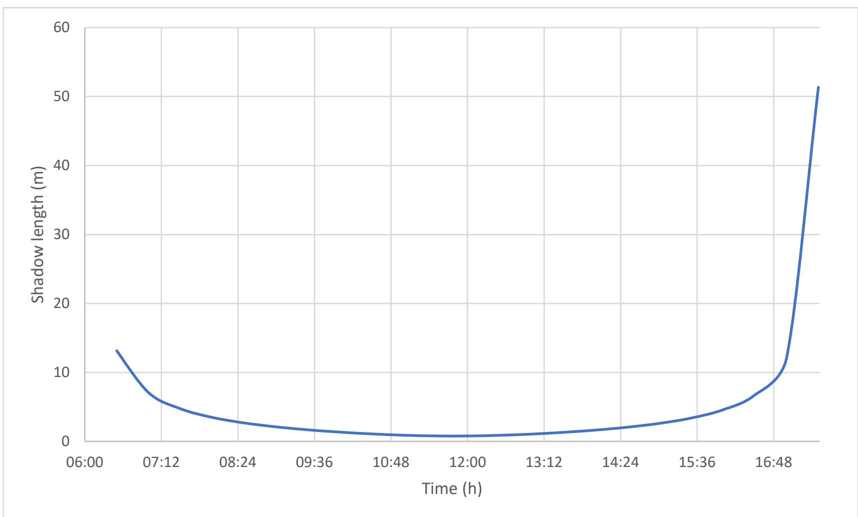


Figure 30.Shadow lengths cast by a 2 m high building in Hagonoy on October 12th 2022.

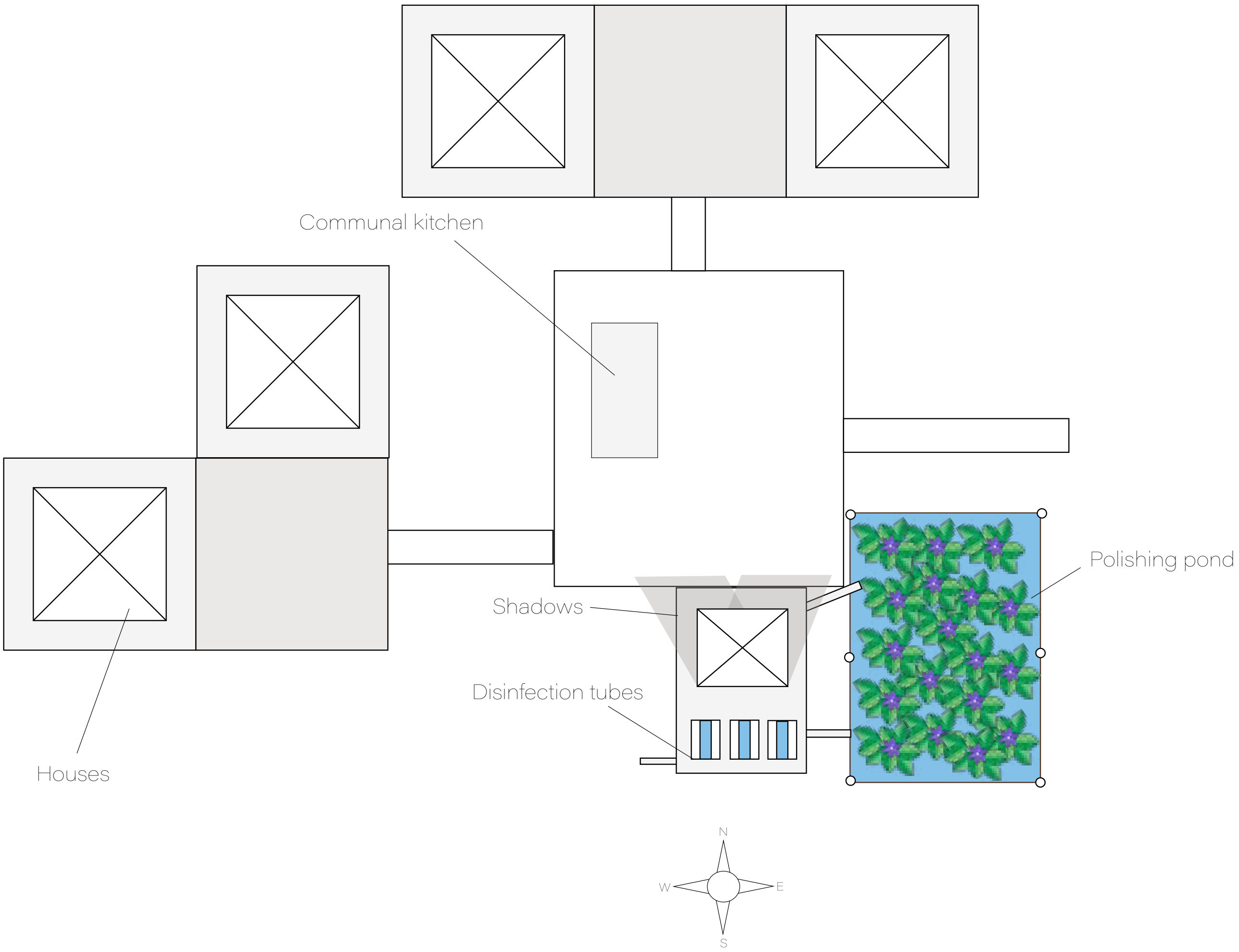


Figure 31. Top view of an interpretation of a part of the floating neighborhood.

