Additional Thesis

The Good Toilet : Valorisation and Treatment of the waste streams

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Msc Environmental Engineering

Academic year 2021-2022

0. Summary

The Good Roll, a company based in Amsterdam, produces 100% tree-friendly and sustainable toilet paper. Half of their profit goes to their foundation, building toilet facilities all over Ghana, called The Good Toilet. With the concept of The Good Toilet, they want to provide access to sanitation for all Ghanaians, with an economically viable facility, and with the least environmental impact. They want to build toilets all over Ghana, going from school projects to household and community level toilets. The Good Toilet is a whole community centre with toilets, showers, hand washing stations, and a store. There are already 285 toilets built in a first design. This current design is examined in this thesis, as after a field trip in November 2021 some non-foreseen problems came to light. During this field visit samples of the used borehole water were taken and brought back to The Netherlands. The current treatment system, a solid liquid separator and activated coal filter was checked as well. The water used in the facilities seemed to be contaminated with *E.Coli*, and the effluent stream was entirely clogged. This raised the first research question, namely how the current system can be free from an environmental and health hazard. Secondly it was examined what a new design for the second version of The Good Toilet could be. For this interviews were conducted with people from the emergency context, professors, and people with experience building toilets in low-income countries. Next to this, a literature research was performed and case studies were examined. With this information and estimated guesses a muti-criteria decision matrix within a framework of requirements was created, deciding upon suitable treatment choices for The Good Toilet 2.

Next to technical considerations, the social aspect of building toilets in low-income countries was looked at as well, as this could increase the usage of The Good Toilet and therefore decrease open defecation practices in Ghana. For this, inspiration was taken from the SaniTweaks document of Oxfamwash.

Combining the technical and social aspects of building toilets, an advice could be drawn up to The Good Roll for their projects in the future.

I would like to thank Bruno Bicudo Perez for help in the lab, and Doris for the sampling during her trip in Ghana and all her tips, without them we would not have known the water used in The Good Toilet was contaminated. Lastly, I want to thank my supervisors Jasper and Merle for all the opportunities and endless support!

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1. Introduction

The Good Roll, a company based in Weesp (The Netherlands), makes recycled toilet paper. Next to this, they have an additional mission: Safe and clean toilets for everyone. That is why they donate 50% of their net profit to their 'The Good Roll Foundation', with the aim to construct toilets in various countries in Africa. The idea of The Good Roll originated from a collective frustration: there are 2.3 billion people worldwide who do not have access to safe and clean toilets, being one third of the world's population (*2.3 Billion People Don't Have Access to Basic Sanitation: Report*, n.d.). In addition, 270,000 trees are cut down every day for the production of toilet paper (*Toilet Paper and Deforestation: Are We Flushing Forests down the Toilet?*, n.d.). The Good Roll and their Foundation aim to tackle both problems.

Safe water and sanitation is an important path to reach the 2030 Sustainable Development Goals. The Good Roll aims to contribute to achieving this goal (and other SDGs, see Figure 1) by building toilets for schools, rural areas and households in Ghana. In 2018, when the foundation was founded, they at first only replaced old, dirty and abandoned pit latrines in Ghana by clean ones. As a second step, the concept of The Good Toilet was introduced. A concept of entire toilet facilities with clean toilets, showers, handwashing stations, drinking water taps, Wi-Fi and a shop (see title page). For a small fee local Ghanaians could make use of all these facilities. With this, the idea is that the facility would be entirely economically self-sustaining, using a business model that a local franchiser can benefit from, increasing the usage, hygiene and therefore the purpose of the newly-built toilets.

FIGURE 1: SDGS TACKLED BY THE GOOD ROLL AND THEIR FOUNDATION

The overall objective of the project 'The Good Toilet' is three-fold:

- Provide access to proper sanitation for all the Ghanaians
- Do this with an economically viable business model, to avoid abandoned, useless toilet sites
- Have a minimal environmental impact installing these toilets.

FIGURE 2: PICTURE OF THE VISIT 10TH OF NOVEMBER 2021 AT 1 OF THE SITES OF THE GOOD TOILET 1

There are already 285 toilets built in a first design (*The Good Roll Foundation | The Good Roll - Duurzaam Wc Papier – Toiletpapier | The Good Roll*, n.d.). In November 2021, a field visit to two sites of The Good Toilet 1 was conducted by Doris van Halem, Didier de Villiers and Jasper Schakel. Due to this visit, some first impressions about the first design could be summed up, the problem statement of this thesis could be defined and conclusions could be drawn. At first, the goal of this research was to optimize the biogas production in the digester underneath the toilet, to make The Good Toilet a circular system in which biogas can be reused. However, there were no design drawings available and it was unclear whether the present system was even anaerobically sealed to produce substantial amounts of biogas. The knowledge gap of this toilet system was partially filled in by the field visit in November. However, some unprecedented problems surfaced that require more urgent considerations and solutions.

Therefore, the goal of this additional thesis became giving technical and social recommendations to improve the current design, and giving recommendations for the future design of a second version of The Good Toilet, The Good Toilet 2, as well. The result will therefore be a guideline to decide upon sanitation solutions in Ghana, applied for new projects of The Good Roll Foundation. It should be noted that this thesis should be considered as an advice and does not hold any liability. As this research was conducted during a pandemic, it was not possible to travel to the project in Ghana. Therefore this thesis was conducted on grounds of literature research, interviews, and estimated guesses. Furthermore, compendia used in emergency context such as SuSana.org, the Octopus forum of Solidarité Social with their case studies were used as well.

This thesis is performed within The African Water Corridor. The African Water Corridor (AWC) is a consortium installed by the TU Delft to examine problems around water caused by rapid urbanisation of African cities. Because of the existing development corridors, these cities are growing at a very high rate, with the water existing infrastructure lagging behind. Examples of this are drinking water shortages and bad sanitation practices. With The Good Toilet, The Good Roll aims to replace existing neglected toilet systems like pit latrines in Ghana, replace them by clean toilets, and thus decrease the open defecation practices in Ghana. Because of this, The Good Roll falls within the goal of the African Water Corridor, as they contribute to reducing bad sanitation practices.

2. Problem statement

In communities in Ghana where there is no access to central water and sewage systems, people mostly use pit latrines. Those latrines smell bad and attract flies, and are also unattractive to see and use. Hence, pit latrines are mostly located far from the houses. Furthermore, those flies are also attracted to food, and can therefore infect food with pathogens. Next to that, the pathogens and nitrate from the faecal matter can contaminate the soil and pollute the groundwater, which is often used as direct source of drinking water (Cairncross, 2003). Therefore, The Good Roll Foundation would do well to look for a better alternative. Their colourful buildings are attractive, clean eye-catchers and a nice alternative to currently neglected pit latrines. However, the prerequisite for The Good Toilet is that the effluent treatment system should be efficient in making the exiting streams no health hazard for the users, nor an environmental hazard.

FIGURE 3: THE GOOD TOILET 1 WITH ITS ATTRACTIVE APPEARANCE

Human waste that is badly disposed in the environment contains excreted pathogens and can lead to adverse health effects in individuals exposed to these pathogens. This goes in various ways: through contamination of drinking water, pollution of fish and shellfish growing waters, contamination of irrigated crops or direct contact. Moreover, developing countries are generally characterized by lack of effective environmental pollution control laws (Baum et al., 2013). Ghana has measures in place, but especially in rural areas, they do not enforce the discharge standards for wastewater or faecal sludge. In addition to this, reaching those discharge standards (See Table 12 in Appendix 3), is not monitored at all. However, to improve hygienic conditions, regional limit values for effluent quality should be used as performance criteria. Because of this, not much is known about the effluent water quality of the waste streams leaving sanitation systems in Ghana, and companies like The Good Roll do not have a strict legal framework to follow. According to the Sanitation Quality Standards for Emergencies from the WASH cluster (*Water Sanitation Hygiene | HumanitarianResponse*, n.d.), Standard 1 is to get the environment free from human excreta. The Good Toilet should be a better option than open defecation: health-wise, environmentally, socially, and for The Good Roll also economically. For this it is important to take social standards into account. These will be examined in this thesis as well and is retrieved from Oxfam SaniTweaks (attached to this thesis).

The problem statement in this thesis can be divided into two parts: firstly the issues of the current system are summed up, and secondly the issues around contaminated groundwater at the sites of the projects. These two types of problems combined will define the research questions of this thesis.

2.1 The current system of The Good Toilet 1

The system that is operated now is a solid liquid separator system, shown in the sketch below (Figure 4).

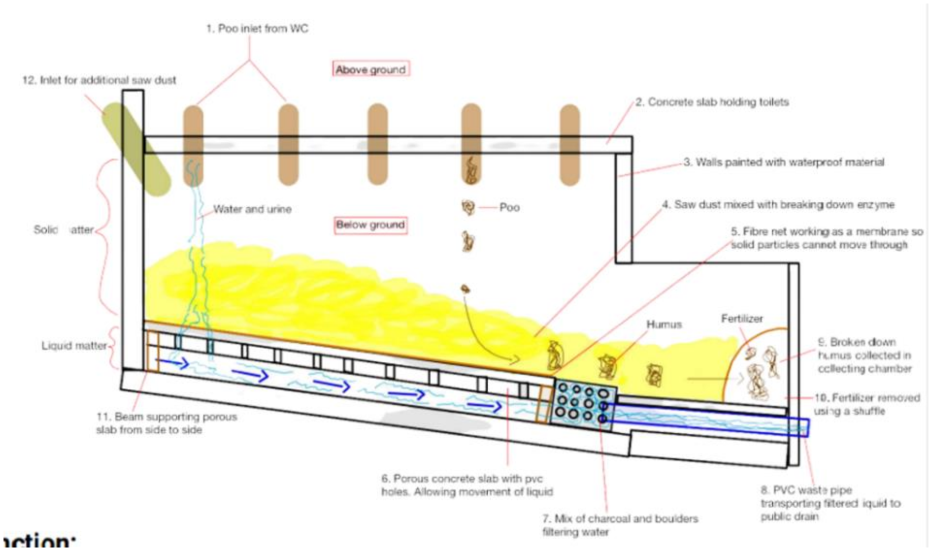

FIGURE 4: SKETCH OF THE SOLID LIQUID SEPARATOR CURRENTLY USED AS TREATMENT SYSTEM OF THE GOOD ROLL.

In the sketch it can be seen how the faecal matter +toilet paper+ urine + flush water all ends up in the same tank. There is one tank for the 5 toilets installed in the toilet hub (represented by the five brown lines). The liquid part of this mixture goes through a fine mesh under which it is collected and sent through a charcoal filter, to the public drain. The solid matter on top of the matter dries out and becomes fertilizer after a couple of months. The tanks are dimensioned in such a way that they get full after around 6 months. Furthermore, the solid matter gets mixed with sawdust and enzymes (composition not known). As the toilets were built not longer than 6 months ago, the destination of the fertilizer is not decided yet, or how the tank will be emptied.

After the field visit in November, some observations could be summed up about this current system, showing that the practical implementation of this system is not the same as theoretically shown on the sketch.

- The SLS (Solid Liquid Separator) did not seem to separate the solids from the liquids very well, creating a watery mixture on top of the mesh. Therefore the solid mater is not dried out properly and no fertilizer is formed.
- Access to the biodigester was not locked. Children were playing at the shutters, which creates a safety and health hazard to the community.
- There are currently no sampling points to check the performance of the system.
- The borehole water used as flush water, hand wash water and shower water in The Good Toilet is currently contaminated with *E. Coli* (See Appendix 1 and 2 and section 2.2)
- The activated carbon filter was not accessible or even present. A picture of the filters is depicted below. The barrels could not be opened, so it was unclear whether the filters were present.
- There was no effluent stream, which probably means that the entire system at that site was clogged.

