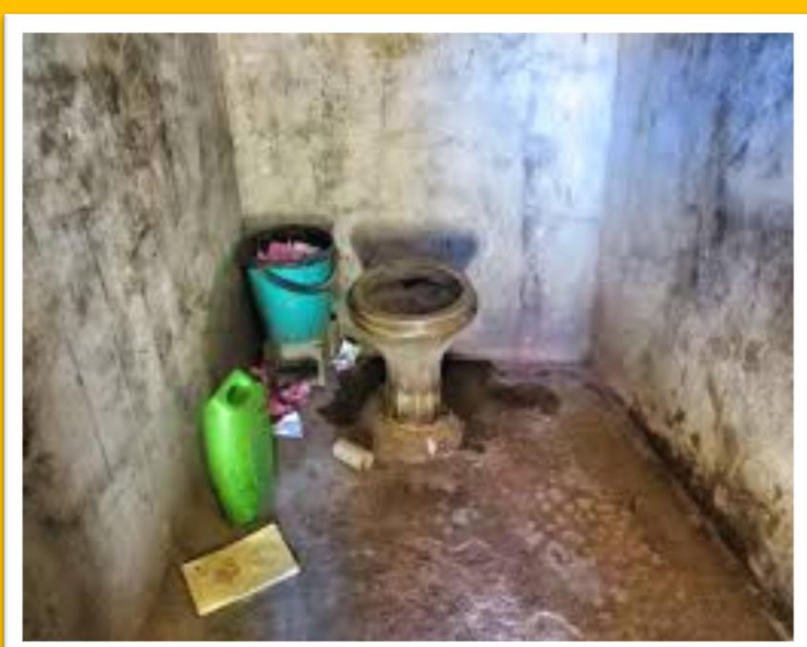
Affordable Rural Single-Family Sanitation Solution: HapiLoo

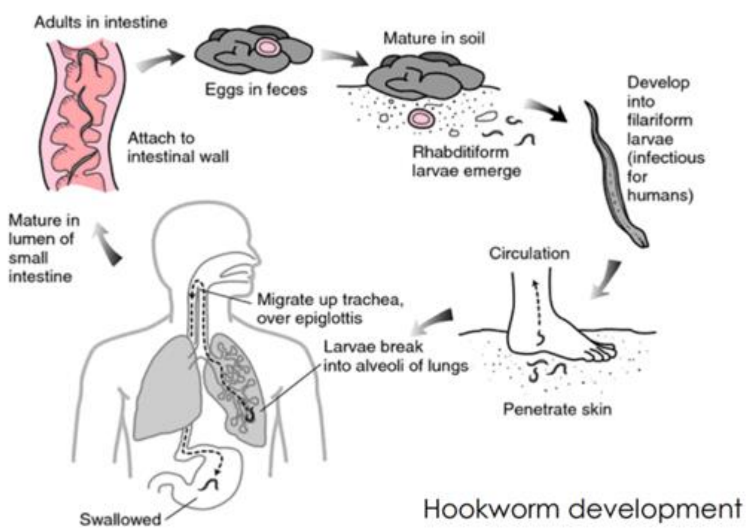


2021

HapiLoo - The Bottle Toilet

1. Introduction

Sanitation is a comprehensive term which comprises of solid waste management, safe disposal of human waste, waste-water management, water supply, control of vectors of diseases, domestic and personal hygiene, and hygiene maintenance in food and housing. A hygienic household toilet is the most important aspect of sanitation. Open defecation is still in practice in many rural areas resulting in serious social, health, economic and environmental problems. According to UNICEF, a gram of human feces has 10 million viruses, 1 million bacteria and 12,000 parasites. Openly lying human waste enables breeding and transmission of pathogens, which carry diseases and infections (Fig. 1). Disease from improper sanitation such as Cholera, Dysentery, Diarrhea, Typhoid and Stomach complication kills more children than HIV, malaria, and tuberculosis combined. E.coli is the most common cause of diarrhoeal diseases infections as well as human gastrointestinal tract infections caused by ingestion of unsafe drinking water in children in low-income countries. In sub-Saharan Africa, with deteriorating environments attributed to high levels of open defecation, drinking water sources remain vulnerable to faecal contamination. Also, contaminants from pit-latrine excreta may potentially leach into groundwater, thereby threatening human health through well-water contamination.



Source: http://medical-dictionary.thefreedictionary.com/hookworm, As of Sept. 18. 2013

Fig. 1 shows how open defecation spreads infections

There is strong evidence that access to improved sanitation can reduce diarrhea morbidity and mortality as well as soil-transmitted helminths (Albonico et al. 2008; Cairncross et al. 2010). Both economic and design must be targeted for successful sanitation project and provide a better hygiene for the society.