Looking at the top view of the neighborhood, the treatment platform takes up approximately half the surface area of a housing platform (Figure 31). The treatment platform is oriented in such a way, that the roof covering the reactor and pump, is situated north of the disinfection tubes. Hagonoy is located north of the equator so the path of the sun will cast a shadow on the north side of the building. It must be noted that the location of the treatment platform with respect to the rest of the neighborhood should also be taken into account to prevent shadows from falling on the tubes.

The treatment platform is not situated on a walking path and therefore does not hinder the traffic flow of the neighborhood. Instead, it is located next to a communal area to make it easily accessible for daily maintenance.

The polishing pond has a surface area of 17 m^2. It can be shaped depending on the available area and the neighborhood design. The flow in the pond is very low so it is expected that the effect of dead flow zones is minimal in every shape. For maintenance purposes, a condition for the location is that the pond is accessible from a platform or walking path.

Depending on the efficiency of the total neighborhood design, the treatment platform can be used to fit the reactors for more houses. Since the reactor is the same size as the rainbarrel, the treatment platform can easily be scaled up. The effect of replacing a rainbarrel on the floating ability of the platform is minimal. The platform can also be modified to hold more disinfection tubes. The scalability of the treatment platform provides flexibility and many options for expanding the neighborhood.

PART 4

Neighborhood integration

Neighborhood integration:

- Communal garden
  - Irrigation
  - Plant reuse
- Communal kitchen
- Maintenance
  - UASB-Septic tank
    - Risks
  - Water hyacinths
    - Risks
  - SODIS-CPC
    - Risks

In this chapter, the interactions between the treatment system and the community are discussed. In the communal garden, recovered resources can be applied in the form of irrigation water and compost. The biogas is easily applied in the communal kitchen.

5. Neighborhood Integration

The placement of the system within the neighborhood depends on the application of the biogas. A central location is required when the biogas is used for community purposes but the location is less important when the gas is collected for individual purposes.

Once the system is up and running, the maintenance has to be done by the residents, this includes the removal of water hyacinths, monitoring the pumping system for disinfection and monitoring the UASB-septic tank.

There are three streams leaving the system that can be used further, the biogas produced in the UASB-septic tank, the nutrient-rich effluent leaving the disinfection step or the polishing pond and the plant mass that can be made into fertilizer, food and fibre. The focus for the areas of application will be community-based to create engagement with the residents. The irrigation with effluent can only be applied in scenario 3 where a disinfection step is included.

In previous research performed by Alazne Jurado, the functions of a floating neighborhood have been investigated (Jurado, 2021). Jurado devised a framework in which she mentions that it is essential for the function of a floating neighborhood to have communal spaces, pathways and social gathering spaces (Figure 32). To create these spaces, clusters of houses can be connected. The shared physical infrastructure creates more social interactions and improves the relations between the residents in the neighborhood (Jurado, 2021).
The communal spaces offer a relaxation or gathering space as well as offering a view of the communal garden and polishing ponds with water hyacinths.

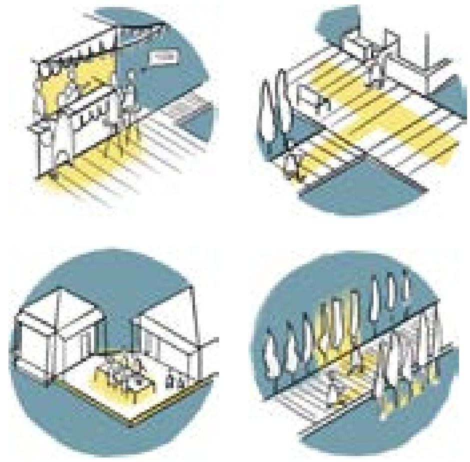


Figure 32. Connectivity systems for generating interactions (Jurado, 2021).

The sanitation system is in line with these visions by becoming an integral part of the communal areas and providing resources for communal activities such as cooking and gardening.

Communal garden

Community gardens can serve multiple purposes depending on the wishes of the community (Figure 33). Decorative plants require less strict standards than when the garden is used for consumables.

