Improving Sanitation in Chiwoko Primary School, Malawi

BREE 495 Final Report

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Table of Contents

1 Executive Summary

This report is a follow-up to a preliminary study carried out by the authors. The previous study identified the Urine Diverting Dehydration Toilet (UDDT) as the most suitable sanitation system to improve sanitation in Chiwoko Primary School, in Malawi. Further research, prototyping and modelling lead to the development of the final detailed design presented in this report, including a cost analysis, different waste treatment options, management strategies, and a plan laying out the main sequence of steps necessary to execute the implementation of the design, addressing some important barriers and obstacles that often make or break sanitation development projects.

2 Introduction

In 2002 the United Nations started the Millenium Campaign and one of the Targets aims at "*halve[ing] by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation"* (U.N., 2010). Attempts at improving sanitation in many communities have failed, not only due to technological shortcomings, but due to incompatibilities with the greater socioeconomic and cultural context surrounding the use of sanitation systems. Human waste often ends up in lakes and rivers, causing water pollution and the spread of diseases. This is the case in Lilongwe, Malawi where 33% of schools do not provide basic sanitation. Therefore, we have selected one primary school in Lilongwe and adapted a sanitation system that enables safe disposal of human waste. The system consists of a urine diverting toilet and a dehydration vault which inactivates the pathogens in faeces and produces soil conditioner. The toilets will become part of a closed-loop environmental sanitation system in our final design, where we implement ways to reuse the waste.

2.1 Design Selection

Among the different designs considered, the dehydration vault received the best grade and was therefore chosen for the final design. The system which stores and treats the waste is fairly easy to use and inexpensive. As the waste remains in the vault until the pathogens are removed, the spread of disease is significantly reduced.

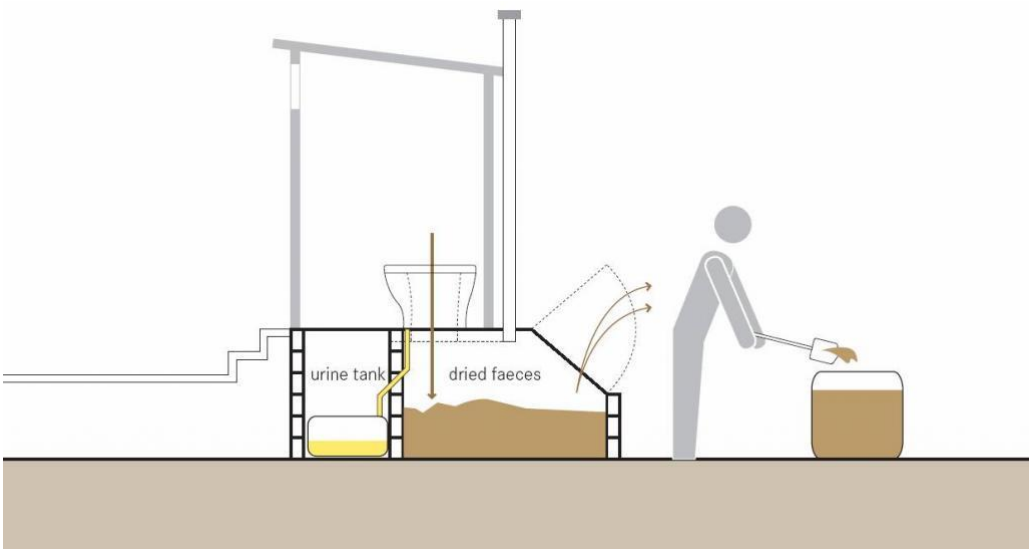

FIGURE 1. THE URINE DIVERSION DEHYDRATION TOILET (TILLEY ET AL., 2008).

Dimensioning of the sanitation system and a primary choice of materials has been carried out. In the case of Chiwoko school, 20 m3 of faeces are produced every 6 months but the system must be designed for 40 m3 as the vaults are used alternately. This allows for continuous use and pathogen inactivation, but it also increases the size and material needed for the toilet building. In total, 4 dehydration vaults will be constructed, allowing 2 systems to always be in use (1 for boys and 1 for girls). Each vault, having a capacity of 10 m3, will be connected to 3 Urine-diverting-dry toilets. Therefore, 3 toilets will always be available for each boys and girls. By constructing one dehydration vault for all 3 UDDTs, it is ensured that one vault does not fill up before the other. Assuming that there are equal number of boys and girls, there will be 38 users per toilet.

A cost analysis has also been carried out, resulting in a toilet unit price of 28.77 USD. We will need to try to find alternatives for the most expensive materials including cement and black pipes. This paper will focus on addressing the functionally of the chosen design, and will address the optimizations made to the design since the previous study, waste disposal options, waste dehydration, and implementation steps, including the most important obstacles and barriers.

3 Prototype

For the purpose of this project, a prototype of one toilet unit was constructed. It allowed us to assess the sizing of the stall and the overall dimensions we had chosen in Design 2. In addition, it aids other students to understand and view the technology of the sanitation system. The functionality of the system can

however not be tested as the prototype is not stable enough to withstand the weight of a person. The prototype is built to scale of the final design, having the same dimensions everywhere except the height of the walls, which were reduced to 130 cm to allow people to look at the prototype from above without having to enter.

3.1 Materials

Other materials than proposed in the final design were used for the construction of the prototype. The main reason is that we had to transport the prototype and therefore lightweight material was chosen. We also wanted to reduce the cost of the prototype, which is why compressed sawdust boards were used instead of adobe bricks. Sawdust boards are very light but also unstable, and therefore 2x2" wood bars were used to connect the boards and provide support. This worked extremely well and the prototype ended up being very stable. Besides sawdust boards, a plastic bowl was used for the urine collection system. Hinges were used to connect the lids to the dehydration vaults.

3.2 Dimensions

Overall, the dimensions of the prototype are presented in the following table:

Table 1. Prototype dimensions.

Stall height	130 cm
Stall width	65 cm
Dehydration vault depth	40 cm
Dehydration vault width (each)	32.5 cm
Stall entrance width	45 cm

3.2.1 Dehydration Vault

The dehydration vault is an alternating sanitation system, meaning that two toilets are used alternately, in this case a switch occurs every 6 months. During this period, the waste is able to dry and dehydrate, deactivating pathogens in the faeces. In the prototype, only one toilet stall was built, hence we could technically only show one dehydration vault. Nonetheless, the goal of the prototype was to demonstrate how the dehydration vaults work and what their effect is on the faeces. Therefore, we chose to connect two dehydration vaults to one UDDT. This design is often used for family-scale toilets that only have one toilet stall.

Another change made in the prototype for educational purposes was the addition of lids to the dehydration vaults (**figure 2**). The functionality of the sanitation system is dependent on the tightness of the

dehydration vaults. If moisture is able to enter the vaults, the waste will not dry and hence the system will fail. For the prototype however, we thought it would be more important to show people how the dehydration vaults work, rather than showing exactly what they look like in real life. Therefore, lids were installed on the dehydration vaults to allow people to look inside. One vault shows the fresh faeces made of soil. The other vault shows the dehydrated faeces (made of ash, toilet paper and dirt). This helps people visualize the dehydration process and its effect on the faeces.

Figure 2. Prototype, back view and front view.

3.2.2 UDDT

The UDDT platform has two holes; the front, oval-shaped hole used to collect urine is approximately 20 cm long. The round hole behind it, 10 cm in diameter, is used to collect faeces. As only one unit was constructed, the collection system (made of pipes) used for the urine in real life could not be shown. In the actual design, the urine gets diverted to the soakage pit below the centre of the building using pipes. Nonetheless, to illustrate the separate collection of the urine, a hose was used as a collection tool. The hose is connected to the UDDT platform with an oval-shaped bowl that has a hole in the centre, as shown in **figure 2**. The hole for the faeces links directly to the dehydration vault.

3.3 Educational purpose

The secondary purpose of the prototype was to spread awareness of sanitation at Macdonald Campus. Many students know about issues related to sanitation, but not what specific technologies exist to store and treat waste. Therefore, the prototype was displayed on campus along with detailed explanation of how the UDDT and dehydration vault work. Fake feces made of soil, and dehydrated feces made of ash, were used to present the effect of the dehydration vault. Overall, we received much positive feedback from students.

4 Simulation

For the first part of the simulation, the drying time was assumed to be the same as in other UDDT systems. Nonetheless, there is not scientific literature showing the drying mechanism for human wastes, in particular for the drying time. Despite the lack of data about this topic, there is a possibility of simulating a drying process using softwares, but they involve many assumptions that could be replace with more data obtained through the implementation of a pilot project. Mathworks simulink will be used for a preliminary simulation showing the minimum possible natural drying time, and COMSOL multiphysics will serve for a higher complexity simulation considering multiple environmental and fluid interactions.