2. Brief of the Challenge

About 2.3 billion people still lack basic toilets, according to the World Health Organization (WHO). And 4.5 billion don't have safely managed sanitation, with waste disposed in a way that won't contaminate drinking water. Unfortunately, the cost of a proper toilet makes them unaffordable to most of the rural poor in many parts of the world and an estimated 2.3 billion people use unimproved toilets or no toilet at all. The above situation shows a dire need of novel ideas, concepts, and technologies to significantly lower the cost of safe, sanitary, and effective toilets for use by a single household.

Fig. 2 shows State of Sanitation

3. Proposed Design

The present solution describes the process of developing a sustainable toilet from the recycled and locally available materials. Instead of mining, extracting, and milling new components, we propose to make use of plastic bottles, this not only reduces greenhouse gas emissions, but reduces weight and provides a new use for landfill-clogging plastic waste. During our research, we found that low-income countries are also facing challenges related to increased plastic waste. Plastic waste pollution, aggravated by limited recycling capabilities, is prevalent across Africa. For example, Ghana produces 1.7 million tonnes of plastic waste annually, with only two per cent being recycled, according to the United Nations Development Programme. Also, approximately 500 shipping containers of waste is dumped in Africa every month, and only 10% of all trash produced in Africa is recycled. Collecting plastic bottles to make wall infill not only will help in improving the surrounding environment but also creates inexpensive building materials. The property of the bottle, being uniform in dimensions, is somewhat very similar to the qualities of a building unit, like bricks. This quality makes it excellent material for construction.

Why Plastic Bottles for Building Construction?

According to the World Bank's What a Waste 2.0 report, waste generation is expected to grow by 70% by 2050, while our global population is expected to grow at less than half of that rate. The report estimates that in Sub-Saharan Africa and South Asia, waste generation will respectively double and triple due to urbanization and economic growth. This crisis will quickly escalate with the two regions currently openly dumping and burning 69% and 75% of each region's waste respectively. In 2016 alone, the world generated about 240 million tonnes of plastic waste – equivalent to about 24 trillion 500-millimeter, 10-gram plastic bottles. The water volume of these bottles could fill up 4.8 million Olympic-sized swimming pools. Hard to visualize, but an immense amount of plastics. The packaging and plastic bottles are unlimited today. They comprise a large portion of the waste to form greenhouse gasses all around the world. The reuse of plastic bottles is a more efficient solution than recycling.

Using plastic bottles as construction material offer two advantages - low-cost and eco-friendly. The proposed design hence will form a secondary function of bottles, to keep them rid from throwing into landfills. They are readily available and an economic building material.

Sourcing of bottles: The proposed design involves gathering of as many as 1.5 litre plastic bottles. The local community can be involved in such projects as they can help in collecting plastic bottles and the local materials (bamboo or sand) or it can be sourced from scrap vendor. Using waste material will help in developing a sustainable structure from the recycled materials. The end users will also have a much greater sense of ownership in the project, as they will have greater involvement in the material sourcing or in the building process. This can help in maintaining the structure and its purpose. As only waste and regional products are used the toilets are cheap and can be afforded even by poor families.

Location of Toilet

Toilet should be constructed close to the house for easy access by all members

• Horizontal distance between toilet pit and groundwater source (e.g. well) should be minimum 33 ft

• In case groundwater source is less than 33 ft away, the inner side of the pit wall should be sealed

Distance to groundwater

Minimum vertical distance (safety gap) between bottom of pit and groundwater table should be 5 ft.

Design of toilet

In our proposal we have holistically designed each component (Containment, interface and super structure) of the toilet to achieve a low-cost integrated system that comply –

- Essential safety, hygiene and privacy requirements during usage
- Easy and low-cost maintenance of toilet
- Low tech but safe and effective human waste management
- Easily usable by those with physical disabilities or the very young
- Durable structure

The design incorporates not only low-cost toilet construction, but also facilitate rural people to construct the toilet by themselves with locally available materials with minimum training requirement.

The brief description of design, material usage and availability, key advantages and cost estimation are given below for each of the following components -

1. Containment
2. Interface
3. Superstructure

Containment is technically important as it provides safe disposal or reuse of human wastes. Interface ensures effective separation of human from solid and liquid waste during usage of toilet. The superstructure provides privacy and safe access of toilet.