FIGURE 5: ACTIVATED CARBON BARRELS AT A SITE OF THE GOOD TOILET

FIGURE 6: LEFT: OPENED SOLID LIQUID SEPARATOR. RIGHT: ACCESS TO THE SOLID LIQUID SEPARATOR FROM THE OUTSIDE.

Assessing the current design, it should be noted that an activated carbon filter is not recommended for blackwater treatment. The organic load is too high and the filter would be saturated too quickly. As the composition of the effluent water of a discontinuous toilet system is very variable, the time of saturation is variable as well and extensive monitoring is required, which is not recommended for The Good Toilet 1. Therefore some new technical recommendations should be proposed for a future design of The Good Toilet 2.

The fact that the system is clogged and therefore the liquids stay present in the tank as well, creates the concern that pathogens are exposed to micropollutants such as antibiotics, therefore potentially creating antibiotic resistance.

2.2 Contaminated Groundwater

FIGURE 7: DORIS PREPARING *E. COLI* DRY PLATES IN THE SHOP OF THE GOOD TOILET

During the visit in November, there was the chance to take water samples and see what is going water quality related at the project sites of The Good Toilet. There were three types of samples taken in Ghana at The Good Toilet sites, namely the outflow after the charcoal carbon filter barrels, the borehole water coming from the hand wash tap, and borehole water used for flushing the toilets. Of each of these three types of samples, 10mL was brought to The Netherlands, and analysed in the Waterlab of TU Delft. The procedure of sample taking and analysis is shown in Appendix 4. The Total Nitrogen content, Total Phosphate and COD content were quantified with spectrophotometric analysis. The results from the lab are shown in Table 1 below. Furthermore, before the start of this thesis, an external company performed a more extensive groundwater water quality analysis at the Kotoku-Papase site, in order to design a treatment scheme to treat the borehole groundwater to drinking water. These results are shown in Appendix 3. On a sidenote, this was the only time the Good Roll wanted to entirely treat the borehole water to drinking water in a The Good Toilet unit, as the investment was too high and the demand too low.

As it was not possible to bring a large volume of samples, no sufficient amount of dilutions could be made, hence the '-' in the tables in Appendix. Dry plates of *E. Coli* were also made, and pictures of the dry plates and the results are shown in Appendix 3 as well. From this it can be concluded that a 3log removal of E.coli from the borehole water Kotoku-Papase is required for a total pathogen-free influent for shower-, handwash- and flushwater.

Using the own analysis and the analysis of the external company about the groundwater at one of the sites of The Good Toilet, it can be concluded that the concentrations of Total Dissolved Solids (TDS), Hardness, nitrate, total coliforms and faecal coliforms are too high.

TABLE 1: ANALYSIS OF BOREHOLE WATER USED IN THE GOOD TOILET 1 AT KOTOKU PAPASE

Component	Concentration	Measuring method
E. Coli (CFU/100mL)	866.66 ± 262.46	Dry plates
TSS (mg/L)	2.00	analysis external company
Total P (mg P/L)	0.00	spectrophotometer
Total N (mgN/L)	8.90	spectrophotometer
COD (mg COD/L)	6.47	spectrophotometer
Hardness (mg/L)	234	analysis external company

3. Research questions

Before defining the actual research questions, it should be decided where the focus of this thesis lies. There are multiple streams leaving The Good Toilet system. The first point of examination is where the biggest demand lies for optimization of the treatment. Which polluted stream is most urgent to be treated, or which stream has the biggest demand in Ghana to be treated, and to which extent should it be treated? In other words, what are the reuse and/or discharge options of the treated streams? These preliminary questions were resolved by brainstorming with employees of The Good Roll in Ghana, Prof. Dr. Ir. Jules van Lier, Dr. Ir. Ralph Lindeboom, and Prof. Dr. Ir. Merle de Kreuk. An overview of the streams leaving the system is shown in Figure 8.

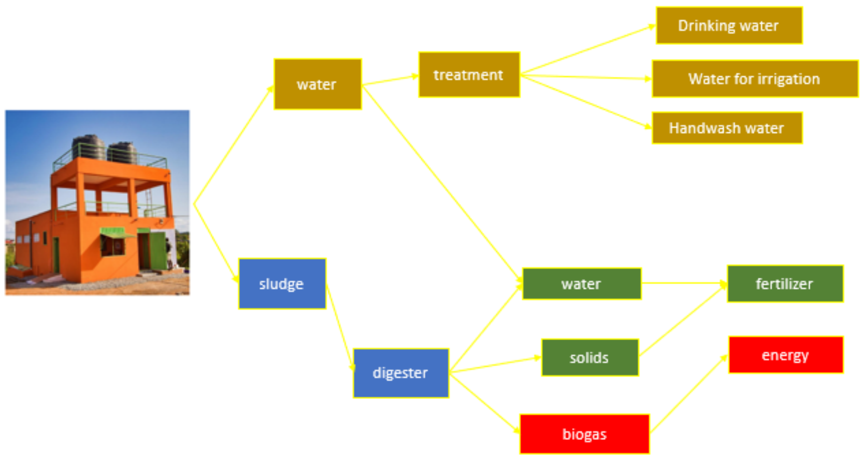

FIGURE 8: OVERVIEW OF THE WASTE STREAMS LEAVING THE GOOD TOILET

At first, the question of The Good Roll to the TU Delft was to optimize their solid liquid separator and create biogas to make the system of the Good Toilet more circular. This biogas could then be used to heat up the shower water, or for cooking. However, looking at the system of the solid liquid separator (which cannot be anaerobically sealed) and the fact that the separation of solids and liquids is lagging, the emphasis was changed to treating the effluent water to be environmentally harmless, while also keeping the system economically sustainable. Therefore, the research questions of this thesis can be summed up as follows:

1. How can there be a pathogen-free influent and effluent in the current design of The Good Toilet 1? (Q1)
2. Is there a general new and optimized design possible for The Good Toilet 2, a second version of The Good Toilet? What are the most attractive treatment scenarios for this new design? (Q2)
3. How is the usage of the toilets guaranteed? How is the safety and the hygiene of The Good Toilet maintained, and how can therefore open defecation in Ghana be decreased? (Q3)

It should be considered that the selection of a sanitation system should be done by considering the following factors (Zaqout & Hueso, 2021):

- Technical and operational
- Health and environmental
- Social, cultural and gender
- Institutional and political
- Economic and financial

In this thesis, emphasis is put on the first two bullet points as for the requirements, with the last three being mostly desires for new technologies.

4. Methodology

The methodology of this additional thesis is divided into 4 different steps , with step 2 divided into 2 sub-steps. At first, a framework of requirements was created, in which the proposed technologies should be filled in.

As a second step, technological changes are proposed to the existing design which is already built, and new technologies and designs are proposed for The Good Toilet version 2.0. Step 2.2 requires entire new ideas and therefore interviews were taken next to literature research. For Step 2.2 a multi-criteria decision matrix was created and scores were given to each plausible technology per criterion. Each criterion was also given a score according to their importance. Step 3 will show the social aspects related to building toilets in the Global South. This section also help to solve research question 3, with which solutions the usage of the toilets can be guaranteed more. Small changes and considerations regarding social aspects can add to an increased use of the facilities. For the first three steps, interviews were performed with Marij Zwart (WASH advisor from the Red Cross), Mariska Ronteltap (expert faecal sludge management), Jasper Swiersta (Environmentors, builds toilets in India), Tineke Hooijmans (Prof. Sanitary Engineering at IHE Delft), and Bas Heijman (Professor Membrane

Technologies, TU Delft). Lastly, Step 4 provides the technical and social advice to the Good Roll. This advice is combined with a more generalized advice to The Good Roll made by Jasper Schakel, Merle de Kreuk and Doris van Halem, in response to the field visit in November.

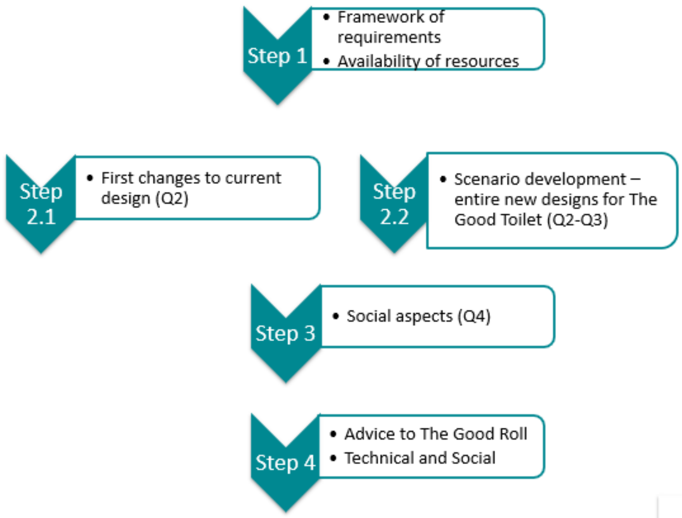

FIGURE 9: METHODOLOGY DURING THIS THESIS

5. Step 1 : Framework of requirements

The requirements for this project are depicted in Table 2. These requirements were determined by conducting interviews of people in for example the emergency context. The difference is being made between requirements and desires, as requirements really are necessary components, as for desires it would be nice to have. At this moment, the biggest requirement is pathogen-free effluent, as the streams leaving The Good Toilet now are a health hazard. Therefore, when looking at effluent quality requirements, in this thesis there is only focused on pathogen-free effluent, as a high N-removal would additionally be beneficial as well if there is no reuse as fertilizer for the effluent stream. According to Marij Zwart, WASH advisor at the Red Cross, the first goal should be to keep the effluent leaving The Good Toilet pathogen-free.

As a safety desire, helminth egg removal is mentioned, as this is a parameter often mentioned in literature. Helminth eggs are the infective agents for worm diseases and are very robust. Only with pasteurisation they can be eliminated (Cofie et al., 2006). However, according to Tineke Hooijmans, if the personnel using the wastewater is well-informed about the presence of helminth eggs, the stream can be used as fertilizer, and is therefore a desire and not a requirement. Later, scores are given to each requirement according to their importance, per project and situation. These scores can vary according to the new project.

TABLE 2: FRAMEWORK OF REQUIREMENTS FOR DESIGNS OF THE GOOD TOILET

Requirements for design	Desire for design
Discontinuous	Locally produced
Scalable	Economical sustainability
Small	Cheap
Robust	Environmentally harmless
Decentralized	
Easy to maintain	
Minimal capital requirement	
Specific Effluent Quality Requirements	Safety desires
Pathogen-free	No helminth eggs

60% N-removal (when not designed for reuse)	

6. Step 1 : Availability of resources

The framework of requirements is one thing to consider for the designs, but the availability of resources on the project sites are important factors as well. For this, multiple questions can be asked:

1. What are the demands of the community?
2. Is electricity available?
3. What is the availability of clean groundwater?
4. The height of the groundwater table?
5. Is there a flood risk in the area?

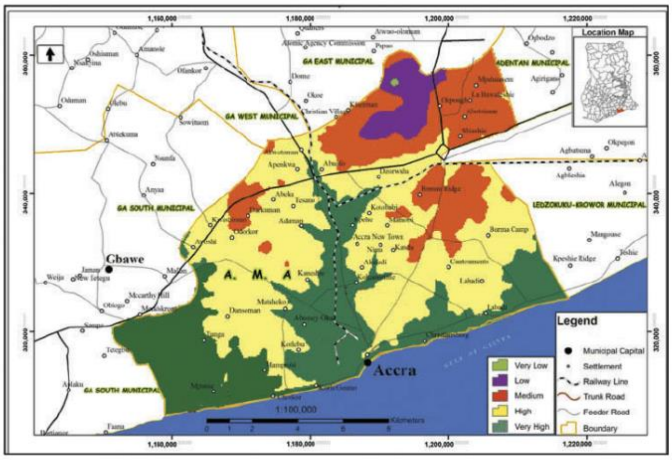

FIGURE 10: FLOOD PRONE AREAS IN ACCRA, GHANA (*Flood Prone Areas In Accra - Meqasa Blog*, n.d.)