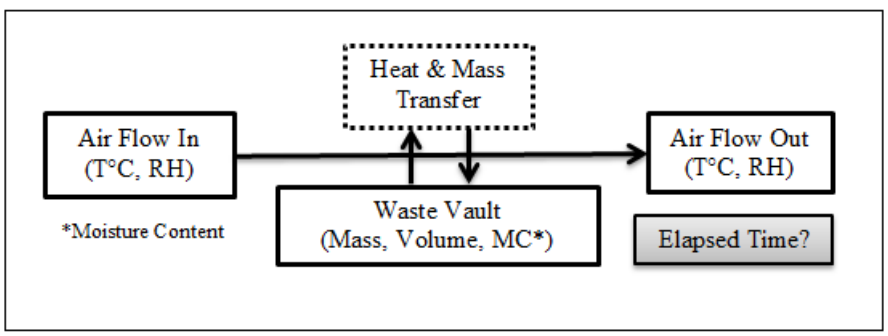

Figure 3. Conceptual model.

As a preliminary analysis of the drying process, a simple model has been developed based on a semi-batch drying principle (**figure 3**). The driving force is mainly based on temperature variation in Lilongwe whereas the heat and mass transfer are related to the exchange between the wastes and the environment. It is clearly a simulation that includes numerous assumptions regarding the variation of air moisture content and waste temperature. Setting limitation factors such as maximum airflow through the venting pipes and the maximum possible heat transfer simulate the minimum possible drying time. In this first model, the diffusion of moisture through the waste is not taken into consideration so the waste is actually an open

volume of water that continuously loses its mass until none is left. It is a discrete system with a one hour time step.

Figure 4 presents a summary of the simulation, which are the called constants from Matlab, the five Simulink diagrams including 4 subsystems and a graphical output showing the variation of temperature, heat, mass transfer and the final output with the decrease of water mass in the Vault. Since moisture have around 75% moisture content, a mass of 750 kilograms of water was used as a baseline for this simulation. The final result give a minimum drying time of about five months and half which means that it might be possible to alternate the vaults in a different schedule than biyearly.

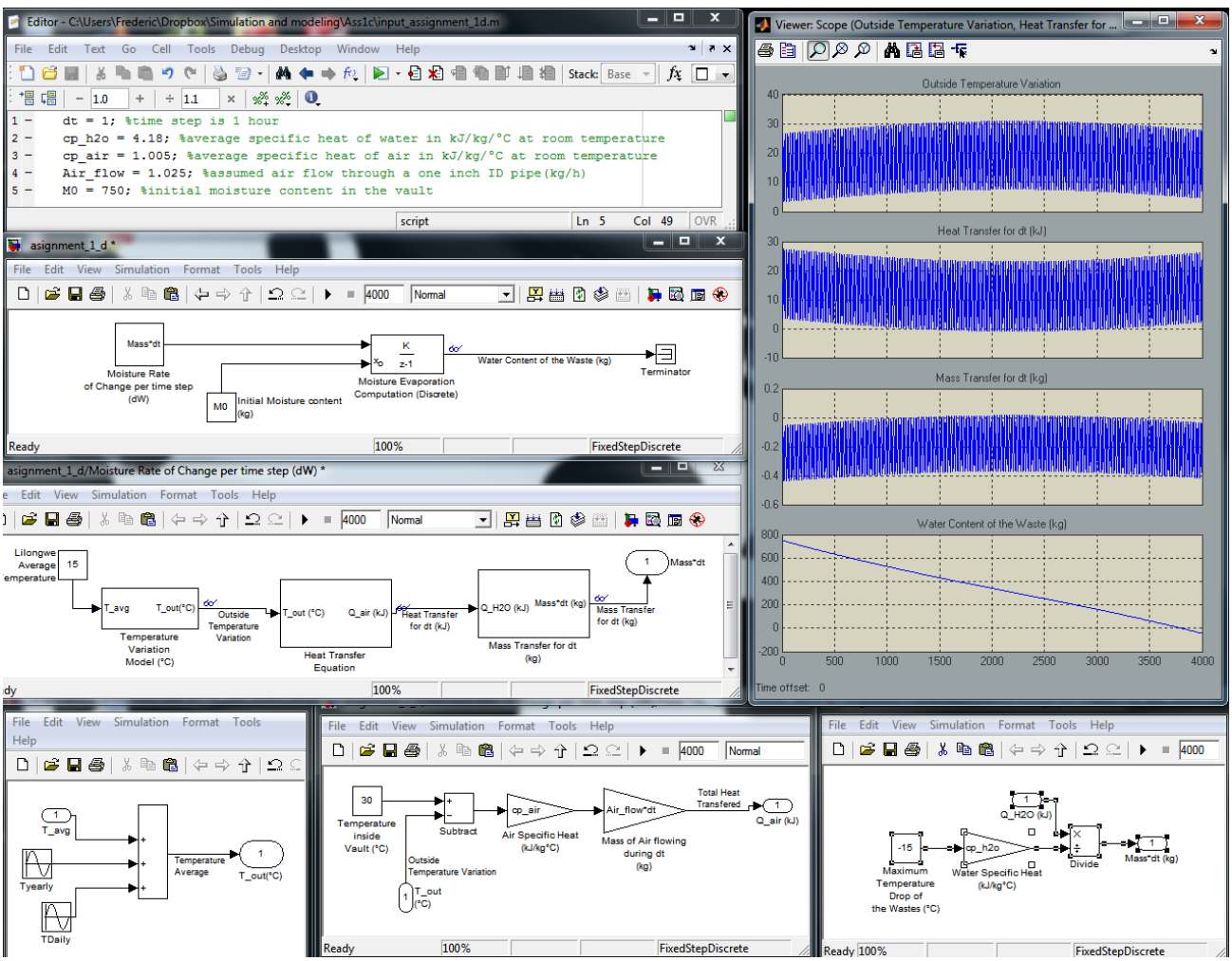

Figure 4. Simulink simulation overview.

The second simulation using COMSOL integrate the diffusion of water through a porous media, which are the feces, and a transfer of heat and mass at the interface between the solid wastes and the low velocity airflow. Instead of looking for a drying time, this part of the simulation process is fixing a time based on the first simulation and evaluate the equations driving the process.

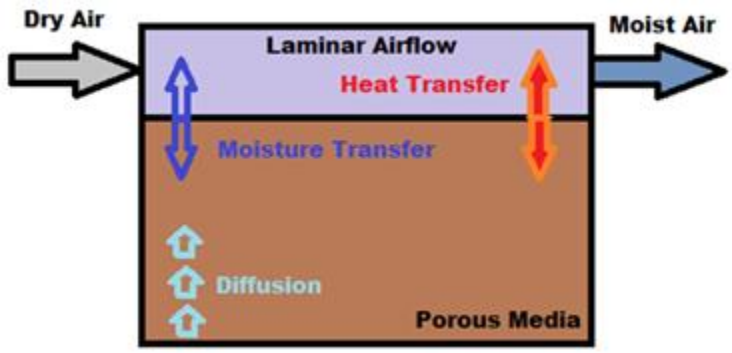

Figure 5. Dehydration vault model.

Although, COMSOL uses limited internal physics and, considering the non-standard analysis to be done, many assumptions were made to adjust the basics principles offered. The conceptual model shown in **figure 5**, though for this is two superimposed rectangles representing the cross-section of the first vault design when full of wastes. In COMSOL, only the bottom rectangle representing the porous media through which the diffusion occurs is modeled. Then, using a fine particle soil such as clay as the moist media, Richard's equations for diffusion, heat transfer equation through the moist and at the exchange interface and mass flux equation at the interface, the model has been computed considering that only the top surface was exchanging with the environment.

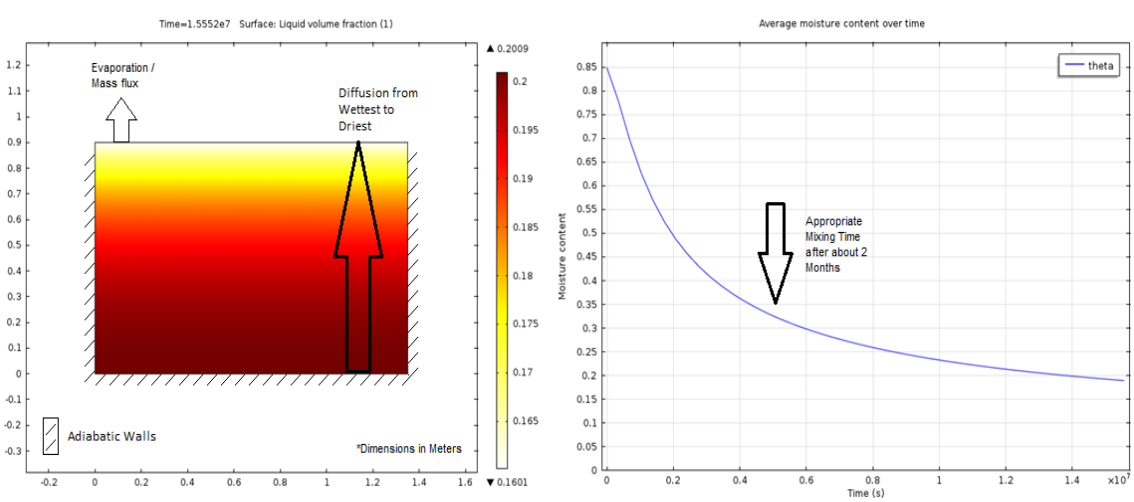

Figure 6. COMSOL results.