1. Containment

There are 3 types of containments generally observed in rural toilet set up, each having its own advantages and challenges described in Table 1

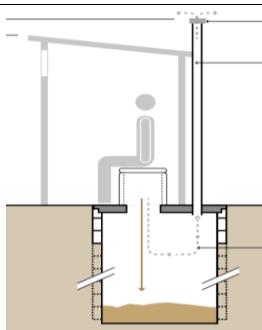
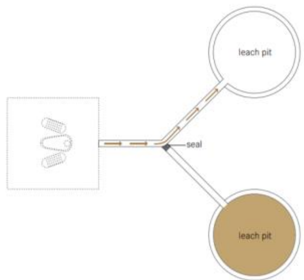
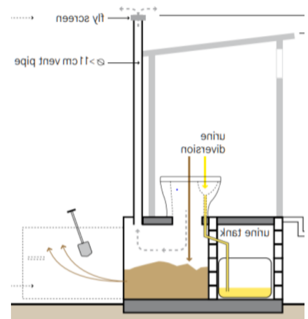
Single pit	Twin pit	Separate containment for solid and liquid waste
		
	Advantages	
• Low cost • Easy to build • Less space to build	• On-site treatment (drying) of human excretion • No requirement of removal of solid and liquid waste – No risk of human contact with pathogenic waste	• Urine, feces and wash water stored separately • Reduced odour (a mix of urine and feces causes substantial odour) • Enables fast drying and decomposition of solid waste • Easy management of waste • Reduces environmental impacts
	Disadvantages	
• On-site treatment not possible • High risk of coming in contact of pathogenic waste during removal (as the waste remains wet throughout the storage life) • Additional cost for removal of waste, transportation and treatment	• Double the cost of single pit • Moderate effort and skill to build • Two pits occupy large space	• Relatively expensive • High effort and skill to build

Table 1 describes advantages and disadvantages of different types of available containments

The challenge demands a unique design of containment with fine balance between cost, contamination risk and ease of operation.

Proposed containment design

1A. Pit position:

Nature of Mozambique's soils are diverse in type. Northern and central provinces have generally more water retentive soil, whereas southern region has more sandy soil. However, in both the cases soils are soft, therefore it is easy to construct underground toilet pit by rural people using basic digging tools. We propose underground pit which is safe for storage and decomposition of pathogenic waste. Moreover, the ground water level at Mozambique is not near the land surface. Hence it is safe to develop underground pit maintaining minimum distance of 2 meter between bottom of pit and groundwater table.

1B. Single pit with 2 chambers:

Segregation of liquid from solid waste and storage in different containment systems helps easy and safe handling of human waste. In absence of liquid waste (urine and wash water), solid waste (feces) disintegrates faster into manure through bacterial actions. Manure is safe to remove manually with very limited risk pathogenic infection. It can be used directly to agricultural land as fertilizer. On other hand, single pit with liquid and solid waste sludge require mechanical removal, transportation and off-site effluent treatment. However, using multiple containers to store liquid and solid waste separately increases construction cost of the containment.

We propose an innovative design, where single pit is divided into two chambers for separate storage and decomposition of solid and liquid waste. Chamber 1 (Table 2 Diagram) is used to store urine and wash water. Layers of activated charcoal and fine sand are provided at the bottom of the chamber 1, that filters the liquid waste and eventually allows it to be absorbed into the ground for further natural filtration. The chamber 2 (Table 2 Diagram) holds feces and facilitates faster decomposition of solid waste to form manure. Since manure is relatively safer to handle, it is then removed through the top of the chamber 2 and directly used in agricultural field. The whole system enables safe on-site treatment of human excretion.

1C. Pit construction:

- **Excavation:** As suggested in the challenge a rectangular shaped, 2 cubic meter of pit is excavated with length, width and depth of 1.5m, 1.5m and 1m respectively. The size of the pit is considered to be adequate for at-least one-year usage by average rural family of 4 members. 1m depth is safe to prevent ground water contamination due to absorption of liquid waste in the soil through the base of the pit. Excavation can be done by local villagers or users using basic digging tools.

- **Innovative Pit Lining:** Lining the inner vertical surfaces of the pit is critical to hold the structure and weight (super structure, interface and human) above the pit. Moreover, it prevents leaching of pathogenic waste (liquid portion) near the surface of the land through side walls of the pit. The lining usually done by building wall of brick and mortar (mixed in 6:1 ratio) or placing a concrete layer along the vertical surface of the pits. However, such constructions increase the cost of the pit significantly impacting overall affordability of toilet in rural area. Sometimes, in order to reduce the overall cost of the toilet, quality of interface and super structure are compromised reducing overall safety and hygiene.