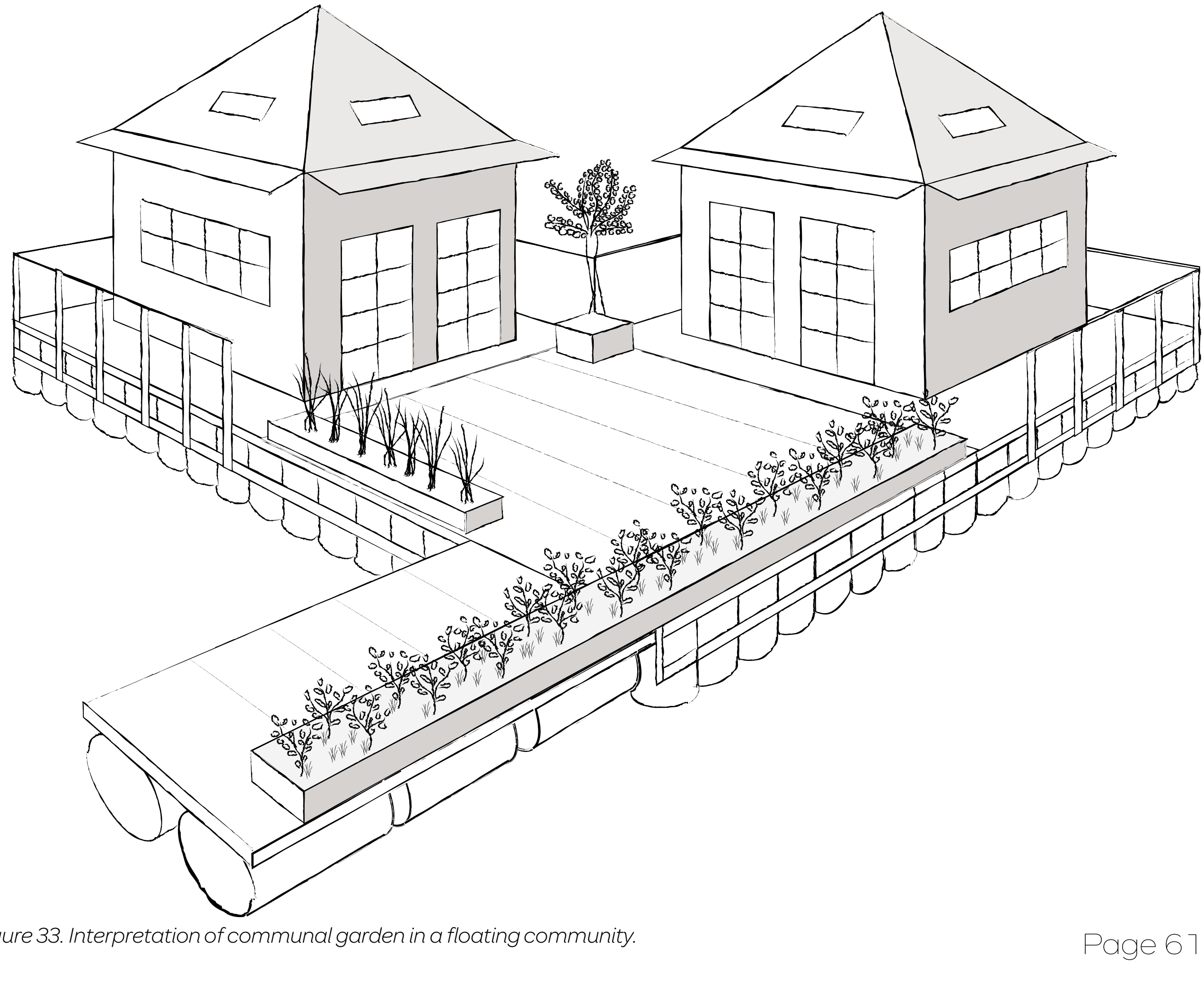


Figure 33. Interpretation of communal garden in a floating community.

Irrigation

When the garden serves an aesthetic purpose and no direct contact with humans occurs, the regulations for pathogen levels in the irrigation water are less strict. The garden serves to liven up the neighborhood and create a nice ambiance. The plants will be selected for their appearance and not for their ability to be consumed. The WHO does not set a standard for the fecal coliform level in irrigation water for trees however they recommend that the water retains in stabilization ponds for 8-10 days (WHO, 1989).

When the garden is used to grow crops and vegetables, the regulations for the pathogen levels are strict. For crops likely to be eaten uncooked, the WHO states that the mean number of fecal coliforms should be <1000 per 100 mL (WHO, 1989). Since the restriction pathogen level is higher than the effluent pathogen levels of treatment scenario 3, the effluent can theoretically be used for all irrigation purposes. The irrigation water can be collected from the outlet of the SODIS-CPC.

Plant reuse

The water hyacinths have to be removed from time to time to keep the growth in check. The removed plants can be reused in several ways.

Fertilizer: Applying fertilizer serves the same purpose as irrigating with nutrient-rich effluent; providing nutrients for the plants to grow. Water hyacinths remove nutrients from water because they take up the nutrients to grow. Hence, the plant biomass contains a high level of nutrients (2,35 mg NH_3/kg wet weight, 0,39 mg P/kg wet weight with a moisture content of 95,5%) (Andika et al., 2016).

As fertilizer, the plants can be used either as 'green manure' or compost. Green manure means either plowing the plants through the soil or using it as mulch, an organic layer covering the soil. The water hyacinth is also very suitable for composting. After the plants have dried for a few days, mixing them with ash, soil or animal manure will break down the lipids, proteins and sugars during the composting process (Andika et al., 2016). The compost can be applied directly to the soil to increase fertility and crop yield. Ghosh and Purkait state that organic manure even yields better results than chemical fertilizer and it costs nothing but labor (Ghosh & Purkait, 2008). Not only is this a cost-effective solution, it fits into the aim of creating a circular neighborhood (Criterium 7).