The results of the simulation (**figure 6**) were obtained after different trials and modifications to the parameters to get as close as possible, for example, to wastes instead of clay. The left hand side figure shows the gradient of moisture in the porous media after 6 months and the right hand side figure shows the average moisture content in the vault over time. As a recommendation, it would be better to improve the quality of the drying to mix the feces every two months to change the moisture transfer rate at the surface closer to the one occurring at the beginning of the simulation.

5 Optimization

5.1 Changes based on prototype

The modifications that will be considered in the new design of the sanitation building were based on the construction of the prototype and the simulation of the dehydration vault. During the planning of the prototype, we started to visualize the sizing of the toilet and realized that some previously made assumptions for the design were incorrect. One of the changes we had to make was the size of the entrance to the stall, which we originally sized at 37 cm. Once we put the boards together, the entrance appeared too small and it gave a claustrophobic feeling when inside the stall. Although the users are children, we decided to increase the entrance space to 45 cm. This still allows privacy, but makes the use of the toilet more comfortable. During the construction, we varied the width of the stall to find the smallest width that is still comfortable. This ended up being 90 cm. The changes are explained in more detail in **table 2**.

5.2 Structural changes

In the original design, the stairs leading to the toilets were made of bricks. Brickmaking is fairly labor intensive, and therefore the stairs have been replaced by a dirt slope. This does not reduce the cost of materials but significantly reduces the amount of work. The slope is still set at 15*. The concrete tile roof has been replaced by a tin roof. Originally, we opposed the idea of a tin roof as they can fly off in storms if not properly secured, and in rainy periods the rain falling on the roof makes a significant amount of noise. The concrete tiles which were used as a roof in design 2 did not have these issues; however it was a challenge to mount the heavy concrete tiles onto the roof. The tin roof is very lightweight and cheap, and significantly reduces the cost of the building, as the tin roof can be purchased locally. As a lightweight roof was chosen, a new window system was adopted. As can be seen in **figure 7**, a zigzag pattern formed by the bricks allows for ventilation and natural lighting. The distance from the ground to the lowest brick of the

window is 2.7m, ensuring that no one, even if they jump, can look inside. The tin roof is angled and has an overhang that prevents rain from entering through the windows (see **figure 7**). No rain will enter the building up to a rainfall angle of 40*, which is equivalent to a wind speed of 30 km/h (The Bluebird Box, 2002). At last, the height of the stalls was increased to 2.10m to ensure that tall students/teachers have enough space.

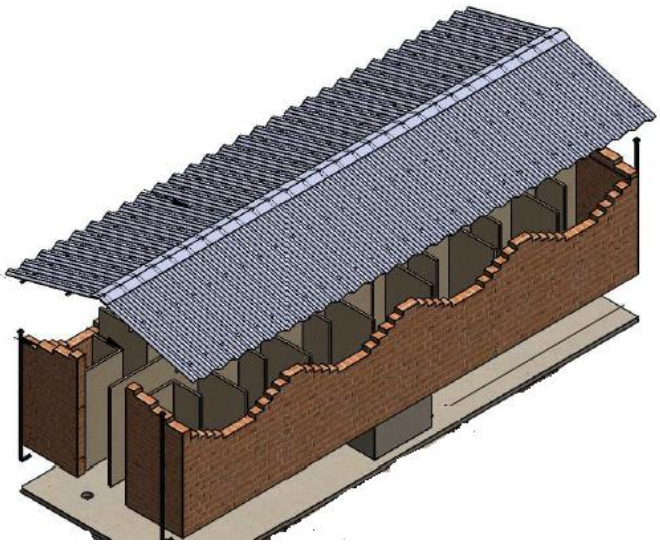

Figure 7. Exploded view of buiding.

5.3 Changes to toilet system

In design 2, there were 38 users per toilet. In order reduce this number, female and male urinals were added, reducing the users to 33 per toilet. One urinal was installed for the female side and a gutter urinal system for the male side. The female urinal is essentially the same system as the UDDT, except that it only has a hole for urine collection. The male urinals system is made up of a gutter on the floor where urine is collected and diverted to the soakage pit. Approximately 5 boys can use the urinals at the same time. The urinals are located over the soakage pit to minimize piping.

In design 2, we had over designed the vault size to avoid overflowing. A smaller safety factor was chosen, as the volume of faeces assumed in design 2 was unrealistic. As a result, the vault height was decreased from 1.3 m to 1m. To reduce the amount of concrete, the walls that separated the vaults were removed (**figure 8**). Therefore, the system no longer has 12 small vaults but instead 2 big vaults. 1 vault will be in use while the content of the other vault is dehydrating. Having fewer vaults facilitates the emptying of the vaults as there is just one big vault to empty, not 6 small ones. Removing the separating walls of the vaults achieved a concrete reduction of almost 50%. This step also helped reduce the number of ventilation pipes, as each

vault needs to be connected to a ventilation pipe to allow successful dehydration. 4 pipes, instead of 12, are now installed at the corners of the building.

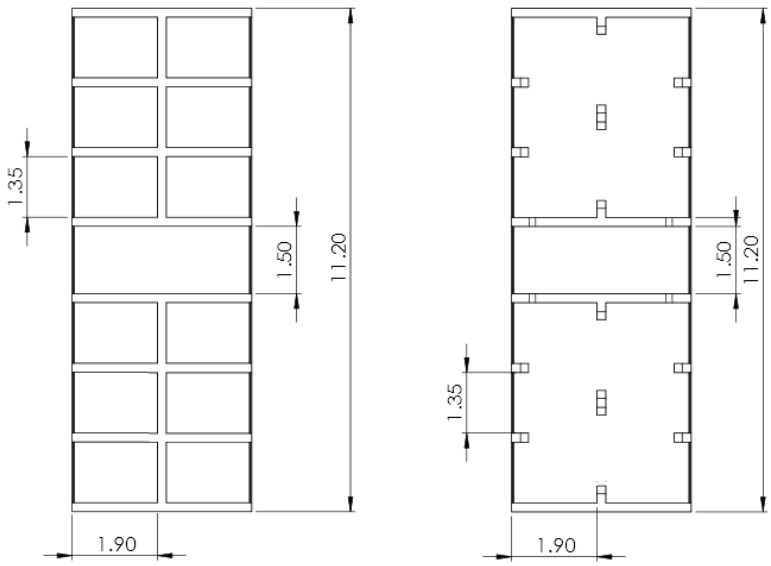

Figure 8. Old and new vault designs.

Table 2. Changes in cubicle dimensions.

Cubicle dimensions (m)	Design 2	Design 3
Height	1.80	2.10
Width	0.83	0.90
Length	1.07	1.12
Entrance	0.37	0.47
Distance between cubicles	0.61	0.55

Table 3. Changes in vault dimensions.

Vault dimensions	Design 2	Design 3
Height (m)	1.30	1.00
Length (m)	1.68	1.90
Width (m)	4.57	4.45
Volume (m3)	10.0	8,455

Table 4. Changes in building dimensions.

Building dimensions (m)	Design 2	Design 3
Height	2.10	2.5
Width	5.08	4.0
Length	9.42	11
Entrance door (m)		
Height	2.10	2.5
Width	2.11	1.2
Access		
Slope	35.6° Stairs	15°
Width (m)	2.79	1.55
Height (m)	1.50	1.20
Roof (m)		
Width	5.76	4.66
Slope	26.5°	15°

6 Testing

As previously mentioned the main purpose of constructing the prototype was for display since unfortunately it could not be tested for the following reasons:

- Limited budget for the purchase of adequate materials
- Unavailability of reliable geographical, climatic and hydrologic data
- Limited time since it is assumed to takes 6 months for the dehydration of faeces
- The hazardous nature of human faeces

Despite these circumstances, case studies were considered for the better understanding of the implications of the implementation of UDDTs in Africa.

6.1 Case study: Rural schools in Nyanza, Western and other provinces, Kenya

This project was carried out by Ecosan in 2007. The construction period lasted 3 years and the monitoring period ended in November 2010. The scale of the project included 70 schools in which double vault UDDTs were implemented. The number of toilets was 2 for boys and 2 for girls. The supporting agencies included:

ACP EU Water Facility (60%), Swedish International Development Agency (30%) and the German Technical Corporation (10%). The main local partner for this project was the Ministry of Water and Irrigation in Nairobi.