Interviews and research have shown that the framework of requirements is not the only level at which technology choices are made. One of the key components in this thesis is the fact that there should be communication with the community, and this is also reflected in these steps. First and foremost, the specific demands of the community must be examined. The availability of electricity must also be considered. If not, a generator must be installed, or solar panels with a battery that can store the electricity. These would then have to be properly secured to prevent them from being stolen. When a project site is chosen, a groundwater analysis should also be perfromed to see if a pre-treatment step is needed to purify the borehole water. The height of the groundwater and the risk of flooding must also be considered. If both are high, it is not a good idea to implement constructed wetlands, for example. Figure 10 shows the risk of flooding in the region around Accra. The height of the groundwater also largely determines the depth to which tanks can be placed in the ground. These external factors can be examined as well on Resource Watch from Deltares (*Resource Watch*, n.d.). In this map, the riverine flood risk, coastal flood risk and Water stress and cropland were combined and mapped out. The map can be accessed via 'https://bit.ly/34pCqYA', and a screenshot is depicted in Appendix 5. These considerations already solve research question Q2 , as a general new The Good Toilet 2 design will not be possible in the whole of Ghana.

7 Step 2.1 Changes to current design

First, there is looked into short-term solutions that can be applied to the current design in order to reduce the environmental and health hazard of the toilets that have already been built and are now operational in Ghana. This can be divided into three parts. As the problem statement says, something must be done about the poor/non-existent purification of the blackwater, and the clogging of the pipes. Secondly, a potential additional source for influent is being considered: rainwater. Thirdly, something needs to be done about the fact that contaminated borehole water is used for showers, hand washing and flushing.

7.1Boreholes
Boreholes can be an excellent water source in a range of sizes. But the proper design and the safety of the water is crucial. In Appendix 1 the dry plates are shown of the borehole water, showing bacterial contamination of *E. Coli*. A 3Log removal is required to have pathogen-free borehole water implemented in the system as handwashing water, shower water and flush water. The groundwater should always be analysed first before usage. If there is bacterial contamination detected, a UV-treatment system should be implemented in the borehole pipelines before usage. Especially while showering, toxic aerosols can be formed or the water can be accidentally drunk, being a health hazard for the person using the facilities. This can be easily implemented within the pipes (*In-Pipe UV Disinfection | Treatment Plant Operator*, n.d.).

7.2 Rainwater
Rainwater harvesting is the principle of collecting and using precipitation (rainwater) from a catchment surface. A 2 m^3 rainwater tank could be installed on the roof of The Good Toilet. Measurements should be taken to prevent algae growth. This also helps urban water demand and promotes sustainable water use. (Dufault et al., 1992). Using dark-coloured rainwater tanks reduces the risk of algae growth.

7.3 Treatment of the streams leaving the solid liquid separator
As seen in the field visit in November, the streams leaving the system are not separated well and are causing an environmental and health hazard. However, better separated solids may be used for composting, or for potentially generating biogas in the future and it also reduces odour. Adding a drying option to the solid liquid separator could be a solution. Next to that, there should be a chemical treatment step added to the SLS to keep the solid waste As chlorine dosing is not efficient, and afterwards the black matter cannot be used as a fertilizer, lime addition or ureum dosing are better options.

Lime addition is used with the main treatment objective to reduce pathogens. The addition of either hydrated lime ($Ca(OH)_2$) or quick lime (CaO) to faecal sludge increases pH and results in pathogen inactivation and limited sludge stabilization. According to the Octopus Case study in Cox's Bazar in Bangladesh. In general, 20g lime per kg of faecal sludge is dosed. However, there should be extensive mixing. The pH should remain 11.5, otherwise more lime should be dosed.

The liquid stream leaving the solid liquid separator could be treated by an unplanted or planted wetland system, or a helophyte filter. Furthermore it could also be left untreated for 6 months in a tank, which will sterilize itself then. A last plausible option could be a second UV desinfection step.

8 Step 2.2 Scenario development for future designs
Multicriteria analysis (MCA) is a flexible and multidisciplinary tool which ranks or scores a finite number of options on the basis of a set of evaluation criteria (Zakaria et al., 2015). According to EAWAG, The decision-making approach must examine every option in terms of environmental impact, resource requirements, and potential for resource recovery. In this thesis, depending on the availability of resources, and the place where the toilet unit is being built, a score between 0 and 1 is given to each requirement, depending on how important the requirement is. For each considered technology then a score is given between 1 and 5 and how well this requirement is filled in using this technology. Then the weighted average is taken. This is done for the 5 steps in on-site non-sewered sanitation, as shown in Figure 11.

FIGURE 11- THE FIVE STEPS OF THE MULTICRITERIA ANALYSIS ACCORDING TO (Zakaria et al., 2015)

The first step, namely user interface, refers to the toilet, pedestal, pan or urinal the user comes into contact with. Collection and storage refers to the way in which products generated from the user interface are collected or stored. The combination of the choice of which user interface and which collection system decides how many effluent streams will need to be treated. The third step, conveyance, describes the way in which products generated from the user interface are moved on from one process to another. As in the beginning is decided to not look into (semi)-centralized treatment of effluents, but only on-site treatment technologies, this third step is not discussed. However proper faecal sludge management is seen as centralized treatment (Strande et al., 2014). The fourth step is treatment of the effluent streams to become pathogen-free and environmentally harmless as much as possible. The fifth step is reuse and disposal, and this refers to the ways in which products generated at the user interface are returned to nature (Zakaria et al., 2015). For each of the four steps a multi criteria analysis is conducted, with the framework of requirements as criteria, on technologies mentioned in the interviews, compendia, case studies and literature. Screenshots of the excel file are shown in Appendix 6,7 and 8.

8.1 Decision of the user interface

A choice is made between wet and dry user interface systems, meaning that they do or do not use flush water, respectively. Wet toilets are most common for sewered systems. If there is no shower implemented in The Good Toilet of that project, the choice should be a dry system as no borehole effluent is required then, and only solids post treatment is required. Wet systems are also more expensive. However dry toilets can have more toilet odour issues, as nothing is being flushed away. The decision matrix on user interfaces is depicted in Table 3. The design of the user interface already makes the decision whether streams will be separated or not, which is an important aspect of post treatment. The relative scores taken in Table 3 for each requirement were determined by estimated guesses, and can be automatically altered in the excel file according to the demands of the project.

8.1.1 UDDT Toilet interface

As can be seen from Table 3, UDDT toilet interfaces score highest. A urine-diverting dry toilet is a toilet that operates without water and has a divider so that the user, with little effort, can divert the urine away from the faeces (Tilley et al., 2014). The decision of building UDDT toilets in-house proves to be a well working solution and a considerable improvement for the environment, for the dignity of the users and for their comfort. UDDT toilets allow for composting directly inside the containment. These composting toilets are waterless, can be used to co-manage additional waste types such as food scraps and leaves. Fertilizer can be produced very easily, as sawdust/lime/ash/earth is added to reduce odour as well. As for the operation and maintenance, a UDDT toilet is slightly more difficult to keep clean compared to other user interfaces. This could be a major drawback for the Good Toilet, as this is one of the most important requirement. However, as the streams are more concentrated, post-treatment becomes significantly more easy.

A recommendation for the usage of UDDTs is to have a toilet franchiser to first tell people how the toilets work, receive a small deposit of money (Ghanaians are used to paying for their toilet use). After the toilet usage, the franchiser makes sure that the toilet is in the same good condition as before.

TABLE 3: MULTICRITERIA DECISION MATRIX FOR THE USER INTERFACE.

User Interfaces	Usage of water (L/day)	Costs	User-friendly	Robust	Maintenance	Discontinuity	Score	Generalizing[1]
Relative scores (0-1)		0.9	0.8	0.8	0.7	0.8		
Conventional flush systems (dual flush)[2]	6-9[3]	2	4	4	3	2	11.9	0.476
Vacuum toilets[4]	1	2	2	3	3	3	10.3	0.412
Single Flush Toilets	7.2	1	3	4	3	3	11	0.44
UDFT[5]	<6[6]	3	4	1	4	5	13.5	0.54
UDDT[7]	0	5	4	4	4	5	17.7	0.708

[1] This generalized column shows the total score divided by the maximum achievable score, and therefore shows the percentage of efficiency compared to a 'perfect system'

[2] Retrieved from the Compendium of Sanitation Systems and Technologies of IWA and EAWAG.

[3] Retrieved from the Compendium of Sanitation Systems and Technologies of IWA and EAWAG.

[4] Retrieved from (*Vacuum Toilet | SSWM - Find Tools for Sustainable Sanitation and Water Management!*, n.d.).

[5] Retrieved from the Compendium of Sanitation Systems and Technologies of IWA and EAWAG.

[6] Depends on the type being used, however it is less water than a conventional flush system.

[7] Retrieved from susana.org case studies, Urine Diversion dehydration toilets at Valley View, University in Oyibi, Greater Accra Region, Ghana (Abbot et al., 2019)

8.1.2 Other considered interfaces

The second highest scoring user interface is the UDFT (Urine diverting flushing toilet). This is slightly less desired for The Good Toilet, as concentrated effluent streams and minimal usage of borehole water is desired. Next to UDFT, vacuum systems were proposed in the interviews as well. As this is a high tech system, the capex costs might be high. But in comparison with a common flush toilet, it can be slightly cheaper in operation. However the availability of electricity is required. In the decision matrix they score the least, as the user friendliness is also less than the other user interfaces (Todt et al., 2021). As single flush toilets require a lot of water, this user interface scores lower as well (Tilley et al., 2014).

8.2 Decision of the collection system

8.2.1 Options for the collection system

Table 4 shows a decision matrix for deciding on the collection and storage of the created streams after using the user interface. The requirement 'pathogen-free' was given a score of 1 for this decision matrix, as this is the main objective of this thesis. Because of this, some techniques were quickly written off with a low score, as this requirement should be strictly followed. Furthermore, it should be mentioned that the decision of collection and storage is also linked to the choice of user interface, and should match regarding the type of streams that are created. After deciding on the collection system, it still needs to be considered whether the tanks can be dimensioned according to the floods and the depth of the groundwater table. It should be noted that the requirement 'pathogen-free' only reflects on whether the collection and storage itself sterilises. The treatment that can potentially happen within these collection systems is examined in section 8.3.

TABLE 4: MULTICRITERIA DECISION MATRIX FOR COLLECTION SYSTEM

Collection system	Pathogenfree	Cost	Maintenance	Robust	Small	Scores	Generalized
Relative Scores (0-1)	1	0.9	0.7	0.8	0.7		
Biodigester[8]	3	3	2	2	2	10.1	0.404
Septic tank[9]	1	3	5	4	1	11.1	0.444
Pit latrine[10]	1	5	5	4	1	12.9	0.516
UASB tanks[11]	2	5	3	3	3	13.1	0.524
SLS[12]	1	4	2	4	3	11.3	0.452
Anaerobic Baffle reactor (improved septic tank)[13]	3	2	2	2	3	9.9	0.396
VIP latrines[14]	1	4	4	5	1	12.1	0.484
Solar septic tank[15]	5	3	3	4	3	15.1	0.604

[8] Retrieved from (Hashimoto & Khanal, 2014)
[9] Retrieved from the Compendium of Sanitation Systems and Technologies of IWA and EAWAG.
[10] Retrieved from (Cairncross, 2003). Looking at the other options of the matrix, a pit latrine is not recommended as this is the technique that The Good Roll wants to replace with their project of The Good Toilet.