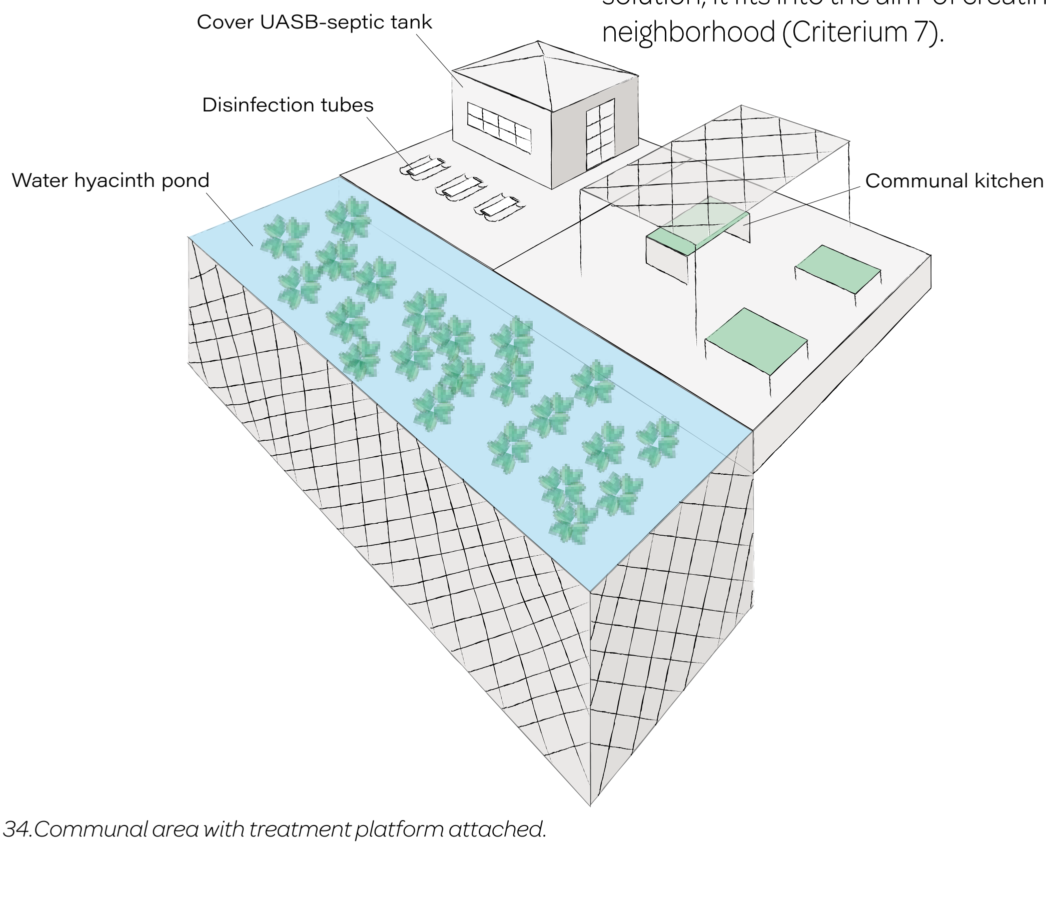


Figure 34.Communal area with treatment platform attached.

It must be noted that creating compost requires land for mixing the materials and leaving it to compost. Hence, this solution is only recommended when a suitable plot of land is available.

Food: The stalks and leaves of removed plants are very suitable for food for animals and humans. In Thailand, the stalks and leaves are added to soups (Chanana et al., n.d.). After sun drying the plants for 5 days, they can also be used for animal feed (Andika et al., 2016).

COD source: When necessary, the plant mass can also serve as an extra source of COD in the UASB-Septic tank. The reactor should be in steady state with the wastewater and the co-digestion of kitchen waste. However, the biogas yield is theoretically calculated and might be different than expected due to a difference in influent concentrations. When the biogas yield is lower than expected, adding extra COD might balance the reactor and reach a good biogas yield. Before adding the plant mass to the reactor, it should be ground up similarly to the kitchen waste.

Communal kitchen

The communal areas serve as a place to gather for everyone in the community. Having a place to cook also makes it possible for the residents to have dinners together or parties. By creating a communal space, social interactions among the residents increase and residents have a higher chance to encounter each other.

Since the current method of cooking is using gas, the community kitchen should be connected to a gas source as well. This gas source can be the gas produced by the water treatment system. Per day, gas for approximately 1,8 hours of cooking is produced by the system. The gas is stored close to the reactor in a bag which is connected to the communal kitchen by a pipe. To prevent the gas pressure from dropping before it reaches the kitchen, the gas storage cannot be located too far from the communal kitchen (Figure 34, 35).