Every toilet with two vaults was connected to one vent pipe. The squatting pan was made out of plastic and was manufactured by a Kenyan company (Kentainers). This pan had two holes with a lid with a handle when the vault is in use and closed when it is not. The urine is collected in two 20 liters plastic containers filled alternatively. There is a 1 inch flexible hose pipe connecting the pan's urine outlet to the containers. The roof has a rainwater catchment facility that directs rainwater to a 100 L plastic tank with a tap for the purpose of hand washing. The total cost for one cubicle of double vault UDDT was 522 Euros. Ecosan argued that the costs could be diminished by using different materials, avoiding painting and omitting the rainwater system.

The problems after the implementation encountered were:

- Overcrowding: Toilets available were limited (4) since schools student numbers can range from 200 students up to 1000 students. The Kenyan standards are 1 toilet per 25 female students and 1 per 30 male students.
- Misuse: Ash was available for students to add into the faeces vault but there were occasions in which ash in the urine diversion part which caused clogging.
- Lack of financial resources: for cleaning and maintaining the toilet facilities

The lessons learned from this project that could be adapted to use are as follows:

- Provide sufficient number of toilets: include female urinals in squatting position to reduce the number of toilets to be constructed and provide more hygienic conditions for girls.
- Leave faeces hole uncovered to avoid confusion and clogging of the urine diversion part
- Use straight vault doors to avoid leakage from rainwater that can cause ineffective dehydration of faeces
- Use 2 to 3 inch standard PVC pipes for urine diversion to avoid clogging if ash is dumped
- Use urine for soil infiltration for fertilization of trees instead of manual application.

7 Cost Analysis

7.1 Materials

7.1.1 Concrete

The estimated price for concrete was calculated from a project in Malawi where pit latrines were constructed using cement. The price for a 50kg bag of cement was 1350 MK (Morgan, 2005) and 8 concrete slabs of total volume 0.32 m3 could be made from a single bag of cement. Only the cost of cement was used to estimate the cost of concrete since it would represent the most expensive component.

7.1.2 Bricks

The walls of the structure will be made of handmade clay Adobe bricks (Leinum, 2012). Adobe bricks are a common construction material in Malawi (Design 2). The recipe includes clay, sand, straw and water. A total of 1300 bricks will be needed assuming a brick size of 10cm x 28 cm x 56 cm.

7.1.3 Waterglass solution

As bricks are not 100% water impermeable a coating of sodium-silicate will be applied. The waterglass solution acts as a varnish, and turns into a hard vitreous film which protects and waterproofs the materials. It is especially suitable to porous concrete and sun-dried bricks as it improves the hardness, and facilitates cleaning (Leinum, 2012).

7.1.4 Wood

The prices for wood were obtained from a study performed by Crickmay and Associates in 2004 in South Africa. It was very difficult to obtain prices in Malawi therefore the value for Industry average roadside price of sawlog 7597 MK/m^3 was taken as an approximation (Crickmay & Associates Ltd., 2004). It will be probably an overestimation since the GDP of South Africa is much higher than the GDP in Malawi.

7.1.5 Black pipes

The price for black pipes that is be used for the airflow in the dehydration vault was obtained from an inquiry sent to PipeIt Company in Malawi. (Pipe it, 2009)

7.1.6 PVC pipes

PVC pipes will be used for the urine diversion to the soakage pit. The price was obtained online from Alibaba.com from G&N Fortune China Limited that exports to African countries. The price for a 6 inch (15 cm) OD pipe was estimated from the available price information to be 1662 MK /m (G&N Fortune China Limited, 2012).

7.1.7 Coarse gravel and sand

Coarse gravel and sand will be needed for the soakage pit. The prices of these materials were obtained from Sustainable Sanitation Alliance report on low cost grey water treatment in Malawi. In this project 3 wheelbarrows of sand (clean and coarse) and 3 wheelbarrows of gravel were used and including transportation added up to an expenditure of 8 Euros. Assuming an average volume of 8 ft^3 per wheelbarrow, the total price of $1m^3$ of gravel and sand each was estimated to 6422 MK (SuSanA, 2010)

7.1.8 Galvanized steel

Galvanized steel will be used for vault doors, roof and ridge flashing. The prices were obtained from an inquiry sent to Corr-line for galvanized steel the price was 1504 MK/m^2.

Table 5. Cost analysis for construction material and labor.

Cost analysis	Quantity	Cost/unit (MK)	Total cost (MK)
Concrete	15.42 m^3	4218 (Morgan, 2005)	65,053
Bricks	1300	2 (TMP, 2012)	2660
Waterglass solution	53.72 m2	0.1 (Leinum, 2012)	5
Wood	5 m3	7597 (Crickmay & Associates Ltd., 2004)	37,983
Black pipes 5 cm OD	12 m	2704 (Pipe it,2009)	32,448
PVC pipes 15 cm OD closed	26 m	1662 (G&N Fortune China Limited, 2012)	43,212
Coarse gravel and sand	1 m^3	6422 (SuSanA, 2010)	6,422
Steel galvanized	20.58 m^2	1504 (Corr-line. 2009)	30,952
Corrugated Steel	60 m^2	1504 (Corr-line. 2009)	90,240
Ridge flashing	11.4 m	1504 (Corr-line. 2009)	17,146
Labor (14 days)	6 men	129 / day / man	10836
Total (MK)			336,957
Total (CAD)			829
Total per toilet (CAD)			**104**

The initial costs of building construction add up to around 337,000 MK which is equivalent to 829 CAD. The amount per toilet was evaluated with respect to the new additions of urinals for girls and boys therefore, 16 toilets will be the total from which only 8 will be in use at the time. The final cost per toilet is 104 CAD; this cost is higher than our previous cost analysis and it is mostly due to the addition of material such as steel and PVC pipes. Also the reference of the cost of concrete was outdated and the new price is much

higher even if the total volume of concrete was actually reduced. New alternatives for funding will need to be explored to make sure that the sanitation facility can in fact be constructed and implemented.

7.2 Maintenance Cost

The expected maintenance cost over the course of one year is shown in **table 6** below. Although it is very likely that most of the work will be carried out by the community, we have assumed that one worker will be in charge of carrying out all maintenance operations. With a minimum wage of MK 129 per 8h working day, the hourly wage is MK 16.15/hour. We expect the main cost of the maintenance to be the emptying of vaults, which is done once every 6 months. It is very likely that students will be in charge of emptying the vaults, but for now we have assumed that the work will be paid. One hour is allocated to spreading out the feces, which is required to ensure even dehydration. Due to the rainy season, it is likely that roof repairs and the application of waterglass solution will be necessary. Also, the soakage pit will need to be maintained if there is any clogging or if gravel is needs to be either added or removed.

Table 6. Maintenance costs.

Maintenance operation	Hours	Labor cost (MK) (At min wages)	Material cost (MK)	Total Cost (MK)
Roof repairs	2	32.30	15.00	47.30
Emptying vaults	4	64.60	N/A	64.60
Spread feces in vaults	1	16.15	N/A	16.15
Waterglass application	1	16.15	10.00	26.15
Soakage pit	2	32.30	N/A	32.30
Total (MK)				186.5
Total (CAD)				0.46

8 Options for Waste Disposal

One of the main advantages of the UDDT is that urine and faeces can be treated separately. In humans urine contains 95% of the nutrients excreted and is mostly pathogen-free (Putnam, 1971). In traditional sanitation systems urine is mixed with highly pathogenic faeces, making nutrient recovery more complicated and riskier. Since many uncertainties remain concerning local conditions and context in Malawi several options for waste treatment are explored and proposed, and in the context of the project the most suitable combination of options is to be selected based on conditions in the field. The decision criteria are presented in more details in section 8.3.

8.1 Urine

8.1.1 Soakage Pit

Even if a combination of urine disposal options are used, the pit should have the capacity to treat all urine since it functions as a fallback. The soakage pit was designed to have a sufficient volume to hold the urine produced in a day, and an infiltration capacity such that all urine collected in a day infiltrates in that same day. The inflow pipe has to have a sufficient diameter to prevent backlog when multiple people use the toilet at the same time; the limiting factor is the infiltration rate of urine in the gravel filling the pit. The pit design is based on guidelines from Peace Corps (2007).

Storage and Infiltration

There are two basic designs for soakage pits: a cylindrical hole or an elongated trench. The trench offers a higher surface-to-volume ratio, and thus a much higher infiltration rate for the same volume. Since the soakage pit for this toilet has a relatively small number of users a cylindrical pit is sufficient. Furthermore, the pit is located under the building, so its area in plan should be minimized to maintain the stability of the building, which could be affected by the differential settling of the gravel and the surrounding soil under the floor slab.