[11] Retrieved from (Graaff et al., 2010)
[12] Solid Liquid Separator. This is the current collection and storage system being used by The Good Roll
[13] Retrieved from (Tilley et al., 2014). The septic tank is improved as the contact time of the wastewater with the active biomass is increased and therefore results in improved treatment.
[14] VIP means Ventilated Improved Pit. With only a small increase in costs, the ventilation is improved and therefore way more user-friendly as no odour problems are experienced.
[15] Retrieved from (Koottatep et al., 2020)

8.2.2 Septic tanks

Septic tanks are the easiest to maintain option. The major benefits of these types of tanks is the simplicity and the low required capital. The sludge can be collected when the tank is full (popular is to design for sludge emptying after 6 months), and then it can be transformed into biogas and fertilizer if required through a semi-centralized treatment. Figure 12 shows the simple implementation of a septic tank and therefore the applicability for The Good Toilet 2.

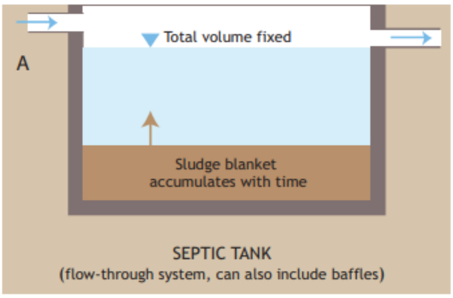

FIGURE 12: SEPTIC TANK SYSTEM AS NON-SEWERED SANITATION SOLUTION (Strande et al., 2014)

8.2.3 Biodigester

As the first goal of The Good Roll was to have a biogas production optimization, the biogas reactor should be considered as treatment step as well. This collection system also allows for potential co-digestion with kitchen waste (increasing the biogas production and therefore the profit for The Good Roll). A biogas reactor should be an airtight chamber that facilitates the anaerobic degradation of blackwater. It also already facilitates the collection of the biogas. Looking at the design, it can be made from locally produced materials, all below ground. They can be built in the form of fixed dome or floating home digesters. Figure 13 shows the practical implementation of a biodigester. As can be seen, 2 tanks are required which would be best built underground to tackle temperature fluctuations.

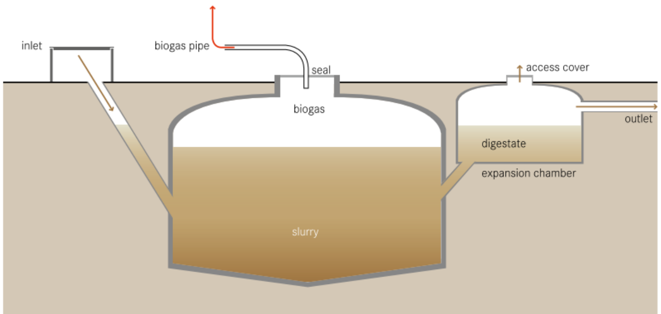

FIGURE 13: BIOGAS REACTOR (Tilley et al., 2014)

8.2.4 The Solar Septic Tank

The solar septic tank (SST) scores high in the decision matrix. As mentioned in Koottatep et al., this is an innovative decentralized wastewater treatment system, already tested at a household scale for blackwater treatment in rural areas in Thailand. The SST achieved significantly higher total removal efficiencies than a conventional septic tank. However, the total TBOD removal efficiency and pathogen inactivation of SST were influenced by the operating temperatures, so special care should be given to that (Koottatep et al., 2020). It also already includes an intrinsic treatment step for pathogen removal, therefore not needing an additional post-treatment step to have a pathogen-free effluent. The solar-heated water system creates higher temperatures than ambient inside the septic tank. The temperature promotes the biodegradation of organic matter and methane formation.

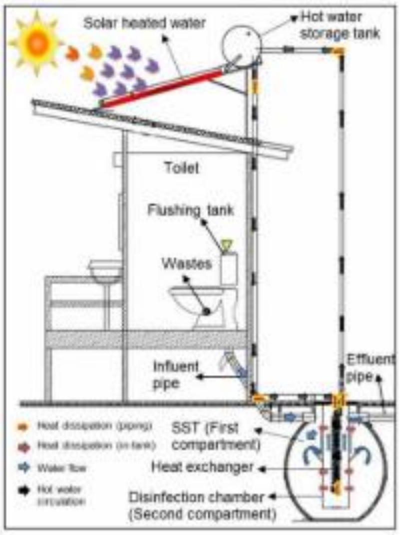

FIGURE 14: SCHEMATIC OVERVIEW OF A SOLAR SEPTIC TANK (Koottatep et al., 2020)

Looking at Table 8, a lot of the framework of requirements can be recognized in many aspects, and therefore this technique seems suitable for The Good Toilet, as the technique scores high in the decision matrix as well.

TABLE 5: ADVANTAGES AND DISADVANTAGES OF A SOLAR SEPTIC TANK (Koottatep et al., 2020; Tilley et al., 2014)

Advantages	Disadvantages
Less expensive to build than other treatment options	Large area requirement
Natural processes	The land should be affordable and available
simple construction with local materials	Not in flood risk areas
Simple operation and maintenance	Dewatering afterwards is more difficult
Cost effective	
Process stability	
Partial pasteurisation	
90-99% BOD removal	

8.2.5 A UDDT Vault collection system

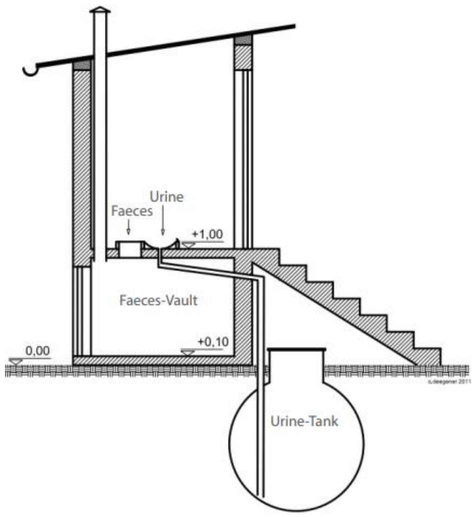

FIGURE 15: SCHEMATIC DRAWING OF A SINGLE VAULT UDDT TOILET (Riungu et al., 2018)

As a UDDT interface system scored highest in the previous section, it is examined first which high scoring collection system could be applied to this user interface. This user interface implies 2 different collection tanks, namely a faeces vault and a urine tank. When urine cannot be used immediately or transported using conveyance technologies, it can be stored onsite in containers or tanks. The storage tank must then be moved or emptied into another container for transport. Furthermore, long term storage (around 6 months) is the best way to sanitize urine. On household level, if a family's urine is used to fertilize crops for their own household, it is safe to use directly (Tilley et al., 2014). Neither the storage tanks, nor the collection pipes should be ventilated to avoid odorous ammonia emissions, but they both need to be pressure equalized.

TABLE 6: ADVANTAGES AND DISADVANTAGES OF A UDDT COLLECTION SYSTEM (Riungu et al., 2018)

Advantages	Disadvantages
Generation of renewable energy	Incomplete pathogen removal, digestate might require further treatment
Small land area required (most of the structure can be built underground)	Limited gas production below 15 degrees
No electrical energy required	Requires expert design and skilled construction
Long service life	
Low operating costs	
Conservation of nutrients	

8.3 Decision of primary treatment system for solids

Depending on the decision of the collection system, there are 1, 2 or 3 streams to be treated. As UDDT toilets are the most plausible choice for user interfaces, 3 different streams of the Good Toilet will need to be treated: Blackwater, greywater and urine. Greywater is left outside the scope of this project. For this stream it is assumed to use vertical constructed wetlands, as the organic loading of greywater is generally not high. According to the interviews, literature and estimated guesses a decision matrix was also created of this third step to decide upon the right treatment technology. As for the urine stream, only UV disinfection will be compared to leaving the urine without treatment, letting it sterilise for 6 months and then reusing it.

TABLE 7: DECISION MATRIX FOR 3 STREAMS BLACKWATER TREATMENT

Blackwater	Pathogenfree	Robust	Small	Scalable	N-removal[16]	Maintenance	Cost	Scores	Generalized
Scores	1	0.8	0.7	0.6	0.2	0.7	0.9		
UASB[17]	2	3	3	4	4	3	5	16.3	0.54
Constructed Wetlands[18]	4	3	1	3	4	3	3	14.5	0.48
Lime Treatment[19]	5	4	4	5	1	4	4	20.6	0.69
Helophyte filter	2	2	2	4	4	2	4	13.2	0.44
Backwashable filters	3	2	3	4	3	2	2	12,9	0.43
Blackwater pyrolysis	5	5	2	5	5	4	1	18.1	0.60
Fish ponds	3	3	2	3	4	2	3	13.5	0.45
Algae treatment	4	3	1	3	4	2	3	13.8	0.46
Biofilm trickling filter	4	2	4	3	3	2	2	14	0.47
Black soldier fly[20]	5	3	3	5	3	3	4	18.8	0.63
Tiger worm treatment[21]	5	3	3	5	3	3	4	18.8	0.63
Solar septic tanks	5	4	4	4	2	3	3	18.6	0.62
Drying out + FSM[22]	4	5	2	4	1	5	4	19.1	0.64
Urine treatment									
No treatment- multi barrier approach	4	5	3	4	1	5	5	20.7	0.69
UV desinfection	5	4	3	3	2	3	3	17.3	0.58
Greywater									
Vertical constructed wetlands[23]	4	2	3	3	4	3	3	15.1	0.50

[16] N-removal is a low importance requirement in this decision matrix as urine is treated for reuse

[17] (Graaff et al., 2010). However, Generally it is not recommended to use an anaerobic technique as a treatment step for The Good Toilet. This is too sensitive and not robust enough. Extensive monitoring is required.

[18] Retrieved from the UN Human Settlements program – Constructed Wetlands manual

[19] Retrieved from the Octopus case study 'Lime stabilisation-Unplanted drying beds' in Cox's Bazar Bangladesh from the IFRC. This treatment is mentioned in step

[20] Retrieved from EAWAGs recent case study on Black Soldier Fly treatment led by Moritz Gold. (Dortmans et al., 2017) According to Mariska Ronteltap, Black Soldier Fly treatment is a promising new technology for on-site blackwater treatment.

[21] Information retrieved by the OXFAM WASH document on Tiger Worm Toilets

[22] The darker brown colour implies semi-centralized treatment. Proper Faecal sludge management is explained by (Strande et al., 2014)

[23] Retrieved from the UN Human Settlements program – Constructed Wetlands manual

8.3.1 Constructed Wetlands

Another technology that came out of the interviews was constructed wetlands. Wetland systems can be around 60-70 cm deep for adequate denitrification. For this techniques there should be space available and the groundwater table should not be too high. Furthermore there should be low risk of flooding. For the design of wetlands ,there can be information obtained from the constructed wetlands manual of the United Nations, provided by Jasper Swierstra and attached to the report.

8.3.2 Biofilm trickling filter

Can be added to the toilet user interfaces themselves. A biofilm filter consists of a course material bed, such as stones, gravel, etc. The liquid percolates rapidly over the medium, but the microbial film that grows on the granular elements.

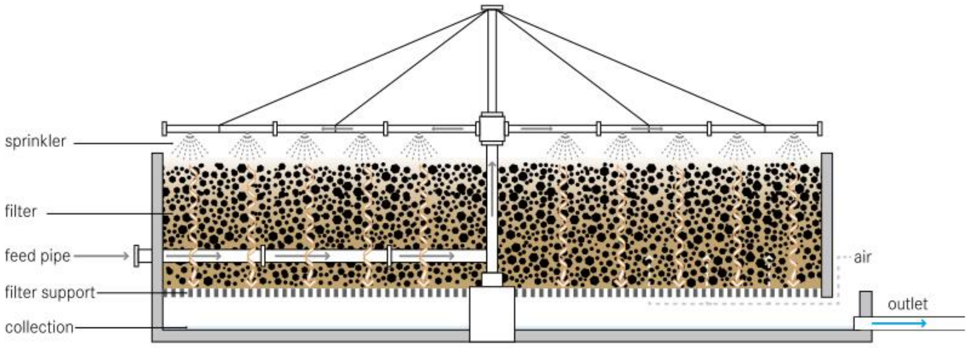

FIGURE 16: SCHEMATIC OVERVIEW OF A BIOFILM TRICKLING FILTER (SOURCE: (Tilley et al., 2014))

Organisms grow on the large surface area, providing a large area for a biofilm to be formed. They oxidize the organic growth in the blackwater to carbon dioxide and water, while generating new biomass.