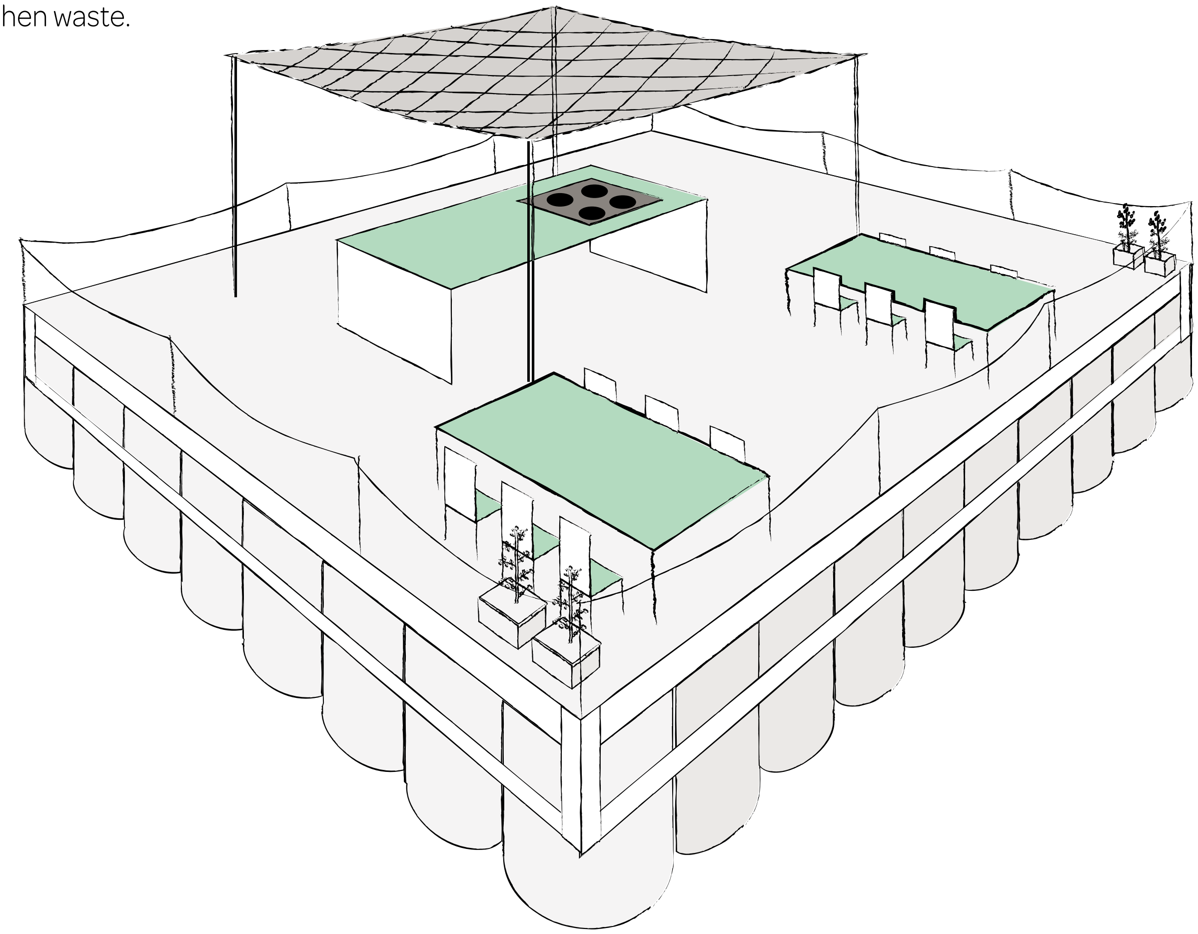


Figure 35.Communal kitchen with a stove for cooking on biogas.

Maintenance

As with all water treatment systems, a certain amount of maintenance is required. The maintenance ranges from monitoring the system to replacing or cleaning parts.

UASB-Septic tank

The lifetime of a polyethylene reactor is expected to be around 30 years. Since the reactor is bought from specialized water treatment sellers, it is relatively easy to replace the entire system after 30 years but more complicated to replace specific parts since the reactor is usually preassembled. An evaluation of the costs has to be made when a specific part has to be replaced.

The maintenance of the UASB-septic tank consists of desludging the tank approximately every 2 years. An increase in the amount of sludge in the effluent is a good indicator that the reactor has to be desludged. The reactor itself hardly requires additional maintenance or monitoring. Since there aren't many treatment facilities in the area where the sludge can be treated, it is recommended that the sludge is transported to an incineration facility to ensure it is not dumped illegally.

What should be monitored however, is the gas collection. The reactor produces approximately the same volume of biogas per day. When a large deviation in this production is observed, this can be an indication of gas leakages. In this case, it is important to localize the leak and replace the broken seals to prevent the methane in the biogas from leaking into the air.

Gas leakages are accompanied by risks. Methane leaking into the surroundings has an adverse effect on the environment since it is a greenhouse gas. It doesn't directly affect human health.
Gas is also highly flammable so gas leakages can form a fire hazard. When the fire reaches the storage bag, there is even a risk of explosion. Considering the treatment system is located close to the houses to reduce transport distances, explosions or fires can directly influence human health and should therefore be monitored frequently.

When the reactor is desludged as soon as the solids in the effluent increase, the risk of clogging is relatively low. When the reactor or pipes do clog, thereis a risk of wastewater leakages into the surroundings. Depending on the location of the leakage, either raw sewage or partly treated sewage enters the water. COD, nutrients and pathogens enter the water, negatively influencing the ecology of the water. The COD and nutrients cause algal growth and a decrease in oxygen levels in the water. The pathogens entering the water may negatively influence human health if the water is used for swimming or other applications where contact takes place.

Water hyacinths

Water hyacinths grow very well in slow-moving waters with high nutrient levels. Under optimal circumstances, they can double in mass every 5 days. It is expected that weekly removal of plants is required to keep the plant population in check. For a small population, manual removal is the most suitable removal option. The plants can be removed by hand or with rakes, pitchforks and nets.
The removal of the plants should be done with care as to not accidentally spread seeds to the surrounding water next to the pond. A single water hyacinth plant can produce up to 3000 seeds. These seeds accumulate in the floating 'mat' of the plants or sink to the bottom.

When the plants spread out in the surrounding waterbody, immediate action has to be taken to remove the excess plants. If this is not done properly, the plants will spread quickly and risk taking over the entire water surface. The thick plant mat prevents any light from entering the water, making it uninhabitable for fish or other water plants. Once the water hyacinths have spread out over a large area, they're very hard to remove completely (Osmond et al., 2013). In large scale infestations, the plants are removed in a chemical, physical or biological manner, or a combination of these removal methods.
Concluding, regular removal of the water hyacinths and monitoring of the enclosure is important to prevent an infestation of water hyacinths in the waterbody.

SODIS-CPC

The SODIS-CPC disinfection module consists of a pump, the storage tube with in- and outflow valves, a water level sensor for filling the tube, a time sensor for emptying the tube and a discharge pipe.

Maintenance of the SODIS-CPC consists mostly of monitoring the compartments. If the sensors or the pump fail, it will be observed immediately since the tubes will not be filled or emptied properly. In this case, the disinfection step will be temporarily unavailable until the sensor or pump in question is replaced. Due to the relatively low flow through the system and low pathogen concentration after the polishing pond, the impact of skipping the disinfection step on the environment is minimal. However, during this period the water is not suitable for irrigation.

The tube and CPC mirrors require regular cleaning to maintain the proper solar energy collection. Fouling of the mirror surface decreases the reflection significantly. Fouling of the tube surface decreases the permeability of the solar energy. When maintenance of the SODIS-CPC is not performed correctly, the pathogen levels in the effluent will not decrease anymore. When residents are not aware of this decrease in disinfection, they might expose themselves to dangerous pathogens and fall ill.