The pit was designed for 250 students producing 600 milliliters per day each, for a total volume of 150 liters per day. It was assumed that the pit is filled with gravel with a porosity of 0.25. The saturated infiltration rate for the soil around Lilongwe is of 3.5 cm/hr (Saka et al., 2003).

Table 7. Dimensions of soakage pit.

Radius (m)	Height (m)	Effective Volume (L)	Infiltration Time (hr)
0.4	1.2	150.800	1.220
0.5	0.8	157.100	1.300
0.6	0.55	155.500	1.340
0.7	0.4	153.900	1.300
0.8	0.3	150.800	1.220

Different combinations of radius and height for the pit will yield a sufficient volume. **Table 7** presents different options that meet the volume and infiltration requirements. The effective volume represents the holding capacity of the pit; it is smaller than the total pit volume due to the presence of gravel.

The infiltration time is the time required for 150 L of urine to infiltrate into the soil based on the surface area of the pit and the saturated infiltration rate of the soil. It must be less than 24 hours. The recommended dimensions are a radius of 0.4 m and a depth of 1.2 m to minimize the area of disturbed soil and to minimize the infiltration time.

Pipe Sizing

The pipes carrying urine to the soakage pit must be wide enough to allow the quick infiltration of urine into the pit gravel when multiple people are using the toilet at the same time. Since children tend to go to the toilet at the same time during recess, it is likely that all stalls and urinals will be used at the same time, and backlog in the pipe could occur.

Counting stalls and urinals, up to seven boys and five girls could urinate simultaneously. A collector pipe for each side is used; a wider one might be required on the boys' side since there are 2 more urinals.

Assuming that seven boys are urinating at the same time and produce 350 mL of urine each in one minute, the pipe must allow 2.45 L/min of urine to infiltrate in the gravel. Depending on its coarseness, gravel has a saturated infiltration capacity of 100-1000 m/day.

Table 8. Sizing of urine collector pipe.

Saturated Infiltration Rate (m/day)	Required Pipe Diameter (in)	
	Boys (2.5L /min)	Girls (1.8 L/min)
100	8.3	7.1
500	3.7	3.2
1000	2.6	2.2

To reduce costs, coarse gravel should be used, in which case 3 inch pipes will be sufficient. This is in line with the recommendations that were made in Kenya case study.

8.1.2 Storage tank

The second option for urine disposal is to store and sell it or apply it manually as a fertilizer on crops or trees. For a day-school, a specific urine production of 250 mL per person per day may be assumed (ESF, 2007), therefore a storage capacity of 62.5 L will be needed for each day of storage. The tank quickly reaches unwieldy dimensions if urine is to be stored for any significant period of time. There must be a system in place for withdrawing and disposing of urine on a regular basis or an overflow option, such as a soakage pit (see 8.1.1) or irrigation system (see 8.1.3).

The main issue with selling urine as a fertilizer is its relatively low concentration of nutrients compared to conventional chemical fertilizers. One kilogram of conventional fertilizers contains roughly as much nutrients as 30 liters of urine, making it much easier to handle and transport. Additionally, urine is high in nitrogen and does not have an ideal NPK ratio for food crops. High salt content can also be an issue as well. It is recommended to dilute urine with water in a 5:1 ratio if it used to water plants (Morgan, 2004). Despite these issues, using urine as a fertilizer may be an attractive option in areas where chemical fertilizers are difficult or impossible to access. Urine application was found to significantly increase production of mulberry, banana and mango in soils with insufficient nutrients (Morgan, 2005).

8.1.3 Irrigation

The last option for urine disposal is an irrigation system, which can be as simple as a perforated pipe. It can be used to irrigate trees or other plants. Salinity and nutrient overload is an issue and the urine must be diluted with water. It is possible to combine the urine with water from hand washing in a tank before using it for irrigation to reduce these risks. Irrigation pipes can function as a standalone system or as an overflow system for a storage tank.

8.2 Faeces

8.2.1 Soil conditioner

Dried faeces can be buried in the ground at a shallow depth, such that plants can utilize the nutrients. Further sanitization is expected to occur in the soil as pathogens suffer from natural die-off and are out-competed by soil organisms (EcoSanRes, 2012).s

It is possible to sell the dried faeces as a soil conditioner but safe handling precautions must be taken since the faeces are not composted and can still be pathogenic, especially if they get rehydrated or if particles are inhaled. Safe handling precautions are discussed further in section 10.

8.2.2 Incineration

The end product of incineration is completely sterile, thus it is considered the safest method for disposal. The ash that is created by incinerating manure can be used as a soil amendment; it contains phosphorus and potassium, but the nitrogen and sulfur are lost to the atmosphere in the combustion process (EcoSanRes, 2012). A small locally made incinerator can be used, such as the De Montfort waste incinerator, which can be built cheaply and easily based on publically available guidelines (Hart and Mate, 2004).

8.3 Comparison of Disposal Options

Figure 9 list the advantages and drawbacks of the different disposal technologies, as well as the barriers and conditions that must be met for their successful implementation, and can be used for guidance in deciding on the most suitable set of options.

	Manual Application	Irrigation	Soakage Pit	Soil Conditioner	Incineration
Benefits	Nutrient recovery Market potential	Nutrient recovery	High treatment capacity Less maintenance	Organic matter recovery Market potential	High treatment capacity
Downsides	Requires labour Risk of contamination	Complexity of design Risk of soil salinity	No nutrient recovery Risk of overflow	Risk of contamination	No energy or O.M. recovery
Barriers	User education Area for application Legal/social acceptance	Area for irrigation Infiltration rate	Infiltration rate	Area for land application Social acceptance	

Figure 9. Comparison of disposal options.

9 Health Risks Management

The outputs from UDDTs can be hazardous, especially faeces. The main risk is disease from infection by disease-causing pathogens. Pathogens can contaminate the environment through fingers, flies, fluids and foods, and can be found in crops, soil, surface water, and groundwater (EcoSanRes, 2012). The drying process reduces the pathogen content of faeces, making them safer to handle, but some pathogens can survive 6 months and drying; they are not completely safe unless they undergo secondary treatment. The main strategies for risk reduction are the treatment of faeces, limiting contact during handling and agricultural practices, and individual hygiene.

The first aspect, secondary treatment, was discussed in the previous section. The following sections discuss the two other aspects of health risk management: hygiene and handling.

9.1 Handwashing Facilities

The National School WASH (WAter, Sanitation and Hygiene) Assessment in Malawi was completed in 2008. This was the first comprehensive analysis of water sanitation and hygiene in Malawian primary schools. Since the introduction of the Free Primary Education Policy in 1994, there has been a concern about the increase of pupils compared to the number of available sanitation facilities. The assessment report has

helped to identify the current gaps and to “increase awareness of the importance of safe, private, and adequate facilities”(WASH in Schools, 2011).

According to EMIS (Education Management Information System) in 2010, only 25% of schools have handwashing facilities for boys and 28% have washing facilities for girls (Heijnen, 2010). Handwashing facilities are essential to ensure that pathogen transmission does not occur. Handwashing facilities will not be implicitly shown in the design of the sanitation building but are strongly recommended. The choice made to implement a waterless sanitation facility had the purpose of not relying on water sources since their availability is not certain for Chiwoko School. However, one option could be harvesting rainwater and collect it in tanks that can be closed with a lid as to avoid any insects entering the tank. A tap can be added to the tank to help students get enough water to wash their hands.

9.2 Safe Handling

The main goal of safe handling practices is to limit human exposure to faeces. To this end, anyone who opens the vaults to empty them or otherwise manipulate dry faeces should wear gloves, rubber boots and overalls. It is important that only adults have access to the vaults.

To prevent children from having contact with the wastes, a fence should be built around the secondary treatment site, for example around the incinerator if one is used

Usually the faeces are dug or ploughed into the soil when if they are applied as a soil conditioner fertilizer, but they should not be applied at sites where there groundwater is shallow to prevent contamination. Groundwater may supply drinking water wells so there is the potential for infection.

Finally, if the faeces are used as a soil amendment for vegetable crops, the vegetables should be well washed and peeled or cooked to remove any pathogens that may have been deposited on the vegetable (EcoSanRes, 2012), and any equipment used to manipulate the manure should be washed as well.

10 Barriers to Implementation

10.1 Social acceptability

For the implementation of this project, primary surveys and interviews would have to be conducted at Chiwoko School. The total number of students, the length of the school day, the amount of urine and feces produce by the students per day would have to be determined to avoid over- or under-design of the

sanitation system. To ensure that the sanitation system is accepted, interviews with students as well as teachers would have to be conducted. Questions could include:

- Where do you usually go to the toilet?
- Have you ever used a squatting toilet?
- Have you ever seen or used a UDDT toilet?
- How would you feel going to a toilet that is inside a building?
- Would you use a toilet that does not have a door that can be closed?
- Do you know if waste can contain dangerous diseases that make you sick?