We have adopted an innovative approach for building the pit lining at low cost without compromising the strength and durability. In current design, we have proposed to use a structure made up of empty plastics bottles which can be filled with dry sand or construction waste, sealed and then pasted with a mixture made of earth, clay, sawdust and a little cement to provide additional strength and durability. Using plastic bottles was introduced by a German citizen name Andreas Froese founder of "Eco-Tec" around 2001 called as " BOTTLE BRICKS". This technique application is done in India, central and south America. There are multiple examples where the technology is used for building houses using empty plastic bottles, which shows the durability of the structure. Please refer to https://www.instructables.com/New-Innovation-in-Construction-using-Waste-Plastic/

Fig. 3 Plastic bottles which have been set in concrete to form a bottle structure

We propose collection of empty and hard plastic bottles from the dump yard at nearly free of cost. It is estimated that approximately 550 plastic bottles of 1 to 1.5 Lt. are required to build the inner lining of one pit. The bottles are transported to the site of the construction. Each bottle is filled with locally collected sand to increase the mechanical strength. Bottles are then placed in structured manner along the vertical surface of excavated pit and cemented to bind them together alongside of the inner pit surface. The process is very similar of constructing brick lining using cement as mortar except the amount of cement would be significantly reduced. Local villagers can build the lining by themselves with minimum training and guidance. Finally, a layer of mud is applied to the inner surface of lining to provide smooth finishing. Such approach not only reduces the cost of the pit significantly but also provide an additional mean for recycling of plastic bottle with positive environmental impact.

- **Pit Bottom:** As mentioned earlier the pit has 2 chambers, Chamber 1 holds liquid waste (urine and wash water). A layer of activated charcoal followed by a sand bed are provided at the bottom of the chamber to allow chemical (through activated charcoal) and mechanical (sand) filtration of liquid waste before it is absorbed in the ground. Such process ensures zero contamination of ground water with liquid waste from the toilet. A layer of mud is provided on the bottom of the chamber 2 that holds solid waste of the toilet.

- **Innovative separation method of storage of solid and liquid waste:** Separation of solid and liquid waste is usually done at interface. However, with existing available technologies, the cost of the interface goes up significantly. Moreover, complicated interface design leads to difficulties in the usage of toilet resulting into low adoption. We propose an innovative method to segregate solid and liquid waste when those drop from the interface into the pit. A bamboo made sieve (mat) is placed in an angle below the pit hole (at the bottom of the interface). While solid waste (feces) falls on the

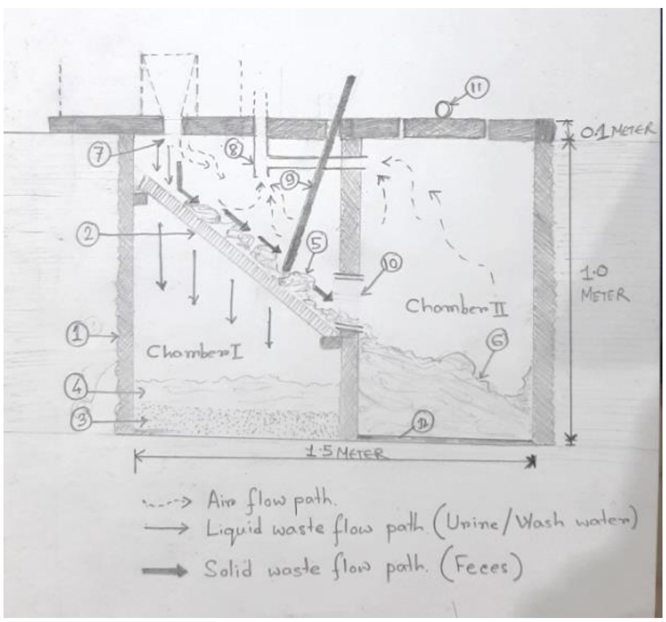
Fig. 4 shows bamboo sieve used to ensure collection of solid waste in chamber 2

bamboo sieve it slides to the far end towards chamber 2 where solid waste is stored. On other hand, when liquid waste falls on the bamboo sieve, it passes through the bamboo sieve and directly stored in chamber 1. Such segregation helps faster drying and decomposition of solid waste into manure, which is easy and safe to handle and use as fertilizer. A wooden lever is provided to access the surface of the bamboo sieve. If solid waste is stuck on the bamboo surface, it can be pushed through the wooden lever towards chamber 2.

- **Pit Cover:** A manhole cover made of HDPE is placed over the chamber 2, which is used as access point to collect manure from the chamber 2.

- **Vent pipes:** A vent pipe is placed on the pit to regulate continuous the air flow through pit hole, pit chambers and vent outlet. It helps in reducing the odour significantly. It also acts as a trap for flies as they escape towards the light.

Containment Design Elaboration



1. Plastic bottle lining along the vertical surface of pit
2. Bamboo sieve
3. Charcoal and sand bed
4. Liquid waste (urine and wash water)
5. Solid waste (feces)
6. Manure (after drying of solid waste)
7. Pit hole
8. Vent pipe fixtures
9. Wooden lever to push solid waste
10. Hole in chamber separator wall
11. Manhole

Table 2 illustrates the design of proposed containment

Materials used and availability:

Following materials are used, which can be collected or sourced by local villagers at very nominal cost.