TABLE 8: ADVANTAGES AND DISADVANTAGES OF A BIOFILM TRICKLING FILTER (Tilley et al., 2014)

Advantages	Disadvantages
Robust: can operate at a range of organic and hydraulic loading rates	High CAPEX
Resistant to shock loadings	Expert design and construction
Efficient nitrification	Operation and maintenance
High effluent quality in terms of BOD and SS removal	Needs primary and tertiary treatment to also have pathogen removal
Small area required compared to constructed wetlands.	Flies and odour
	Risk of clogging
	Not all parts and materials are locally available

The conclusion about trickling filters is that the technology might be too complex and requires too much monitoring. The odour and fly problems require that the filter be built away from homes. The capital costs are high depending on the type of filter material needed and feeder pumps used. The energy consumption of pumps should also be looked at, and it should be considered whether the electricity is freely available (see section availability of resources).

8.3.3 Vermifiltration

According to the interviews, the last couple of years a trend is rising on using vermifiltration as treatment in septic tanks in low-income countries. In this thesis two types of vermifiltration are examined, namely tiger worm treatment (originating in Asia) and Black Soldier Fly treatment (Developed by EAWAG, Zurich). As there are many advantages to vermifiltration techniques, the biggest drawback here is the social barrier of having worms in a toilet tank.

Tiger Worm treatment was included in the decision matrix as this is a common example of decentralized toilets waste treatment, mentioned in the conducted interviews. This treatment shows vermifiltration where tiger worms digest the organic waste directly in the toilet to create vermicompost. This vermicompost is valuable as fertilizer, as it is pathogen-free. With this the accumulation of sludge decreases and reduces the need to empty the tanks as well. Furthermore, TWT (Tiger Worm Toilets) typically cost a similar amount to a typical latrine for materials and construction. The aerobic process within the pit also creates less smell than a conventional pit latrine, increasing the toilet usage. They also have fewer flies, meaning less disease vectors. The key considerations for this type of treatment is the water availability, worm availability, soil infiltration and user behaviour and acceptance. Additionally, TWTs require good soil infiltration to function correctly, so this is an extra consideration added to the examination of the project site. A design document is attached to the thesis. For this treatment wet user interfaces are necessary, therefore it needs to be combined with for example conventional dual flush toilets. The single drawback is that the tiger worms should be imported as they are not indigenously found in Ghana. However the climate of operation is similar.

FIGURE 17: RED TIGER WORMS (SOURCE: OXFAM WASH)

FIGURE 18: BLACK SOLDIER FLIES IN THEIR WORM STAGE (DORTMANS ET AL., 2017)

The second technique mentioned in the decision matrix is the use of black soldier flies, *Hermetica illucens*, to feed on faecal sludge (FS). Just like tiger worm toilets, it is an innovative way of reducing FS and generating animal feed protein. BSFT (Black Soldier Fly Treatment) contributes to sanitation of FS by reducing *Salmonella* and *E. Coli*, creating a pathogen-free dry fertilizer (Dortmans et al., 2017). This techniques is already applied in neighbouring countries, confirming good climate conditions. There is no need for sophisticated high-end technology to operate such a facility. Therefore, it is suitable for low-income settings that rely mostly on simple technology and unskilled labour, perfect for The Good Toilet 2 .

8.3.4 Reuse of urine

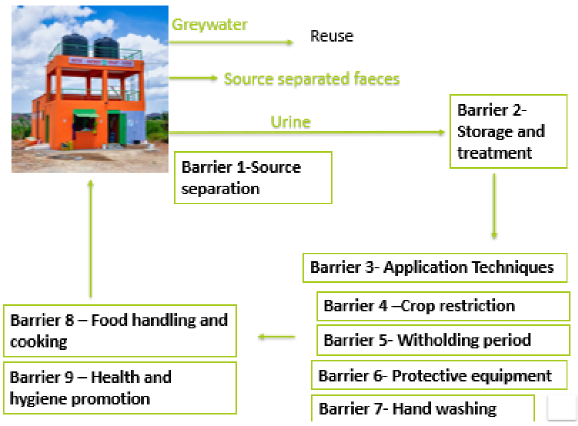

FIGURE 19: SCHEMATIC OVERVIEW OF THE MULTI BARRIER APPROACH TO REUSE URINE AS FERTILIZER IN A PATHOGEN-FREE WAY, WITHOUT TREATMENT (BRACKEN ET AL., 2007)

When streams are already separated from the user interface onwards (like with UDDT and UDFT), the decision matrix shows that leaving urine for 6 months in a tank is the best, most robust solution to reuse this stream in a fertilizer way. However, to be entirely sure that no environmental or health hazard for the workers is created, a multi-barrier approach should be performed to use the urine in a safe way (see Figure 19).Using nine barriers during the reuse of urine, it should be safe to use it without any treatment. This goes from storing it for a long time, to wearing proper gloves, to restricting the use of the fertilizer only to non-leafy crops. When the crops are grown and ready to be eaten, they should not be eaten raw, and so on (Bracken et al., 2007).

8.3.5 Drying out + Faecal sludge management (semi-centralized treatment)

One of the highest scores in the decision matrix is for drying out the sludge and afterwards proper faecal sludge management. Mupprat et al. conducted experiments in Kumasi, Ghana, aimed at increasing drying rates through simple modifications to FS drying beds. The drying bed designs used by Cofie et al. were adapted and applied to the construction of experimental scale beds (Cofie et al., 2005). A dewatering cloth is added between the sludge and sand layers. The conclusion of this study was that faecal sludge can efficiently be dried with drying beds and that a transparent roof is a simple design intervention to speed drying and thus decrease the land area needed for drying beds (Muspratt et al., 2014). Overall in Ghana, stabilization and settling ponds have been the method-of-choice to date. However, system based on this option prove little effective where fresh undigested and highly concentrated faecal sludge from public toilets form a major fraction of the faecal sludge delivered to the treatment plants. However, knowing that the faecal sludge for The Good Toilet is collected in tanks and only emptied after a couple of months, this should not give a problem for the current drying trends in Ghana. In most cities in Ghana, public toilet sludge (PTS) form up to 50% of the faecal sludge collected, which means the logistics are there for centralized treatment of faecal sludge (Cofie et al., 2006). Tips on pit emptying and proper faecal sludge management for The Good Toilet 1 are given in the section ‘Further recommendations’.

9 Scenarios

FIGURE 20: PICTURE OF ST. ANNE'S PUBLIC SCHOOL (RETRIEVED FROM THE LINKEDIN OF THE GOOD ROLL)

Looking at the high scoring techniques in Chapter 8 of this thesis, some treatment scenarios can be drawn up. The three most attractive pathways are explained in this section, and the collection tanks are dimensioned according to a project of The Good Roll in 2021. In St. Anne’s public school, 200 children go to school (and an assumption of 20 adults working there). A toilet system was built of 8 toilets, which means around 30 people per toilet per day.

9.1 Scenario 1: UDDT toilets with semi-centralized FS treatment

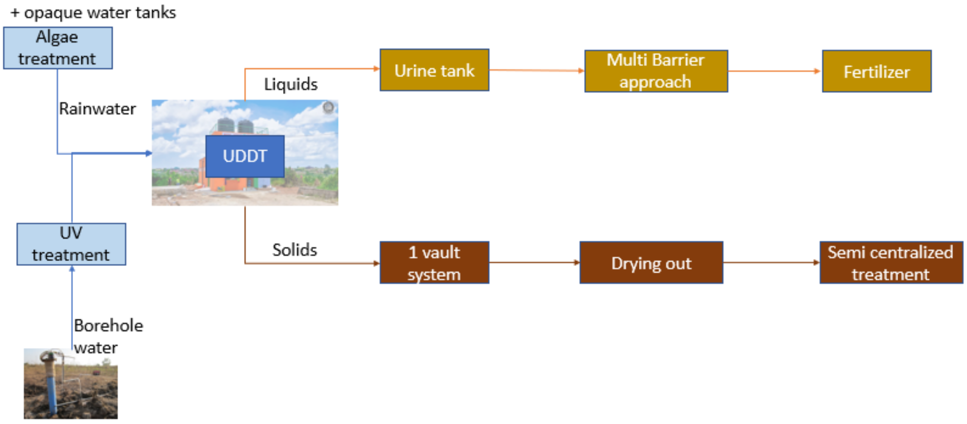

FIGURE 21: SCHEMATIC OVERVIEW OF SCENARIO 1

The first scenario shows a UDDT user interface, with a collection system as depicted in Figure 15, namely a single vault UDDT collection system. As effluent treatment there is opted for drying out and semi-centralized faecal sludge management. Rainwater and borehole water as influent therefore are only used for the hand wash and shower applications. As already explained in section 8.3.4, urine can be reused without treatment using the proper measures. Other destinations for urine could be infiltration into the soil, as this is a source of N,P and K. Reuse of urine and faeces from UDDTs may contribute to increased crop production, as N,P, and K are essential for plant growth. Organic carbon in treated faecal material can contribute to the sustained fertility of arable lands. The UDDT is simple to design and build, using such materials as concrete and wire mesh or plastic, which is locally available. The UDDT design is also flexible and can be altered to suit the needs of specific populations.

One person produces around 500 litres of urine and 50 kg of faeces during the period of 1 year. The dimensioning of the faeces vault and urine tank for this scenario, for St. Anne's public school, is shown in Appendix 7. For the urine storage tanks dimensioning: 1.2L of urine per person per day is taken as assumption (Tilley et al., 2014). However this is dependent on the climate and the liquid consumption. Over time, a layer of organic sludge and precipitated minerals (primarily calcium and magnesium phosphates) will form on the bottom of the tank. Any tank used for urine storage should have an opening large enough so that it can be cleaned and/or pumped out.

Additional considerations are the vault door design, the ventilation, and type of cover material. The vault doors should be above the established flood lines, the doors should be vertical with roof overhang, and there should be a firm locking of the door. As for ventilation, there should be an air flow through the ventilation pipe. However this design cannot be built in flood prone areas (see step 2.2), or at a low topographic point, as rainfall can typically collect in such areas and increase the likelihood of flooding the vault. Cover material such as sawdust should be added, and toilet paper can go into the vaults'. With this system the faecal matter can be dry and odourless (*Urine Diversion Dry Toilets for Humanitarian Response | Oxfam WASH Resources*, n.d.). Lastly, There should be sufficient awareness creation on Urine Diversion dry toilets. The community should be trained (including mobilisers) to help with a follow-up. As there are slight adaptations necessary from the toilet user, there should be a manual ready to explain the proper usage of the toilets.