Mechanical failures of the SODIS-CPC module are easily caught and will not form any risk of harming humans. The higher pathogen levels demand that contact with humans is minimized.
In case of improper cleaning of the tubes and mirrors however, the decrease in disinfection is not easily noticed. When the effluent is used for irrigation, the pathogen levels may cause serious damage to human health such as diarrhea, vomiting and infections such as hepatitis (Queensland Government, 2020).

CONCLUSION

Conclusion & Recommendations

Conclusion

Recommendations

In this chapter, the research questions are discussed and how they are answered throughout the report. After this, recommendations are made for future research.

Conclusion

In this research, the following research question was answered through literature research, context analysis and design iterations:

What is a suitable sanitation system for a floating community in the Philippines?

The research question was answered by means of 4 subquestions corresponding to the 4 parts of the research.

Subquestion part 1: What aspects are important for the design of a sanitation system in the neighborhood of Hagonoy?

After the neighborhood context was analyzed, a set of eight design criteria was drafted based on the important neighborhood aspects which answers subquestion 1. The criteria are:

1. Land availability
2. On-site
3. Low-tech
4. Flexibility
5. Affordability
6. Weight and floatability
7. Resource recovery
8. Social acceptance

Based on the design criteria, a framework was set up for compiling a suitable sanitation system for several scenarios. The scenarios were compared based on the reuse possibilities, the costs and the final effluent qualities for the parameters: COD, pathogens, NH_3 and P. The framework laid out a treatment system that can be built up from the following compartments: a primary treatment step with a UASB-septic tank, a polishing step with water hyacinths and a disinfection step with a SODIS-CPC setup. Different combinations of the compartments offered different effluent qualities, making the framework suitable for a range of situations. Scenario 2 offered the most cost-effective solution with regards to the reuse possibilities, the costs and the effluent quality. In this scenario, primary treatment was combined with a polishing step to achieve an effluent quality of 200 CFU/100 mL of pathogens, 3 g/L COD, 0,05 mg/L NH_3 and 53 - 134 mg/LP.

Subquestion part 2: What possibilities regarding nutrient and energy recovery, does the treatment system offer?

The treatment system following from the design criteria offered several reuse possibilities. The UASB-septic tank produced 440 - 943 L biogas per day that can be used for 1,4 - 2,9 hours of cooking in a communal kitchen or residents' homes. After disinfection by the SODIS-CPC, the nutrient-rich effluent can be applied as irrigation water up to 152 L/d. Lastly, the nutrient-rich plant biomass produced by water hyacinths is suitable to use as extra COD in the UASB-septic tank, as fertilizer, as food or as fiber for fabric.

Subquestion part 3: How can the treatment system be implemented in a scalable and sustainable way, considering the unique neighborhood aspects?

The construction was worked out in a compartmentalized manner to offer scalability. The floating platform was built up in modules that each held eight rainbarrels. The UASB-septic tank had nearly the same diameter as the rainbarrels and could therefore fit into the existing design of the platform, circumventing the need for specialized platforms. The rainbarrels around the tank were placed in a vertical orientation to create maximum support. The reactor itself was acquired from a specialized water treatment seller, ensuring a maximum lifetime of the system.
The disinfection tubes were constructed as individual modules and placed on top of the platforms. No special construction is required, making it possible to implement the disinfection step at any time in any scenario.
As for the polishing pond, materials for construction were sourced locally. The pond can be shaped according to the specific location of the neighborhood with a surface area 17 m².

Subquestion part 4: What are the risks when implementing a sanitation system and how can they be minimized?

Lastly, the integration of the treatment system in the community was evaluated. The residents have to perform daily maintenance tasks such as cleaning and monitoring. Improper maintenance or monitoring of the biogas reactor may result in a failing reactor or gas leakages. The gas leakages form a fire hazard and pose a threat to human health. A failing reactor mainly poses a threat to the ecology of the receiving waterbody. These risks are minimized by monitoring properly.

Maintenance of the water hyacinth pond consists of removing plant mass every week to keep the growth in check. Monitoring the pond is very important due to the invasiveness of the plants. When seeds or plants spread to the surrounding waterbody, they create an infestation that is hard to get rid of. The plants then form thick mats, heavily affecting the ecology since no sunlight can penetrate the water. All risks for the treatment compartments are minimized by proper maintenance and monitoring.

And lastly, maintenance of the SODIS-CPC consists of cleaning the mirror surface and tube surface in order to maintain maximum disinfection levels. When the tubes are not maintained properly, the pathogen levels in the effluent will not decrease which is invisible to the naked eye. Residents potentially risk a bacterial infection by coming in contact with the water if it is then used as irrigation water.

In short, this research offers a practical guideline for deciding what kind of sanitation system is suitable for a specific floating neighborhood. The focus of the research was on functionality and implementability with the aim to produce a functional design that could be scaled up to a pilot. So hopefully in the future, Filipino families will have dry feet and safe sanitation.

Recommendations

In this research, the basis was created for sanitation decision-making in floating communities. As mentioned in the introduction, this research fits into a larger scope within floating communities and can be built upon for further research.

In the context of the Finch Floating Homes project, several future research projects can be proposed. First, a great deal can be learned from involving local inhabitants in the improvement of the design since they provide insight into the social aspects that a floating sanitation system might have in the Philippines. Aspects to consider are, that they need to change some habits such as collecting food waste and minding how much water is flushed. Also, daily maintenance of the system is required which the residents have to be willing to do. Or an incentive has to be devised to make it more appealing. Therefore, the recommendation is to interview the inhabitants of the area and the people who have already lived in the pilot home about the social aspects and implications.

Secondly, when the design is reviewed with the inhabitants' feedback, it is recommended to build and test a pilot sanitation system. In this stage, testing the water quality will give more insight into which treatment scenario is most applicable. The pilot can be implemented in a part of the future floating community to analyze its interaction with the residents.