Interviewing the users would allow us to get a general overview of the students view on sanitation and their current defecation habits. This knowledge is crucial as it will influence the level of education that is necessary on sanitation and UDDT toilets. As the UDDT has two holes it is slightly more complex than most other sanitation systems that just have one hole (e.g. single pit, composting toilet). Therefore, operating issues are easily created which prevent users from using the toilets. In addition, it needs to be ensured that the users completely understand how the toilet functions, not just how to use it. If operating issues occur, for example the clogging of a pipe, the users may be intimidated by the system and return to open defecation or other unimproved sanitation practices. A prototype showing the UDDT could be constructed and used for demonstration and explanations. The students and teachers should also be involved in the construction of the building, even if it is just simple tasks. Including them in the construction will reduce the risk of vandalism and increase their understanding of the system being installed.

10.2 Behavioral change

In 2006, the Department of Water Supply and Sewerage and UNICEF developed a report on Guidelines on School Led Total Sanitation (DWSS & UNICEF, Nepal. 2006); its objective is to make schools and their catchments free from open defecation with collaborative efforts of stakeholders. The key components of SLTS include: behavioural transformation, environmental sanitation, sanitation facilities and total elimination of open defecation.

It is essential to identify the roles and responsibilities of stakeholders to create a good base for behavioural change. The following are some of the responsibilities of each stakeholder:

1. Task force: implement sectorial policy, undertake impact studies, develop indicators for monitoring and evaluation etc.

2. District level task force: develop monthly action plan
3. Teachers, parents teacher association: impart knowledge on personal health, hygiene and environment, promote sanitation as part of the curriculum at school
4. Child Club: Act as role model to promote sanitation in school and nearby communities, work as pressure groups to motivate the individual and communities to build sanitation facilities.
5. Community: Mobilize human resources, provision of locally available materials and indigenous knowledge and skills, create potential to generate local funds.

Some of the tips for Intervention of the SLTS program include:

1. Inspire students through appreciation, recognition and rewards to work as pressure group and be catalysts of change
2. Let communities internalize that they are highly affected by the open defecation behaviours
3. Facilitate to develop a social map including community people involving women and children

The crucial role of behavioral change in the success or failure of sanitation projects has been recognized for many years. The Community-Led Total Sanitation and School-Led Total Sanitation programs have been adopted by the government of Malawi as part of their national sanitation strategy in 2008. SLTS pilots have been established by Plan Malawi since 2009, with support from UNICEF and Engineers Without Borders Canada (IDS, 2010). The implementation of SLTS programs in is overseen by Program Officers at the district level. Students are unlikely to adopt new sanitation habits without coupling the construction of new facilities with a behaviour change program. It is therefore essential to identify and establish ties with local SLTS Program Officers in the district.

10.3 Funds for construction, operation and maintenance

The major issue with this system is the high implementation cost. Even if the maintenance cost should be very low or null and the building should last for very long or even forever with appropriate maintenance, there is still a need for initial funding as a governmental long term investment in academic infrastructures for example. Also, the help of NGO's would increases the chances the system get implemented, taught and used by the student population. A great advantage with this type of system is that it offers multiple avenues for private investments as the by-products can be used. The engagement of various actors increases the chances of success and the sustainability aspect of the project. In other words, more people get involved and interested, and more the system can be exploited to its maximum extends.

The possibility of selling outputs from the UDDT should be investigated further. Urine and faeces can be valuable resources, as fertilizer and soil conditioner respectively. Their sale could provide a source of funding for operation and maintenance, thus helping ensure the sustainability of the project.

11 Implementation Plan

Figure 10 is an illustration of our implementation plan, which describes the steps we would take to execute our design project. The plan was developed as a general, flexible framework, applicable not only to the Chiwoko sanitation project but to any sanitation project of a similar scope.

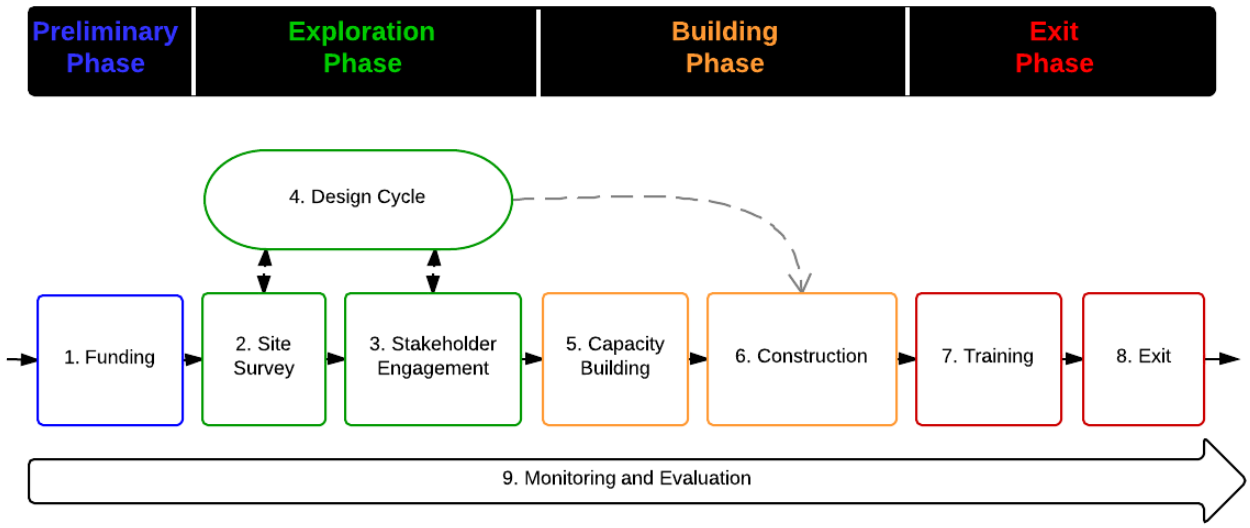

Figure 10. Steps of the implementation plan, divided into four phases.

11.1 Funding

The first step of the implementation process is to secure funding. Initial funds are needed for the exploration phase, at the very least. The following phases will depend on the results of the exploration phase. CIDA funds various development projects and is a possible source of funding, as well as private charitable organizations, such as the Bill and Melinda Gates Foundation, which is giving a hard push in the sanitation sector. Financing for later stages, including construction and operation, is discussed in more details in section 10.3.

11.2 Site Survey

Once on site, the first step is an initial survey to identify and assess environmental and geographical conditions that could impact the design. A non-exhaustive list is provided below.

Item	Significance
Soil characteristics	Irrigation rate, stability
Groundwater depth	Contamination
School layout	Irrigation area, building location
Existing sanitation systems	Familiarity, lessons learned
Market	Sale of outputs, construction materials
Neighboring schools	Scalability

11.3 Stakeholder Engagement

The second and last step of the 'exploration phase' is stakeholder engagement. First, the key actors are identified. In a small-scale sanitation project, stakeholder engagement can be done in an informal way.

Stakeholder	Potential role or contribution
Teachers	Operation and maintenance, education
Staff (e.g. janitors, administration)	Operation and maintenance, funding
Students	Education, user needs
Parents	Funding, education
Local NGOs	Lessons learned, funding, capacity building
SLTS Program Officer	Behaviour change, user training
Construction firms	Insights into local building techniques and materials

As part of the process, it is important to assess whether different actors have the capacity required to carry out the project. For example, there might be no local construction firm with the required expertise to build certain features, or there might be no capacity at the district level to perform SLTS in the particular community where the project is carried out. A new sanitation technology is less likely to be adopted if no effective user training is done.

It is also important to assess the interest and degree of investment of stakeholders in the project. The willingness of stakeholders to invest labour or money in a project or pay for deliverables is a good

indication that the project responds to a real need, and is a good sign for the long-term viability of the project. Some strategies for stakeholder engagement are presented in section 10.1.

11.4 Design Cycle

It is unavoidable that some minor or major elements of the proposed design will change based on new information gained through site survey and stakeholder engagement. It might be necessary to return to the design cycle to adapt to challenges or conditions that are not as expected, or to apply insights and lessons learned from stakeholders. For example, in the case of the Chiwoko project, it is necessary to select a suitable set of treatment and disposal technologies based on the site survey.

11.5 Capacity Building

Capacity building might be required but is outside the scope of this report. For instance, building capacity in the government for SLTS training might be needed but it is very much non-trivial. If the capacity to build and operate the sanitation system is insufficient, the project should not be pursued further until the capacity exists.

11.6 Construction

The sanitation system design resulting from the revisited design process can be built with labour from a construction firm and/or by volunteers in the community, if there is a willingness to contribute.

11.7 Training

This includes training people responsible for operation and maintenance as well as user training and behavior change. More information on this topic can be found in section 10.2.