9.2 Scenario 2: Conventional dual flush with solar septic tank

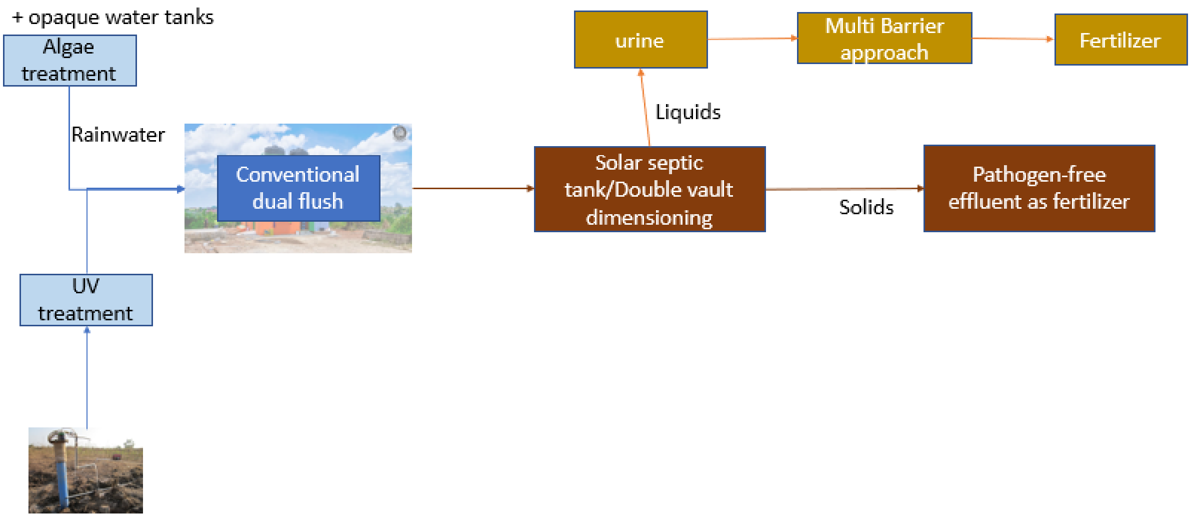

FIGURE 22: SCHEMATIC OVERVIEW OF SCENARIO 2

When dimensioning the septic tank system (for urine and faecal sludge combined), the following factors need to be taken into account: The volume of the faecal material deposited, the required storage time of the faeces, and it should match with the anticipated floor plan of the toilet cubicle above the vault. The dimensioning of the double vault solar septic tank system is shown in Appendix 7 for St. Anne's public school. This dimensioning has been performed with the emphasis to empty the tank after 6 months. The wastewater flow is assumed as 60 L/p/day (retrieved from the UDDT vault design manual). The hydraulic retention time is taken as 1.5 days. The sludge accumulation rate is assumed as 70L/p/year. After sludge accumulation, the hydraulic retention time becomes 22h for St. Anne's public school (as can be seen in the appendix). Just like in conventional septic tanks, the liquid fraction collects itself on top of the solid stream and can be taken out. Because of the solar desinfection this is pathogen-free and can be used as fertilizer using the multi-barrier approach. The influent streams here are again rainwater and treated borehole water, as flush water is required for the user interface and for heating up the solar septic tank.

9.3 Scenario 3 Conventional dual flush with Tiger Worm treatment

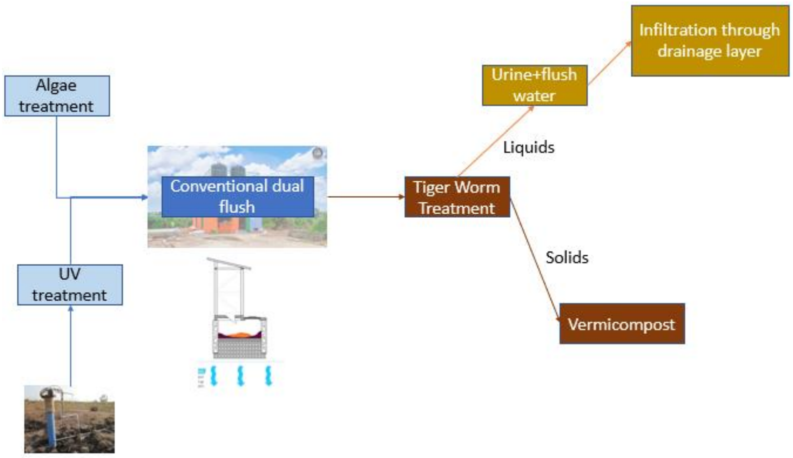

FIGURE 23: SCHEMATIC OVERVIEW OF TIGER WORM TREATMENT AS A THIRD SCENARIO

The third chosen scenario is again a conventional dual flush with tiger worm treatment in septic tanks. As tiger worms need a moist environment a wet user interface is necessary. As continuous usage of the toilets is necessary for the survival of the worms, this treatment scenario is recommended for projects where daily usage is guaranteed. Therefore it is estimated that school projects are not recommended for this treatment scenario, as in the weekends and during holidays nobody is there. The vermicompost that the worms produce is dry and soil like. It can be easily emptied by hand with a shovel and the compost buried onsite. Therefore this treatment is mostly suitable for rural areas in Ghana, where agriculture is performed close by. As for the dimensioning, the collection tank can be about 30% smaller for the same emptying frequency, as the tiger worms reduce the volume of sludge while vermicomposting. In this scenario there is also bigger emphasis on monitoring and awareness creation of the end-users, as having worms in a toilet collection tank might be a burden for people to use the toilets.

10 Step 3: Social Aspect

Sanitation is an extremely complex issue that impacts on the daily life of every human being. According to the Sanitation Quality Standards for Emergencies from the WASH cluster, the first important step is to get the environment free from human excreta. The Good Toilet should be a better option than open defecation, looking at the health of the users but also looking at the environmental impact. For this also social standards should be taken into account. The information in this section is mostly retrieved from the SaniTweaks document from OxfamWASH. According to Oxfam, agencies are failing to properly consult or collect and act on feedback from the users of the latrines they build, leading many people - especially women and girls- to stop using those latrines as they find them inaccessible, unsuitable and/or unsafe. Consequently, this actually increases public health risks. In Figure 25, the 7 social topics that should be considered when installing new toilets are visualized. For example, attention should be given to the lights leading to the toilets, as it should be light enough to be safe to access the toilets. The windows should be installed on the roofs instead of in the doors or sideways for more privacy. Furthermore, there are recommendations mentioned on door locks, accessibility, privacy, wall height, wall material, doors.

FIGURE 24: PLAYING CHILDREN NEXT TO THE SOLID LIQUID SEPARATOR OF THE GOOD TOILET.

FIGURE 25: THE 7 SUBJECTS REGARDING SOCIAL CONSIDERATIONS WHEN BUILDING TOILETS ACCORDING TO SANITWEAKS, FROM OXFAMWASH

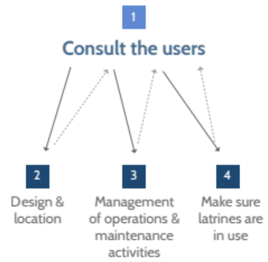

FIGURE 26: THE FOUR SOCIAL STEPS THAT NEED TO BE CONSIDERED BEFORE INSTALLING A TOILET

Before installing a toilet, some key questions need to be asked. There should be looked at religious practices, preferences and cultural habits (like anal cleansing practices). Are there other options that would be acceptable? What are the main concerns about using public or shared family latrines? Practicalities should be discussed with the end-users. This includes location and design, maintenance, handwashing, operations (see Figure 26). Therefore, there should be a thorough questionnaire for the schools, communities and households that will benefit from The Good Toilet, before installing the toilets.

In the field visit it was also seen that the key of the toilets was difficult to find, the facilities were not entirely clean, and people were just defecating in the bush next to The Good Toilet. The people who run and clean the toilets should get a financial compensation for their work, to keep the Good Toilet as clean as possible and most attractive to be used by the end-users. According to an interview with Jasper Schakel, Ghanaians are used to pay for clean toilet facilities. Another option than having a person keeping The Good Toilet clean, is providing keys per toilet per household (or per group of households). Then the families themselves find motivation to keep their own toilet clean.

Lastly, according to Tineke Hooijmans there should be taken care of the fact that things can get stolen. Soap should be put in dispensers that is not easy to detach, potential solar panels should be locked, as well as toilet paper, and cleaning products.

11 Step 4: Advice to The Good Roll

Considering the field visit, lab tests, interviews, and the previous chapters of this thesis, an advice for the Good Roll for future projects can be formed. For each new project, a new relative scoring of importance of the requirements should be performed. With this, the new user interface, collection system and treatment technologies can be chosen. While considering the technological side of the project, the social considerations provided in SaniTweaks should be implemented as well.

When building toilet facilities in rural villages, the context of use should be examined thoroughly. Should it be an individual or shared facility? According to interviews conducted with people that went on-site in informal settlements, it is beneficial to invest in household level toilets rather than communal toilets when building toilets for entire villages. Practice shows that household level toilets are used more often. If then the owners are made aware of the fact that the tanks need to be emptied frequently, this could be an attractive solution. It could also be beneficial to contact the municipalities or external companies (like Safisana) for collection of the faecal sludge, and proper faecal sludge management in a centralized approach.

If household level toilets are not feasible and communal toilets are being built, giving keys of different toilets to families is also a good solution. Next to that, rather than even improving the designs of the toilet system, there should be special attention to monitoring and surveillance whether the services provided are sufficient. The monitoring of toilets has several objectives:

- To check that they are being used properly, and ensure any problems with use are rectified
- To determine the filling rate of the toilets, to assist in the plans for emptying of the vaults
- To determine improvements that can be made to the UDDTs or to the community mobilisation. The monitoring system should consist of continuous surveillance of the toilets, a systematic survey and focus group discussions. (*Urine Diversion Dry Toilets for Humanitarian Response | Oxfam WASH Resources*, n.d.)

There are not a lot of examples of projects yet where sanitation is economically profitable. To achieve this, the toilets should be perfectly clean and the services provided should be in communication with the community and their demands. As mentioned by the WASH advisors that were interviewed, the technologies should be kept as simple as possible, with the least monitoring needed. Maintenance should be the biggest emphasis. To choose suitable technologies that cause no health or environmental hazards, and are as simple and robust as possible, the matrices in this thesis can be consulted. As for opted technologies for future designs, the following Figure 27 shows a schematic overview of the considerations for the end use of the streams, and a general overview of the idea of the scenarios in this thesis:

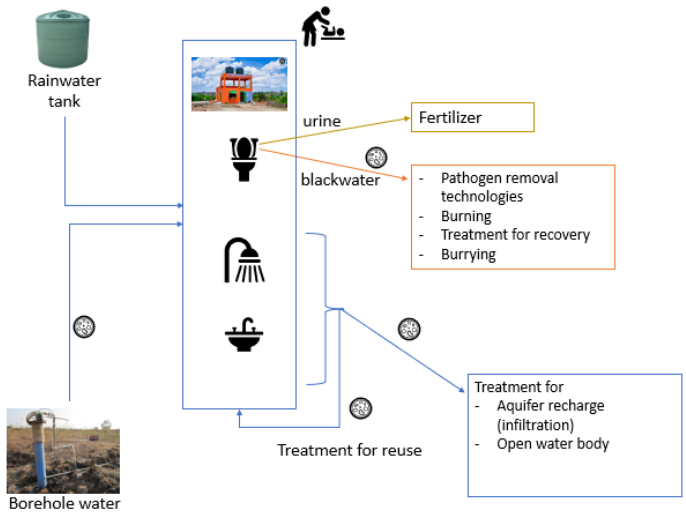

FIGURE 27: SCHEMATIC OVERVIEW OF THE OPTED TREATMENT SCHEME FOR THE GOOD ROLL. THE STREAMS WITH THE PETRI DISH SIGN SHOW PATHOGEN LOADED STREAMS

The option to have a dry user interface for the toilets (like UDDTs) and to keep the greywater treatment separate shows the biggest potential for pathogen-free effluent streams and optional for biogas optimization in a centralized treatment. Greywater treatment is more easy (think about vertical wall biofiltration systems), which could also make the Good Toilet more green appealing. However this requires some monitoring and expert knowledge. Tineke Hooijmans also suggested to reconsider the showers in The Good Toilet 2, and to really examine the demand of showers in the facilities, as removing this waste stream would make treatment more compact and easier. Lastly, it is recommended to have a more modular approach for the collection tanks, meaning that each user interface has a separate collection tank. When one of the tanks is defect, the other toilets can still be used.