Material Description	Availability
Empty plastic bottle (1 to 1.5 lt.)	• Can be collected from dump yard at free of cost • A new way of recycling of plastic bottle
Cement	• Can be purchased locally
Bamboo sieve	• Can be made of bamboo stick collected locally
Activated charcoal	• Can be sourced locally. Alternatively, it can be prepared by collecting plant waste
Mud and sand	• Can be collected locally

Vent pipe and fixtures	• Can be sourced from local hardware market
Plastic made manhole cover	• Can be sourced from local hardware market
Wooden lever	• Can be collected locally and cut to give proper shape

Table 3 describes the building materials used for constructing containment and their source of procurement

Key advantages:

- Low cost ($ 20.53 per unit) due to use of innovative usage of plastic to construct pit lining
- Promote recycling of plastic bottle
- Minimum maintenance cost (no requirement human waste sludge removal
- Innovative approach of segregation and separate storage of solid and liquid waste
- On-site decomposition of solid waste
- Safe handling and management of solid and liquid waste
- Ventilated to reduce odour
- Can be made by local villagers (user) with minimum training

Cost summary:

The containment cost is estimated for 1 pit of 2.25 cubic meter capacity. The cost includes both material and hired labour cost. Use of used plastic bottles as pit lining drives the low cost.

#	*Activity*	*UOM*	*Qty*	*Rate*	*Amount*	*Remarks*
1	Excavation of Pit	Man-days	2.00	$ 1.690	$ 3.38	2 Man-days of unskilled considered for the job
2	Plastic bottles of 1litre to 1.5 litre	# of bottles	550	$ 0.002	$ 1.10	Waste and used plastic bottles to be collected and used. Cost considered as 5 cents/Kg
3	Transportations Cost of Bottles	NA		$ -	$ 0.06	Collected from local area still 5% considered
4	Filling of the bottles with Sand /Excavated land	NA		$ -		Soil filled by local villagers or users
5	Cost of Mud and Sand and cement	# of cement bags	1	$ 5.20	$ 5.20	Used soil with cement (cement 1 bag/cubic meter)
6	construction of the Pits with Bottles	Man-days	1	$ 3.380	$ 3.38	1 Man-days of 1 Skilled and 1 Unskilled considered for the job
7	Use of Bamboo Shelf for filtration	NA		$ -	$ -	Locally collected bamboo sticks

8	Use of Shuttering to cast the slab using bamboo			$ -	$ -	Locally collected bamboo sticks
9	Use of the plastic bottles and cement, Sand for casting 0f slab		120	$ 0.002	$ 0.24	Bottles used to cast the slab. Waste and Used product is proposed to be used and amount considered basis the current cost of 1 kg/5 cents
10	Slab casting of the slab using cement	# of cement bags	0.5	$ 5.200	$ 2.60	Used soil with cement (cement 1 bag/cubic meter)
11	Manhole cover of 2x2 feet in HDPE	# of manholes	1	$1.000	$ 1.00	Locally procured
12	Cost of Vent pipe and fittings	# of set	1	$ 3.000	$ 3.57	Cost of vent pipe and fittings for Air
	Total for the containment				***$ 20.53***	

2. Interface:

Interface is the one component, where multiple technologies are developed targeting low cost and hygienic solutions in rural toilet set up. The most widely used options are Arborloo, Humanure, Pour Flush Water system and Urine Diverting Dry Toilet. However, each of these currently available designs has their own challenges to optimally balance the cost and hygiene factor. While Arborloo and Humaure are the most simplistic and lowest cost forms of rural toilet designs, those are not considered as completely hygienic. On other hand, Pour flush and Urine Diverting Toilet provides better separation of human from the waste material but those are relative expensive to procure, install and maintain.

Aborloo	**Humanure**	**Pour Flush**	**Urine Diverting Toilet**
			
Advantages			

• Low cost • Easy to manufacture, install and maintain	• Low cost • Easy to manufacture, install and maintain	• Hygienic • Matches regular sitting practices • Easy to use	• Ability to segregate liquid (urine, wash water) from soild waste (feces)
Disadvantages			
• Issues of smell or order • No barrier and waste material • Does not segregate liquid and solid waste • Required careful collection and off-site treatment of waste	• Issues of smell or order • No barrier and waste material • Does not segregate liquid and solid waste • Required careful collection and off-site treatment of waste	• Moderate to Higher cost • Need mass manufacturing set up • Required skilled labour for installation • Does not segregate liquid and solid waste • Required careful collection and off-site treatment of waste	• Higher cost • Low acceptability due to difficulty in use and clean • Need mass manufacturing set up • Required skilled labour for installation

Table 4 describes advantages and disadvantages of different types of available interface structures

Proposed eco-friendly interface design:

We have studied thoroughly all the available interface designs and their advantages and limitations; finally came up with an original design that ensures right balance between hygiene assurance, ease of use and cost effectiveness. Moreover, we have tried to reduce the usage of mass material like plastic or porcelain replaced (not fully replaced) it with green material like bamboo.