11.8 Exit

The end of the project. This phase can be important to the long-term sustainability of the project. At that point all essential roles and responsibilities, e.g. cleaning, operation and maintenance of the toilet, must be taken in hand by stakeholders.

11.9 Monitoring and Evaluation

The implementation process presented here is meant to be flexible and should be re-evaluated and adjusted periodically along the way. Monitoring and evaluation should happen in parallel at all stages of the project, and should even be continued beyond the exit stage in order to evaluate the sustainability and long-term viability of the project.

12 Conclusion

The outcome of this design project is a preliminary design of a sanitation system for a school in Malawi. Nonetheless, to finalize the design, more data needs to be collected on the current situation at Chiwoko Primary school. This project focused on the technical side of the toilet system, ensuring that the system will increase sanitation and improve health. Although functionality of the design plays the central role in the success of a sanitation system, it is important to take a broader systems view including social, economic and environmental aspects to ensure long-term success.

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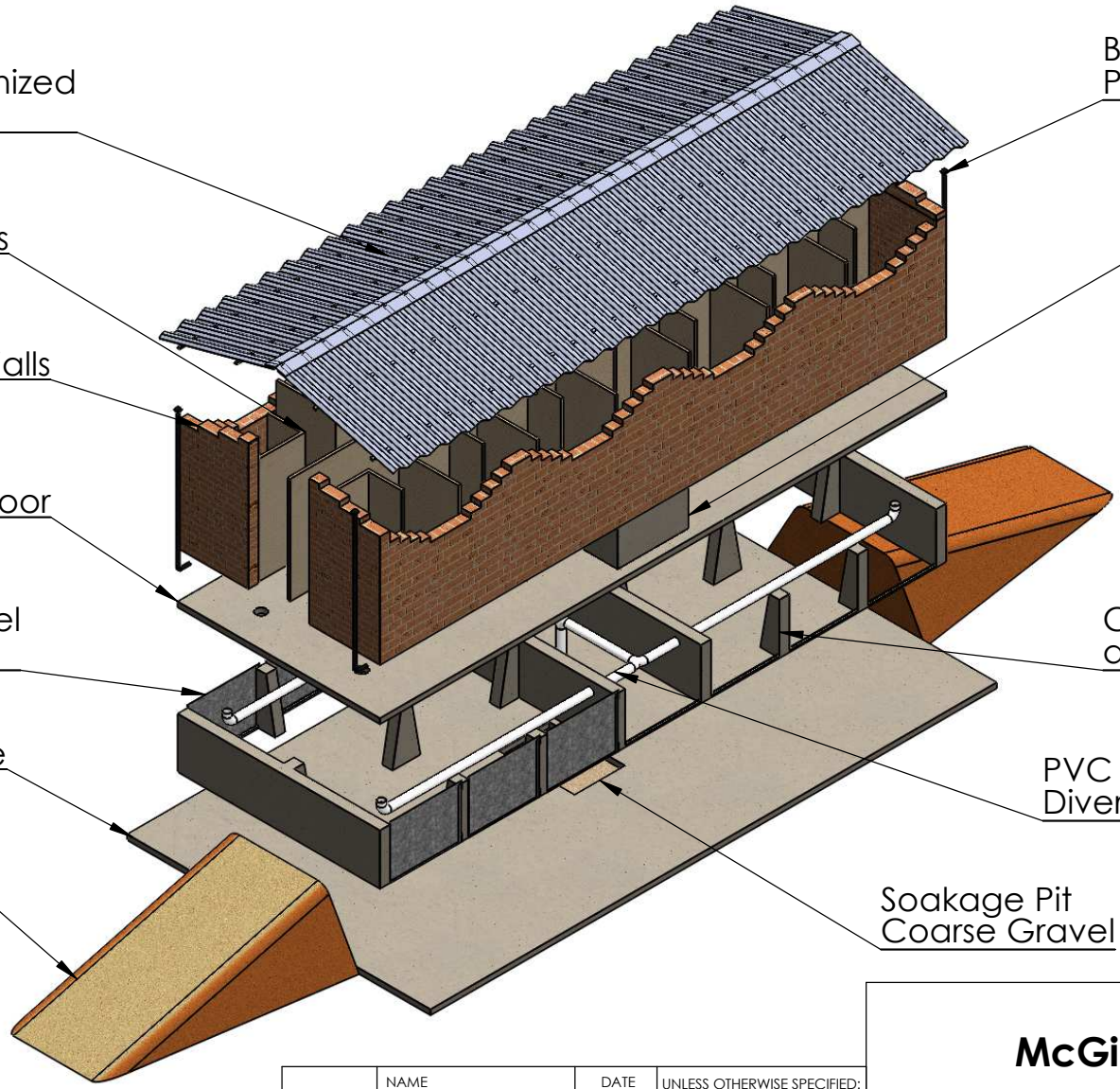

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	Isabelle Alvarez-Murillo	MATERIAL:	
	Laura Braun	Concrete, Wood, Brick, Galvanized Steel & Soil	
	Jérôme Boisvert-Chouinard		

McGill University

Sanitation System - Exploded

LTR

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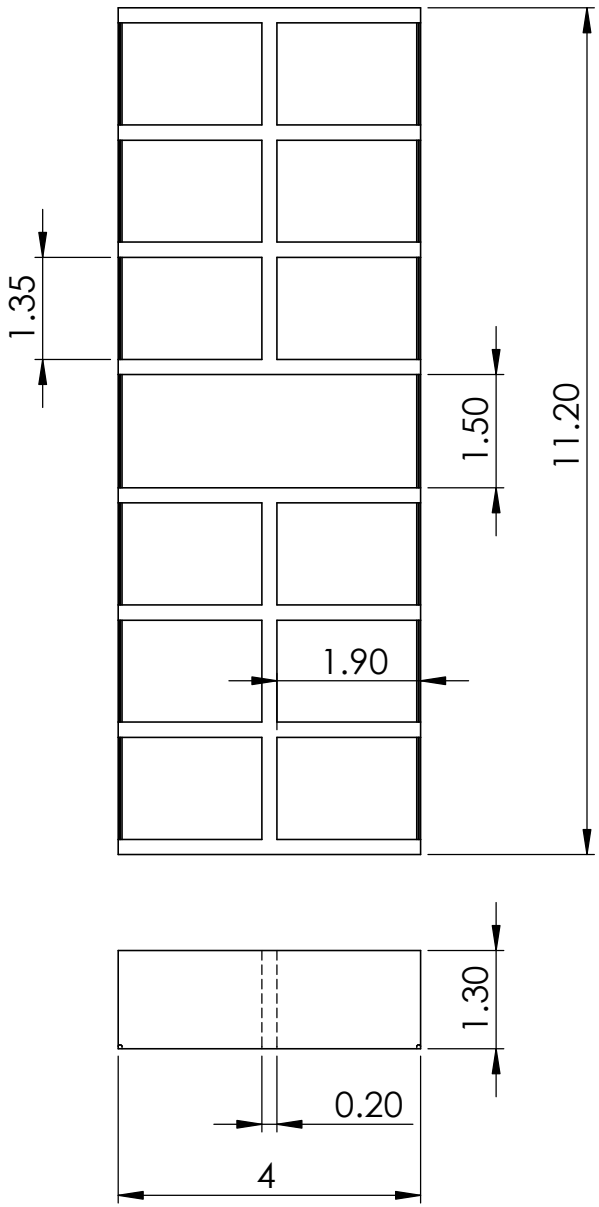
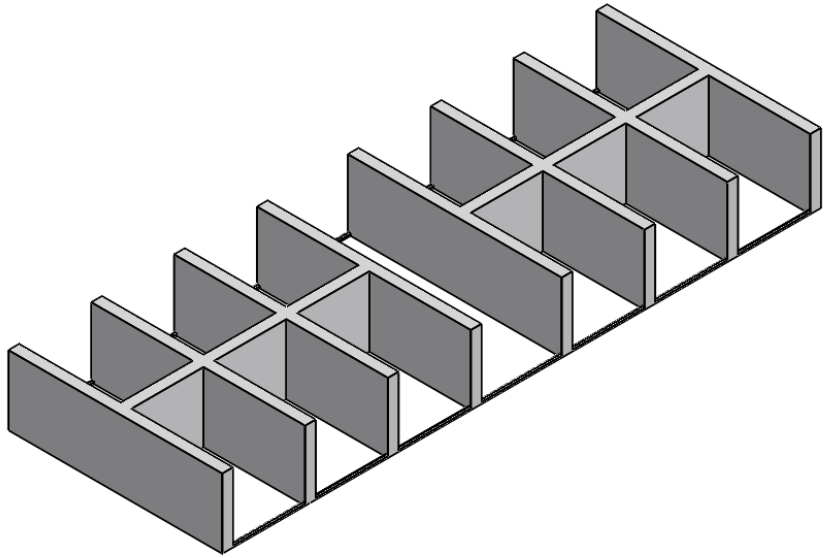
SHEET 1 OF 4