12 Further recommendations

12.1 Pit emptying

For the existing designs, there is no pit emptying approach designed yet. In this thesis conveyance technologies were not really examined, as decentralized treatment for the Good Roll is proposed. However there are some aspects that can be summed up when emptying the already existing Solid Liquid Separators of The Good Toilet 1. There should be looked at:

- Equipment
- Safety
- Frequency of emptying

As for the Good Toilet 1, it is proposed to use motorized emptying and transport to a centralized faecal sludge treatment facility. This refers to a vehicle equipped with a motorized pump and a storage tank for emptying and transporting faecal sludge and urine. The truck is fitted with a pump which is connected to a hose that is lowered down into the SLS. The faecal sludge is pumped up into the holding tank of the vehicle. This design is also called a vacuum truck. The fact that the sludge is not really dense, and still liquid, makes this a fitting technique for collection. A drawback of this techniques is that an external company should be contacted for the collection of the sludge.

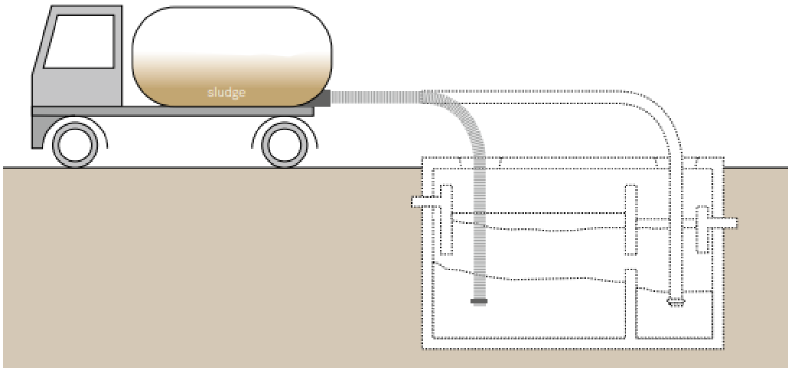

FIGURE 28: SCHEMATIC OVERVIEW OF MOTORIZED EMPTYING AND TRANSPORT (TILLEY ET AL., 2014

A second option that can be considered is Human-Powered Emptying and transport. However this is not the best solution to be applied in the proposed collection systems (Tilley et al., 2014). This system could then also be applied if there is opted for a semi-centralized faecal sludge treatment for The Good Toilet 2.

12.2 The Circular Story of the Good Roll

FIGURE 29: ALLAN, THE GOOD ROLL 'DIGESTER MAN', POSING AT ONE OF THE TOILET SITES.

As The Good Roll on the longer end wants to make the Good Toilet 2 a circular facility, some reuse options of the mentioned treatment technologies are shown in Table 10 (Strande et al., 2014) Proper faecal sludge management enhances proper reuse of the streams. Faecal sludge management refers to the storage, collection, transport, treatment and safe end use or disposal of faecal sludge in a (semi-) centralized approach.

TABLE 9: REUSE OPTIONS FOR THE GOOD ROLL (Diener et al., 2014)

Produced product	Treatment or processing technology
Soil conditioner	Untreated FS
	Sludge from drying beds
	Compost
	Pelletising process
	Digestate from anaerobic digestion
	Residual from Black Soldier Fly treatment
Reclaimed water	Untreated liquid FS
Protein	Black Soldier Fly process
Fodder and plants	Planted drying beds
Biofuels	Biogas from anaerobic digestion
	Incineration/co-combustion of dried sludge
	Pyrolysis of FS
	Biodiesel from FS

Furthermore, as planted drying beds would be used, bamboo could be planted there, making the whole bamboo toilet paper line more circular. Bamboo has a high biomass production and is recognized as a carbon sink. The could therefore even contribute to the reduction of greenhouse gases! However, prevailing waste management options currently limit the possibility of nutrient recycling in developing countries. Muspratt et al. conducted research on the viability of using faecal sludge a solid fuel (Muspratt et al., 2014). This could be an end use that unlocks an environmentally and financially beneficial replacement of fossil fuels, and could therefore be a source of income for The Good Toilet.

13 Conclusion

For this thesis a conceptual problem needed to be solved, as the current design of The Good Toilet 1 is an environmental and health hazard. The goal was two-fold: improving the current design, but also thinking of new designs. By means of interviews, field work samples, a lab test, literature research and estimated guesses a solution could be found to the research questions. At first it needed to be examined how there can be a pathogen-free influent and effluent in The Good Toilet 1. This can be achieved by firstly examining the groundwater and performing a thorough water quality analysis. After this, there can be opted for a UV-desinfection step of the borehole water. Additionally, opaque rainwater tanks can be added to the toilet buildings. For the effluent, the activated coal filter should be removed and replaced by treatment within the solid liquid separator, e.g. lime or ureum dosing.

The second question was whether there is a general new and optimized design possible for The Good Toilet 2, a second version of The Good Toilet, and what the most attractive treatment scenarios for this new design are. To solve this research question, a multi-criteria decision matrix was developed within a framework of requirements. This was done on user interface, collection system and effluent treatment level. The user interface decision depends on the communities wishes. It is most likely to take a UDDT toilet, but if the community doesn't accept, there can be opted for a conventional dual flush system. As for the collection system, solar septic tanks, septic tanks, UASB tanks scored high in the matrix. As for treatment of the effluent, vermifiltration techniques, semi-centralized treatment, solar desinfection, and lime treatment scored high. Of the high scoring solutions 3 treatment scenarios were made and dimensioned to the project 'St. Anne's public school'.

A third question was how the usage of the toilet is guaranteed and how the safety and the hygiene of The Good Toilet can be maintained, and how open defecation in Ghana can therefore be decreased installing The Good Toilet. For this step, the social aspect of building toilets is considered by using the document 'SaniTweaks' from OxfamWASH. There 7 different subjects are considered: sexual harassment, locks, fear of vermin, cleanliness, lighting, lack of privacy and not wanting to be seen going to the toilet. If all seven factors are considered when the Good Roll will build their The Good Toilet 2, the usage of the toilets can be guaranteed, as long as they communicate with the community beforehand as well.

As for later emptying of the thanks, motorized emptying is recommended and multiple treatment proposals enable the option for reuse and circularity in The Good Toilet 2.

14 Further research

There are still a lot of research gaps for The Good Toilet 2 that could be examined in further research. Firstly, The Good Roll now has a new toilet paper line, with toilet paper made from bamboo. Sander, co-founder, would like to know what happens to the carbon in the toilet treatment systems proposed to see what are the options are regarding carbon credits. Furthermore, greywater treatment has been left out of this research. The treatment options can be examined for this stream as well, with optional circular approach.

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16 Appendix

Appendix 1 : Pictures contaminated borehole water and plate counts

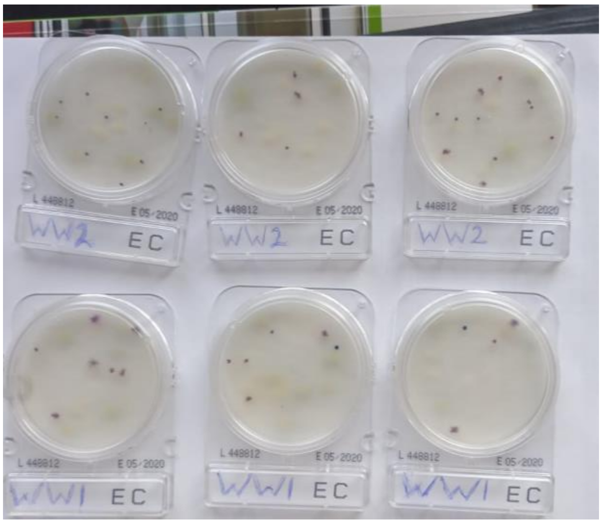


FIGURE 30: PICTURES OF THE E. COLI DRY PLATES MADE IN ONE OF THE SITES OF THE GOOD TOILET (UNDILUTED).

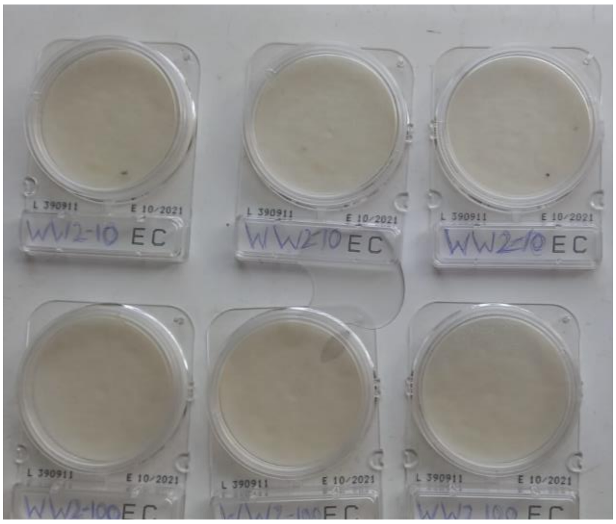


FIGURE 31: PICTURES OF THE E. COLI DRY PLATES MADE IN ONE OF THE SITES OF THE GOOD TOILETS (10X DILUTED). WW1= BOREHOLE WATER TAKEN FROM FLUSHWATER, WW2= UNFILTERED BOREHOLE WATER

Sample	Duplicate	E. Coli count in 1mL	CFU/100mL
WW2	1	10	1000
	2	5	500
	3	11	1100
WW1	1	7	700
	2	6	600
	3	4	400
WW2-10 (10x diluted)	1	1	100
	2	1	100
	3	2	200
TW	1	0	0
	2	0	0

TABLE 10: PLATE COUNTS OF THE DRY PLATES SHOWN IN FIGURE 28 AND 29. TW = TAP WATER, WW1= BOREHOLE WATER TAKEN FROM FLUSHWATER, WW2= UNFILTERED BOREHOLE WATER

Appendix 2 : Picture dry plate drinking water and lab analysis results

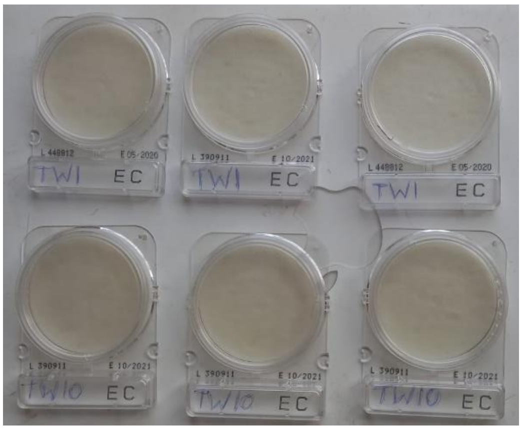


FIGURE 32: E.COLI DRY PLATES OF THE TAP WATER AT KOTOKU PAPASES THE GOOD TOILET SITE. LUCKILY NO E.COLI SEEN THERE.

TABLE 11: COMPOSITION OF THE SAMPLES TAKEN AT THE GOOD TOILET PROJECTS AND ANALYSED IN THE WATERLAB USING SPECTROPHOTOMETRY.

Compound	Outflow	Borehole flush water	Drinking water	Unfiltered borehole water
COD (mgCOD/L)	180	6.47	10.2	7.66
TN (mgN/L)	97	8.9	-	-
TP (mgP/L)	4.57 (oor)	0	0	0

Appendix 3 : Groundwater Quality Analysis Kotoku Papase

TABLE 12: GROUNDWATER (BOREHOLE) WATER QUALITY ANALYSIS OF KOTOKU-PAPASE. INDICATED IN YELLOW ARE THE CONCENTRATIONS EXCEEDING WHO LIMITS.