Our proposed interface consists of plastic made, open faces (both side) cone at the center that can be placed on top of the pit hole. The diameter of the top face should be higher (~0.4 m) than the bottom face (~0.3 cm). Inverted cone shape of the interface not only guide human excretion (Urine, feces and wash water) directly into the pit but also provides barrier with smaller opening at the bottom. While placing the cone on the top of the pit hole, the external circumference of the bottom face should be sealed with cement along the surface of the super-structure to prevent leakages of water (storm water or water used outside the interface) into the pit.

The plastic cone is completely covered vertically with an oval shaped structure made of strong bamboo sticks to provide strength to the interface suitable to carry the weight of a person in western style sitting position. The bamboo sticks are cut into equivalent height (~0.45 m) of the plastic cone and tightly roped around the cone to make it a stable western style pan. Smooth plastic sheet is cut like a ring and attached on the top of the surface to provide comfortable sitting condition. A plastic made lid is attached in the back of the structure, so that the interface can be kept closed while it is not in use.

Sitting arrangement:

We propose western style sitting which is the most common practice across the world and can be used easily by children, aged and physically disabled people.

To ensure design simplification, ease of installation and cost effectiveness, we purposefully avoided any provision of separation of liquid (urine and wash water) and solid (feces) wastes at interface. However, such separation is incorporated in the design of the pit. The proposed interface can be made and installed by local villagers (users) using locally available materials, with minimum training.

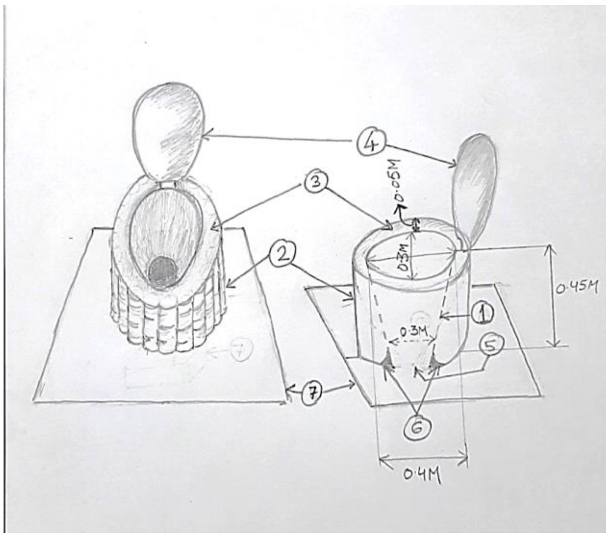
Interface Design Elaboration	
	1. Plastic cone made from bucket/jar type plastic container 2. Round shaped bamboo sticks 3. Ring shaped plastic made sheet for comfortable sitting arrangement 4. Plastic lid 5. Pit hole 6. Cement sealing 7. Floor of the super structure

Table 5 illustrates the design of proposed interface

Materials used and availability:

Following materials are used, which can be collected or sourced by local villagers at very nominal cost.

Material Description	**Availability**
Cone shaped plastic container	• Locally collected (used household or commercial plastic bucket / container) • Collected at zero or negligible cost
Bamboo stick	• Locally collected and cut as per required shape • Bamboo is naturally distributed throughout the Central and Northern regions of Mozambique, covering a estimated area of 500,000 hectares • Mozambique recently joined INBAR (an multiple government international organization – consists of 47 individual country members) top promote sustainable use of bamboo (reference: https://www.inbar.int/about-inbar/)
Plastic sheet for lid and interface sitting ring	• Can be sourced from the local market. Used sheet will also work
Cement (Only to seal interface bottom around the pit hole)	• Sourced from local market

Table 6 describes the building materials used for constructing interface and their source of procurement

Key advantages:

- Low cost ($ 6.69 per unit)
- Made by locally available material (Plastic sheet, plastic bucket, bamboo)

- Durable and can be used for long term. Completely modular, any part of the interface can be replaced easily at site
- Can be made by local villagers (user) with minimum training
- High rate of adoption due to ease of use (no changes in current common sitting practice)
- Suitable of children, aged and physically disabled people
- Ease of installation
- No maintenance and cleaning required
- Effectively create barrier between human and waste material. Minimum chances of contamination and hygiene breach
- No spillages of external water into the pit (except the water used for anal cleaning)
- Structure can be dismantled easily in case the toilet is moved to another place

Cost summary:

The interface cost is estimated for 1 unit of interface. The cost includes both material and hired labour cost. Simple design, used material (bucket) and use of bamboo drives the low cost.