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	Isabelle Alvarez-Murillo	MATERIAL:	
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	Jérôme Boisvert-Chouinard		

McGill University

Vaults Intermediate Design

LTR

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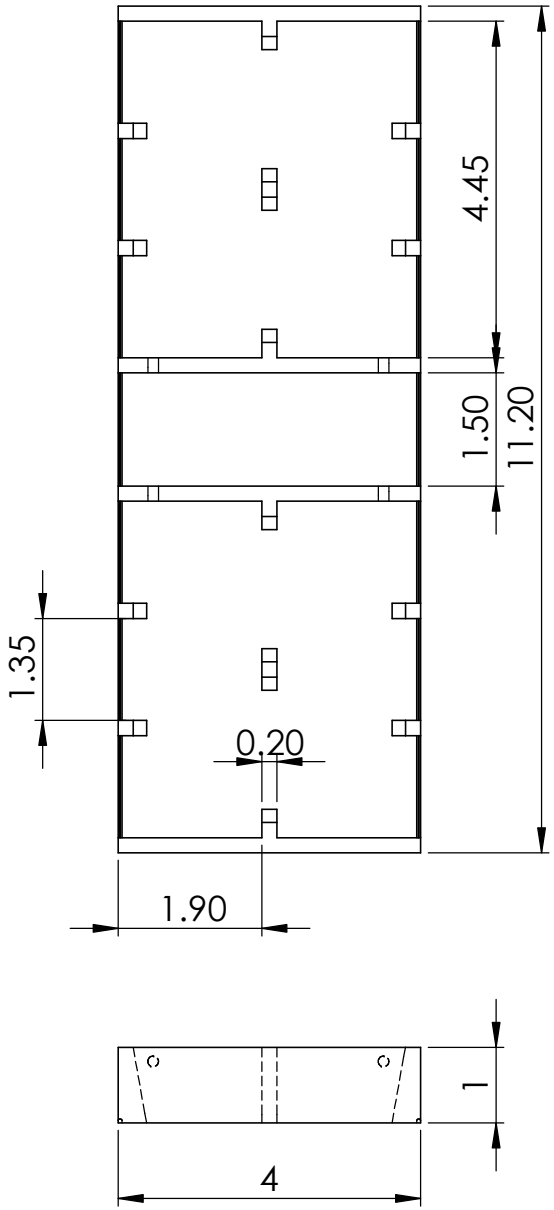
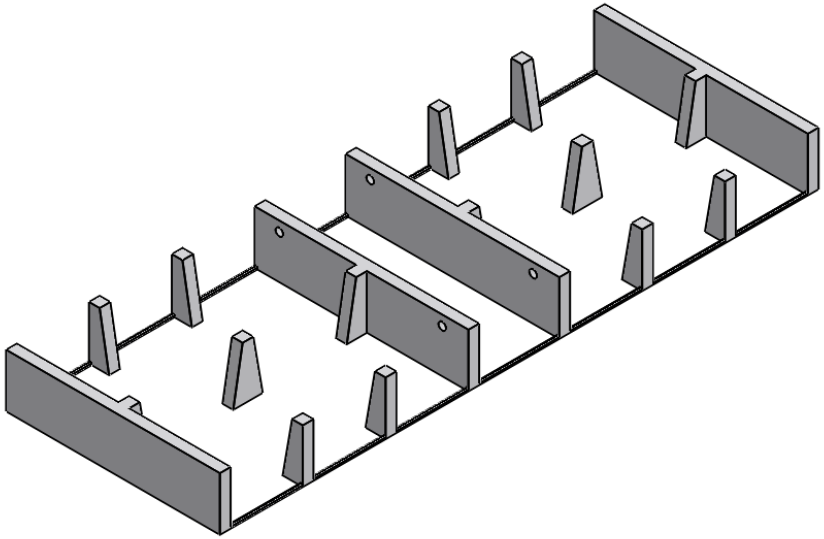
SHEET 2 OF 4





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	Isabelle Alvarez-Murillo	MATERIAL:	Concrete
	Laura Braun		
	Jérôme Boisvert-Chouinard		

McGill University

Vaults Final Design

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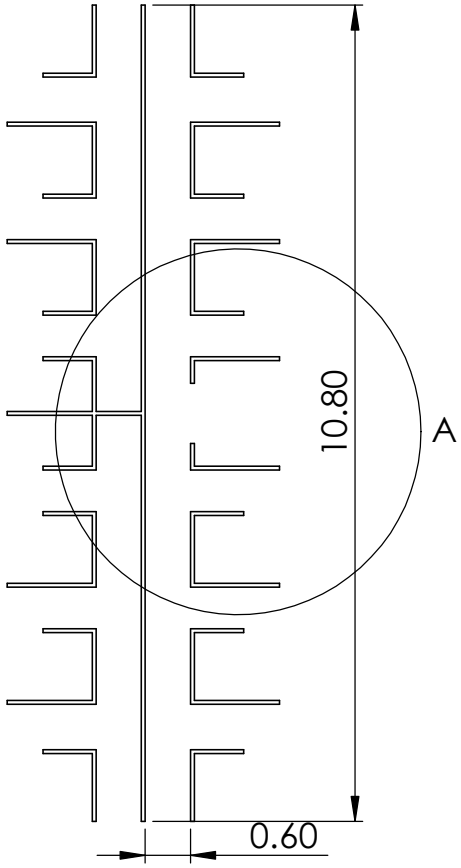
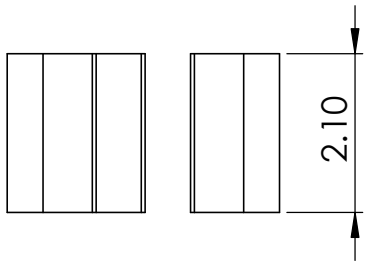
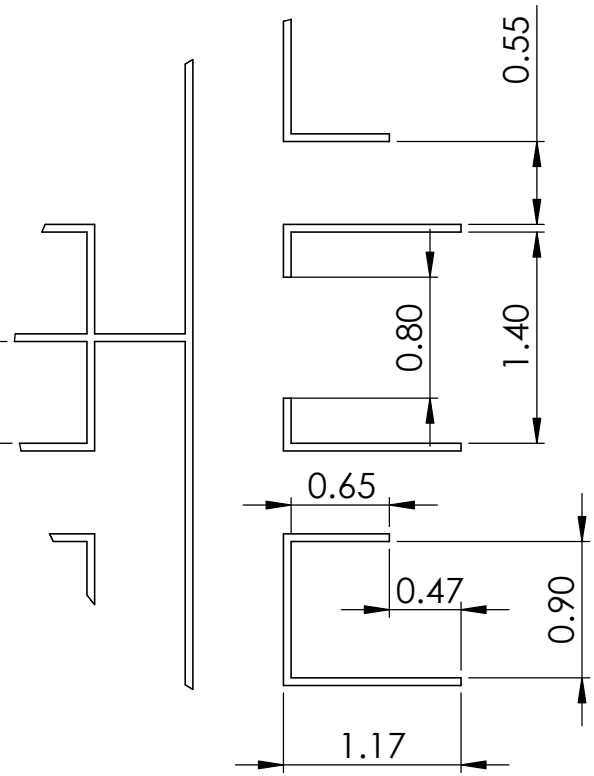
SHEET 3 OF 4







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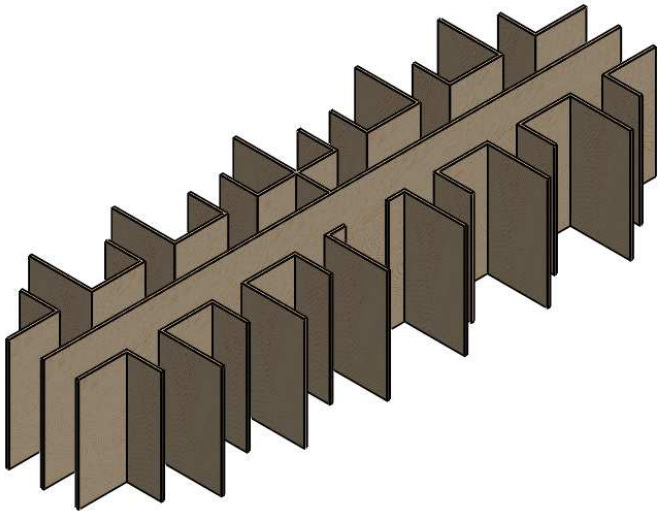

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	Isabelle Alvarez-Murillo	MATERIAL:	
	Laura Braun	Treated Wood	
	Jérôme Boisvert-Chouinard		

McGill University

Cubicles Disposition

LTR

SCALE: 1:100

SHEET 4 OF 4