PARAMETERS	TGR KOTOKU-PAPASE	WHO/GHANA STANDARD AUTHORITY GS175-1 GUIDELINES	REMARKS	POST TREATMENT PARAMETER VALUES (EXPECTED)
Temperature(OC)		N/A		
pH (pH)	6.9	6.50-8.50		
Conductivity(mS/m)	115	150.00		
Turbidity(NTU)	0.4	5.00		
Total Dissolved Solids (TDS mg/l)	620*	1000.00	<300	Based on our RO treatment processes
Dissolved oxygen(mg/l)		N/A		
Total Suspended Solids (TSS mg/L)	2	-		
Hardness (mg/l)	234*	120-170	<170	Based on our Softener & RO treatment processes
Nitrate(NO3 mg/l)	77.0*	50.00	<50	Based on our RO treatment processes
Sulphate (SO4 mg/l)	85	250.00		
Phosphate(PO4 mg/l)	0.17	30.00		
Ammonia(N mg/l)	0.08	1.50		
Nitrite(NO2 mg/l)	0.08	3.00		
Sulphide (mg/l)		N/A		
Fluoride(mg/l)		1.50		
Chloride(mg/l)	150	250.00		
Colour(Pt/Co)	<3	5.00		
COD(mg/l)		N/A		
Potassium Dissolved (mg/l)	2.7	30		
BOD(mg/l)		N/A		
Alkalinity(mg/l CaCO3)	136	N/A		
Manganese(mg/l)		0.30		
Total Iron(mg/l)	<0.1	0.30		
Magnesium Dissolved (mg/l)	31.6	150		
Magnesium Total (mg/l)	0.006	-		
Copper Total (mg/l)	0.003	2		
Zinc Total (mg/l)	0.005	-		
Chromium (VI) (mg/l)		N/A		
Tot. Coliforms(MPN/100)	547.5*	N/A	Zero	Based on our Chlorination treatment processes
Faecal Coliforms(MPN/100)	29.2*	N/A	Zero	Based on our Chlorination treatment processes
E. Coli (MPN/100ml)	35.5*		Zero	Based on our UV treatment processes
Total Organic Carbon (TOC (mg/l)	1.6	4.0		
Sodium Dissolved (mg/l)	142	200		

Total Arsenic				
Calcium Dissolved (mg/l)	41	200		

.

Appendix 4 Measurement plan for Doris and Jasper on the site

Meetplan TheGoodToilet

Helena Verloo

Parameters to quantify:

- E. Coli as indicator organism for other coliforms
- TDS
- TSS
- Nitrite, Nitrate, Ammonium
- pH
- Hardness - alkalinity
- Metals
- Phosphate

E.Coli

Needed:

-Incubator

- Compact dry EC counting plates (36x)

- pipettes 1mL and 5mL

- pipette tips for 1 mL and 5mL

-PBS buffer

-thermometer

-gloves

-15 ml tubes for dilutions

- tube rack

Plan

- **Take samples before filter and after filter**
- **Make PBS buffer for dilutions: 1 PBS 'pill' in 200 mL water.**
- **Dilutions: 1x, 10x, 100x,1000x, 10 000x, 100 000x**
- **Triplicates of every dilution (Table below times 3)**

Name	Which type	dilution	how?
I1	Influent	1x	1 mL sample
I2		10x	1mL sample + 9mL PBS
I3		100x	1 mL I2 + 9mL PBS
I4		1000x	1 mL I3 + 9mL PBS
I5		10000x	1 mL I4 + 9mL PBS
I6		100000x	1 mL I5 + 9mL PBS
I1	Effluent filter	1x	1 mL sample
I2		10x	1mL sample + 9mL PBS
I3		100x	1 mL E2 + 9mL PBS
I4		1000x	1 mL E3 + 9mL PBS
I5		10000x	1 mL E4 + 9mL PBS
I6		100000x	1 mL E5 + 9mL PBS

- Of every dilution, 1mL on the middle of the compact dry EC

- Incubate for 24h between 38 and 44 degrees

TDS

Need:

0.45 um filters

syringes

15 mL tube

Plan

Filter 5 mL influent and 5 mL effluent and keep both in a 15mL tube

TSS, Nitrite, Nitrate, Ammonium, pH, Hardness – Alkalinity, Metals, Phosphate

- pH strips? Is this in the lab suitcase?
- Alkalinity strips in suitcase?

Take 100 mL sample of influent and 100 mL effluent and keep it in the ‘samplezakjes’ for analysis in the Waterlab at TU. Preferably kept at fridge temperatures as long as possible to keep microbial activity low.

Appendix 5 Resource Watch Flood Risk Map

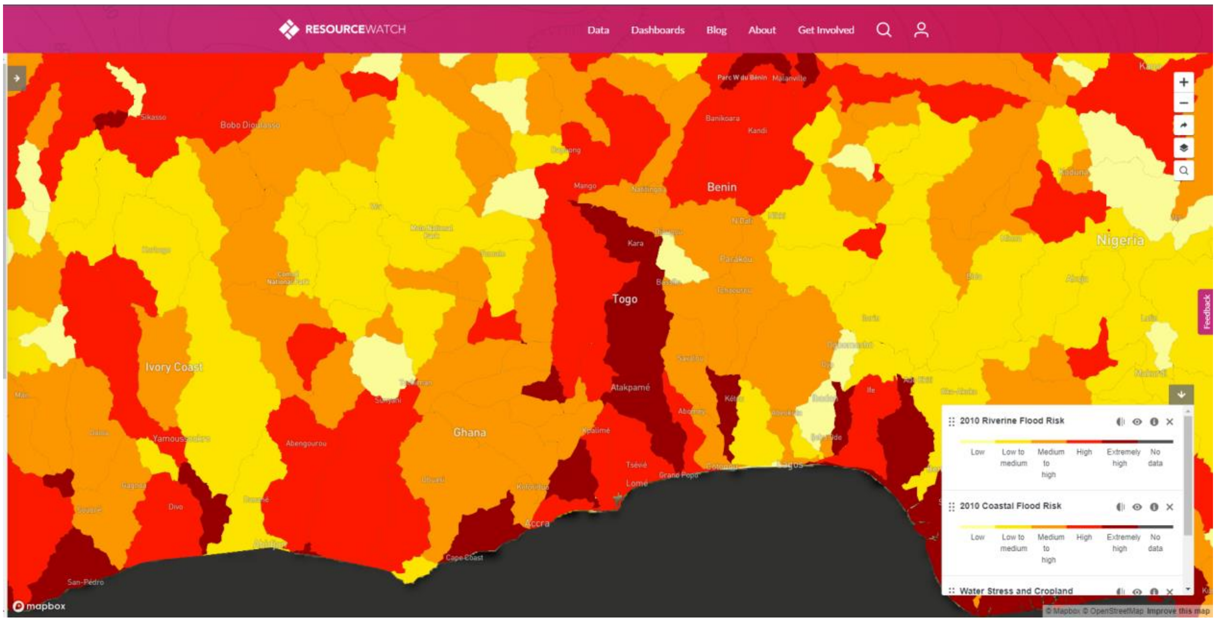


FIGURE 33: SCREENSHOT OF THE FLOOD MAP OF GHANA FROM RESOURCEWATCH. RIVERINE AND COASTAL FLOOD RISK ARE TAKEN INTO ACCOUNT.

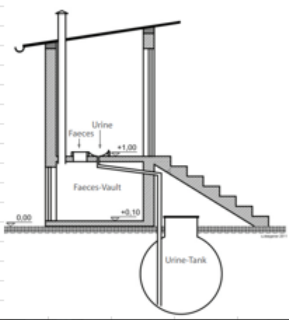
Appendix 6 Grading sheet framework of requirements (screenshot excel 1)

		Score	#Range between 0 and 1, variable or not per project?
Framework of requirements	Requirement	Level of importance	Does this change?
Design	Discontinuous	0,8	fixed
	Economic viability/Costs	0,9	fixed
	Scalable	0,6	changes per project, becomes 1 in cities
	Small	0,7	fixed
	Robust	0,8	changes per project, becomes 1 at rural areas
	Off-grid	0,6	changes per project, becomes 1 at rural areas
	Decentralized	0,5	fixed (not mentioned in decision matrix)
	Easy to maintain	0,7	fixed
	User-friendly (interface)	0,8	fixed
	Locally produced	0,3	desire (not mentioned in matrix)
Water Quality	Pathogenfree	1	Most important
	N-removal	0,2	Low when treated for reuse
	Helminth egg removal	0,4	According to interviews not mentioned in the decision matrix. When properly communicated
Availability of Resources	electricity	This layer is not mentioned in the decision matrix yet	
	clean groundwater		
	groundwater table		
	Flood risk		
	Demands of community		
Characteristics project	Amount of children	200	#For the dimensioning of the tanks.
	Amount of adults	20	
	Amount of people in total	220	
	Amount of toilet units bui	8	
	people per toilet	27,5	

TABLE 13: SCREENSHOT OF EXCEL SHEET ON THE SCORING OF THE FRAMEWORK OF REQUIREMENTS.

Appendix 7 Dimensioning single vault UDDT toilets for St. Anne's Public School

Faeces Vault	Amount	unit
cover material	0,05	kg/p/day
	0,4	kg/day
	72	kg
	0,072	m3
toilet paper	8,9	kg/p/year
	71,2	kg/year
	0,1951	kg/day
	35,112	kg
	0,0351	m3
density faeces	1	kg/L
storage duration (months)	6	months
storage duration (days)	180	days
faeces/day adult	0,4	kg/p/day
faeces/day child	0,15	kg/p/day
total amount faeces adults	80	kg/day
total amount faeces children	3	kg/day
total amount faeces	38	kg/day
	38	L/day
	0,038	m3/day
Amount of toilets	8	
	6,84	m3
	0,855	
-25 percent moisture loss	0,6413	m3
TOTAL INITIAL VAULT VOLUME	0,7484	m3
FINAL VAULT VOLUME PER TOILET	0,898	m3



Urine Tank	Amount	Unit	
urine	1,25	L/p/day	
	34,38	L/day	
	515,6	L before emptying	
emptying after	0,5	months	
	15	days	0,5 tot 2L
INITIAL VOLUME	0,516	m3	
FINAL VOLUME (with reserve)	0,619	m3	

TABLE 14: DIMENSIONING SINGLE FAECES VAULT UDDT TOILET FOR ST. ANNE'S PUBLIC SCHOOL (SCREENSHOT OF EXCEL FILE)

During these calculations, some assumptions were taken into account: namely that the density of the cover material and of the toilet paper are taken the same as for the faeces, namely 1 kg/L. Furthermore, all the toilets should be used at the same amount.

Appendix 8 Dimensioning of the double vault solar septic tanks

	Amount	Unit	
population	220	p	
wastewater flow	60	L/p/day	#assumption
Average volume wastewater (Q)	13,2	m3/d	
HRT	1,5	days	
	36	h	
Required volume septic tank	19,8	m3	
Volume 1st compartment	13,2	m3	
Volume 2nd compartment	6,6	m3	
Depth septic tank	1	m	#assumption
Width septic tank	3	m	#assumption
Depth septic tank -15% border	0,85	m	#Zodat hij niet tot de nok vol zit
Length of first compartment	7,7647	m	
Lengt of second compartment	2,5882	m	
Check of the HRT after sludge accumulation			
Sludge accumulation rate	70	l/p/y	
Desludging interval	0,5	y	
Sludge volume	7,7	m3	#sludge accumulation rate* number of users* desludging interval
Available volume for wastewater	12,1	m3	
HRT after sludge accumulation	0,9167	d	
	22	h	>12h so design is oke

TABLE 15: CALCULATION DOUBLE VAULT SEPTIC TANK FOR ST. ANNE'S PUBLIC SCHOOL (SCREENSHOT OF EXCEL FILE)