#	Description	UOM	QTY	Amount	Remarks
1	Bucket of 20 litre	# of bucket	1	$ -	Used waste container/bucket/Jar
2	Bamboo cost	NA	1	$ -	Used Local bamboo sticks for stand
2	Bamboo labour	Man-days	1	$ 1.69	Labour of one skilled and unskilled person considered for 1 man-day each
3	Plastic Seat cover	# of plastic seat cover	1	$ 5.00	As per available data in India _AP average price
	Total cost interface			**$ 6.69**	

3. Super Structure:

The main toilet room has the following sub-components:

a) Walls
b) Roofing
c) Flooring
d) Door

Various type of available roof and wall structures were taken into consideration while designing the toilet. Each structure has unique advantages and a detailed entity comparison is discussed in Table 7. The proposed design suggests usage of plastic bottles waste as a building material which has a lot of potential for its ubiquitous and durability.

S.No	Structure type	Material details	Advantage	Disadvantage	Illustration
1.	Straw house	Wall and roof materials: Straw	• Low cost • Local materials • Skilled mason not needed for construction • Ventilation can be created at the top of the wall by making a space between the roof and the wall	• Temporary structure • Needs regular repair • Maintaining privacy is difficult if not constructed properly • Placing door latch might be difficult	
2.	Bamboo house	Wall materials: Bamboo Roof materials: Straw	Low cost • Local materials • Skilled mason not needed for construction • Ventilation can be created at the top of the wall by making a space between the roof and the wall • Can be easily upgraded to clay- or cement- plastered wall structure	• Temporary structure • Roof material needs to be replaced periodically • Needs regular repair • Maintaining privacy is difficult if bamboo is not fixed properly	
3.	Clay-plastered house	Wall materials: bamboo or straw wall plastered with clay on both sides Roof materials: straw	• Low cost • Local materials • Skilled mason not needed for construction • Privacy can be maintained	• Temporary structure • Roof material needs to be replaced periodically • Needs regular repair- clay will erode through contact with water • Wall may collapse if not constructed properly	

4.	Wooden house	Wall materials: wood Roof materials: CGI sheet	• Semi-permanent structure • Privacy can be maintained	• Semi-skilled mason needed for construction • Maintaining privacy is difficult if wood is not fixed properly	
5.	Zinc sheet	Wall and roof materials: CGI sheet	• Semi-permanent structure • Privacy can be maintained	Semi-skilled mason needed for construction • Toilet becomes hot during the summer and noisy during the monsoon rain	
6.	Stone house	Wall materials: stone Roof materials: CGI sheet	• Permanent structure • Privacy can be maintained • Maintenance is easy	• Skilled mason needed for construction • Costly	
7.	Brick house	Wall materials: brick Roof materials: CGI sheet	• Permanent structure • Can use both clay and cement mortar for laying bricks • Privacy can be maintained • Maintenance is easy	• Skilled mason needed for construction • Costly	

Table 7 describes advantages and disadvantages of different types of available super structures

Proposed Super Structure Design

a) Walls

The proposed method involves the initial construction of the build structural frame using bamboos. Later the sand/soil filled bottles are arranged like bricks, lying on side and stacked neatly to form the horizontal bottle wall. When the bottles are filled with soil or sand they work as bricks and form a framework for walls in proposed design. Previous research shows that PET bottle walls can bear up to 4.3 N/mm² when the bottles are filled with sand which is considered as a strong material. Further a mixture of clay and small amount of cement is used to fill the space between all bottles. The structures are well insulated, incredibly strong, and fire resistant. For better structural integrity an overall frame with the help of rope can be used.

Brief overview of design of a bamboo frame: Begin with corner posts firmly planted in the corners set out at the site. Next, attach joists (horizontal culms that will support the floor and roof). Then attach studs (vertical culms that will form the wall frame). Since bamboo cannot be cut to make perfectly measured joints, the shafts must be lashed with vines, bark' or wire. The only cut that can be made is a notch or cradle-like cut that can be used at the upper end of posts to support a horizontal piece.

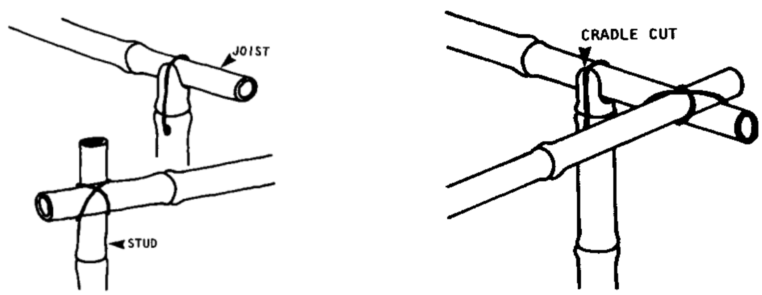


Fig. 5 illustrates the overview of design of a bamboo frame

b) Roofing

The roof will be constructed using whole bamboo poles as support beams. The strips will be cut out from the plastic bottles as shown in the figure below. The overlapped plastic strips are joined by thermal joining to make a thatch like structure. Layered on top of a roof frame like a thatch, the bottle structure can last many years as opposed to one year using regular thatch. While breathing and maintaining the cooling advantage of organic thatch the plastic strip roof also allows natural light through, a dramatic benefit in areas where electricity is an issue. Also, the structure offers the sound dampening from rains compared to conventional roofing and the plastic thatch looks very promising as a way to improve the durability of toilets.