Lastly, one of the design criteria in this research was for the system to be affordable. A calculation was made with estimations of the capital and operational costs combined with estimated lifetimes of the compartments. However, to get a more accurate cost indication, research has to be done into the local prices in the Philippines. This will give a good overview of the feasibility of the project.

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Appendix 1

The inflow into the anaerobic digester consists of 4 streams, the urine, the feces, the flush water and wash water. Table A1 contains the relevant concentrations in the urine and feces.

Table A1. Concentrations in the inflow per stream. the streams are Urine, Feces and flushwater (Rose et al., 2015).

Parameter	**Unit**	**Numerical value**
Urine		
TS	g/L/cluster	-
COD total	g/L/cluster	8,37
N total	g/L/cluster	7,54
P total	g/L/cluster	0,62
Feces		
TS	g/L/cluster	316,83
COD total	g/L/cluster	702,97
N total	g/L/cluster	17,82
P total	g/L/cluster	3,47
Urine + Feces		
TS	g/L/cluster	4,15
COD total	g/L/cluster	8,71
N total	g/L/cluster	1,31
P total	g/L/cluster	0,13

Co digestion

With the mixing of food waste with the wastewater the concentrations in the inflow increase. This is displayed in table A2.

Table A2. Concentrations of the wastewater combined with food waste (Mehariya et al., 2018; von Massow et al., 2019).

Parameter	**Percentage of total waste**	**Unit**	**Numerical value**
Food waste			
TS	23,8 %	g/d	0,89
Carbohydrate	12,2 %	g/d	0,45
Protein	3 %	g/d	0,11
Total inflow			
TS	n.a.	g/L/cluster	5,04
COD total	n.a.	g/L/cluster	9,16
N total	n.a.	g/L/cluster	1,42

Appendix 2

This appedix contains a list of all compartments with their associated prices. With these prices the OPEX and CAPEX costs are calculated. Since residents perfom maintenance tasks, no OPEX is allocated for wages.

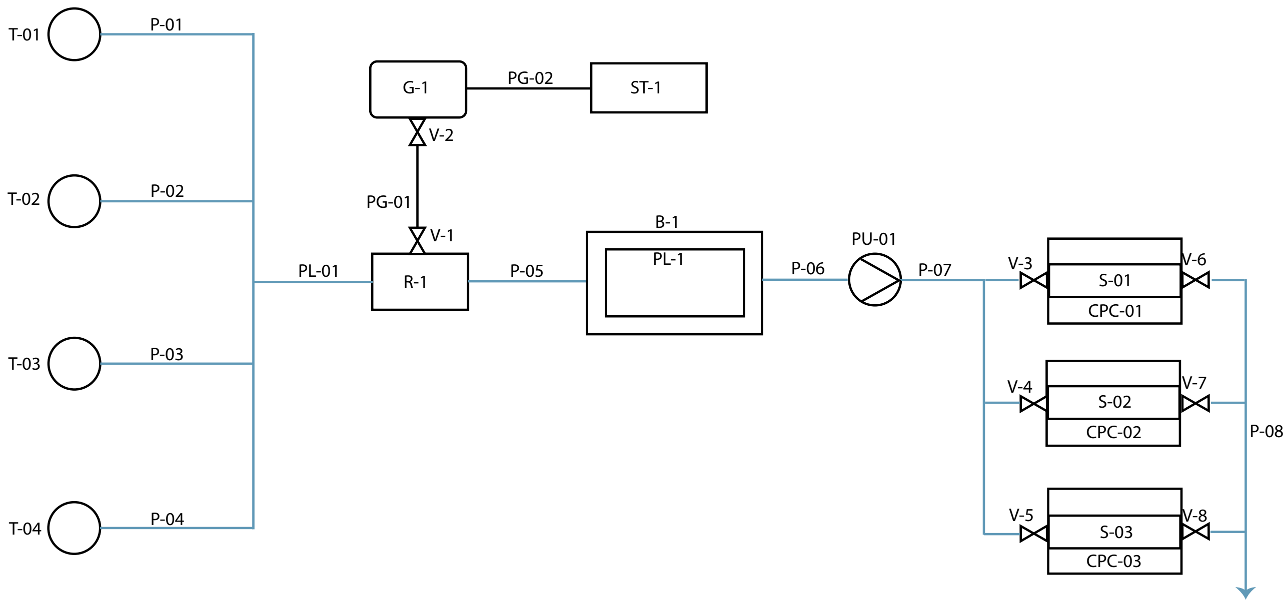

Figure 36. Overview of compartments displayed in table A3.

Table A3. List of compartements of the treatment system. The names in the first column correspond to Figure 36.

Amount	**Compartment**	**Lifetime**	**Price**	**Details**
4	Tabo	-	4	Assumption: couple euros for tabo and timba
4	Timba	-	1,6	
4	Gas backpack	10 y	140	35 dollars per bag. Source: https://www.alibaba.com/product-detail/Home-biogas-plant-small-household-pvc_1600382307290.html
4	Kitchen grinder	5 y	520	Source: https://nl.aliexpress.com/item/1005004542353864.html?spm=a2g0o.productlist.0.0.212979bcHSAXMc&algo_pvid=24f5b8f3-42fc-4175-8b38-f4339a27e58f&algo_exp_id=24f5b8f3-42fc-4175-8b38-f4339a27e58f-5&pdp_ext_f=%7B%22sku_id%22%3A%2212000030329084421%22%7D&pdp_npi=2%40dis%21EUR%21211.26%21130.98%21%21%21%21%21%402100bdf116673150743972163e4762%2112000030329084421%21sea&curPageLogUid=R0fSMohkrJkx
	Weeding material for maintenance	1 y	10	Source: https://www.lazada.com.ph/tag/weeding-tools/?page=2
	cleaning material for maintenance	1y	50	Estimation.
Name:	**User interface:**	**Lifetime**	**Price**	**Details**
T-01	Toilet	-	100	~6000 philippine pesos is around 100 euros. Source: https://iprice.ph/home-improvement/toilets/bowls/
T-02	Toilet	-	100	"
T-03	Toilet	-	100	"
T-04	Toilet	-	100	"

Name:	Primary treatment:	Lifetime	Price	Details
R-1	UASB-septic tank	10 years	200	Septic tank in philippines costs ~100 euros. Source: https://manila.philippineslisted.com/garden-house/plastic-septic-tank_6796634.html
G-1	Gas storage bag	10 years	250	In dollars 100-400. Source: https://www.alibaba.com/product-detail/pvc-soft-biogas-storage-bag_60364183232.html
ST-1	Stove	-	75	50-100 euros for double burner. Source: https://www.alibaba.com/showroom/biogas-stove.html
	Shed	-	1760	Source: https://www.gamma.nl/assortiment/tuinhuis-talinn-276x236-cm/p/B583297
Name:	**Polishing pond:**	**Lifetime**	**Price**	**Details**
B-1	bamboo fencing	5 y	188	1,8 m x 4 m is 47 euro. Source: https://www.amazon.com/DearHouse-Natural-Fencing-Eco-Friendly-Privacy/dp/B092M414XK/ref=sr_1_11?crid=55ZDKB6Z7AKF&keywords=bamboo+fence&qid=1667308420&qu=eyJxc2MiOiI3LjA1IiwicXNhIjoiNi42MSIsInFzcCI6IjUuOTEifQ%3D%3D&sprefix=%2Caps%2C131&sr=8-11
PL-1	Pond plastic	10 y	272	for 10x8 m the price is 7900 philippine pesos = 136 euros. Source: https://www.lazada.com.ph/products/10x6m10x7m10x8m-pond-liners-durable-bache-pour-bassin-etang-de-jardin-film-aquarium-fish-i242654844-s330142409.html?clickTrackInfo=undefined&search=1&spm=a2o4l.searchlist.list.148
50	Plants	-	127,5	per plant 2,55 dollars. Source: https://pondmegastore.com/products/water-hyacinths-eichornia-crassipies
10	Pikes	10 y	20	
Name:	**SODIS:**	**Lifetime**	**Price**	**Details**
S-01	SODIS	10 y	200	Estimated price for total prototype with mirrors and base. Source: (Ubomba-Jaswa et al., 2010)
S-02	SODIS	10 y	200	“
S-03	SODIS	10 y	200	“
	Closing materials of tube	-	50	Rubber lining, bolts and cap for the tubes on both sides. Assumption: around 50 euros
PU-01	Pump with time sensor	2 y	25	Water pump with 0,5 HP is around 25 euros in philippines
CPC-01	CPC mirrors	-	-	Price included in the 200 euro
CPC-02	CPC mirrors	-	-	Price included in the 200 euro
CPC-03	CPC mirrors	-	-	Price included in the 200 euro
	Base of tubes	-	-	Price included in the 200 euro
	base mirror surface	-	-	Price included in the 200 euro
	Solar panel for powering pump	25y	92	

Name:	Valves:	Lifetime	Price	Details
V-1	Valve	-	1	PVC ball valves are between 8 and 25 euros on amazon. Source: https://www.alibaba.com/trade/search?fsb=y&IndexArea=product_en&CatId=&tab=all&SearchText=PVC+valve&selectedTab=product_en
V-2	Valve	-	1	"
V-3	PVC Valve with water level sensor	-	2	Source: https://www.alibaba.com/product-detail/Water-Level-Control-Valve-Control-JUNY_1600619976743.html?spm=a2700.galleryofferlist.normal_offer.d_title.385875d6vbXXHZ&s=p
V-4	PVC Valve with water level sensor	-	2	"
V-5	PVC Valve with water level sensor	-	2	"
V-6	Valve with time sensor	-	40	Source: https://www.alibaba.com/product-detail/factory-supply-A20-S15-S2-C_60465663881.html
V-7	Valve with time sensor	-	40	"
V-8	Valve with time sensor	-	40	"
Name:	**Piping:**	**Lifetime**	**Price**	**Details**
PL-01	Pipe with latch	-	10	
PG-01	Gaspipe	-	10	Same as normal pipes?
PG-02	Gaspipe	-	10	
P-01	Pipe	-	100	PVC pipes of 100 mm in philippines is 590 pesos per pc = 10 euro. Assumption: only pipe 1 to 4 needs multiple pcs (~10?)
P-02	Pipe	-	100	
P-03	Pipe	-	100	
P-04	Pipe	-	100	
P-05	Pipe	-	10	
P-06	Pipe	-	10	
P-07	Pipe	-	10	
P-08	Pipe	-	10	
Amount:	**Platform: (2,5x2,5)**	**Lifetime**	**Price**	**Details**
18	Beam (2,4x0,051x0,127)	-	180	1100 pesos per beam = 19 euro
10	Beam (0,061x0,051x0,051)	-	100	580 pesos per beam = 10 euro
16	Barrels	-	208	Barrels 750 pesos per pc = 13 euro
1	Floor panels (fibre cement board)	-	20	1200 pesos per board = 20 euro
2	Beams for floor (0,038x0,089x1,2)	-	38	
4	Beams for floor (0,038x0,0892,2)	-	76	

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