Fig. 6 illustrates the method of utilization of empty plastic bottles for construction of roof

c) Flooring

In the proposed design the sub-base is prepared by watering and ramming, properly to ensure no loose materials are left. The concrete mixture made of aggregate, soil and cement are laid uniformly in thickness of 100 MM. After pouring of concreate mixture, surface should be levelled with a straight edge and finished with a wooden float or trowel. The final troweling should be done before the concrete has become hard. There should not be any mark left on the finished surface and care should be taken that no cement slurry spread on the surface.

d) Door

The door will be prepared using bamboo, the locally sourced stems, or culms will be cut to make a gate measures approximately 2 meters by 1-meter. It is suggested to use flat strips of bamboo and not concave pieces. The Bamboo's are chosen as it is an excellent building material and it offers a very high strength-to-weight ratio which is very sturdy for such a light-weight material. Also, it is easily available and handled, with little waste and no bark to remove.

Dimension of super structure

The proposed super structure can be constructed using the following:

- Total area of super structure (inside) – 1.08 Sq. meter
    - Length – 1.2 meter
    - Width – 0.9 meter
- Height of super-structure at door side – 2.4 meter
- Height of super-structure at door side – 2.1 meter
- Door size: height - 2-meter, width - 1 meter
- Height of vent pipe: 6 in above the highest roof point
- Light fixture is recommended inside

Fig. 7 Diagram illustrating the different parts of a super structure A. Wall structure constructed using used filled plastic bottles, stacked on their sides and bound together with mud or a cement mix, creating solid walls; B. Roof strucutre with Bamboo and Plastic Bottles; C. Shutters for door is made of bamboo

Materials used and availability:

Following materials are used, which can be collected or sourced by local villagers at very nominal cost.

Material Description	Availability
Empty plastic bottle (1 to 1.5 lt.)	• Can be collected from dump yard at free of cost • A new way of recycling of plastic bottle
Cement	• Can be purchased locally
Bamboo frame	• Can be made of bamboo stick collected locally
Bamboo door	• Can be made of bamboo stick collected locally
Mud and sand	• Can be collected locally
Nylon rope	• Can be sourced from local hardware market
Door hinges	• Can be sourced from local hardware market
Floor -Concrete mixture, sand, cement	• Can be collected locally or purchased from local market

Table 8 describes the building materials used for constructing super structure and their source of procurement

Key advantages:

- Low cost ($13.95)
- The total waste generated is reduced
- The source of building material is local. No additional cost for the same
- The natural resources are preserved
- The carbon footprint is reduced
- The technology used is small and easy to implement
- The structure is fire proof, bullet proof and earthquake resistant

Cost summary:

The super-structure cost is estimated for 1 unit of super-structure. The cost includes both material and hired labour cost. Use of used plastic bottle to build walls and drives the low cost.

#	*Activity*	*UOM*	*Qty*	*Rate*	*Amount*	*Remarks*
1	Erection of bamboo columns and frame	Man-days	1	$ 1.95	$ 1.95	1 Man-days of 1 skilled labour considered
2	Bottles required to construct the wall	# of bottles	1000	$ 0.002	$ 2.00	Waste and used plastic bottles to be collected and used. Cost considered as 5 cents/Kg
3	Transportations Cost of Bottles	LS		$-	$0.10	Collected locally
4	Filling of the bottles with Sand /excavated land	LS		$ 1.95		Soil filled by local villagers or users
5	Cost of Mud and Sand and cement	Cubic meter	1.5	$ 5.20	$7.80	Used soil with cement bag ratio cement 1 bag/cubic meter
6	Use of Shuttering to cast the slab using bamboo			$ 1.95	$ -	Use of bamboo stick as framing to hold the material cost.

						Considered 1 day for framing of walls and roof
7	Use of Plastic bottles cut half and thermal press joint by applying heat	# of bottles	50	$ 0.00	$ 0.10	44 bottles may be needed to cast one roof and added additional 10%
8	Door Fittings	# of sets	1	$ 2.00	$ 2.00	Hinges, AL drop for doors
	Total for the super-structure				**$ 13.95**	

Summary: An affordable integrated toilet system for rural population:

While designing the proposed integrated toilet system for Sub-Saharan Africa, we have carefully studied the challenges of all existing systems and made an attempt to provide innovative and practical solution to improve affordability and adoption thereby impacting quality of life of rural population.

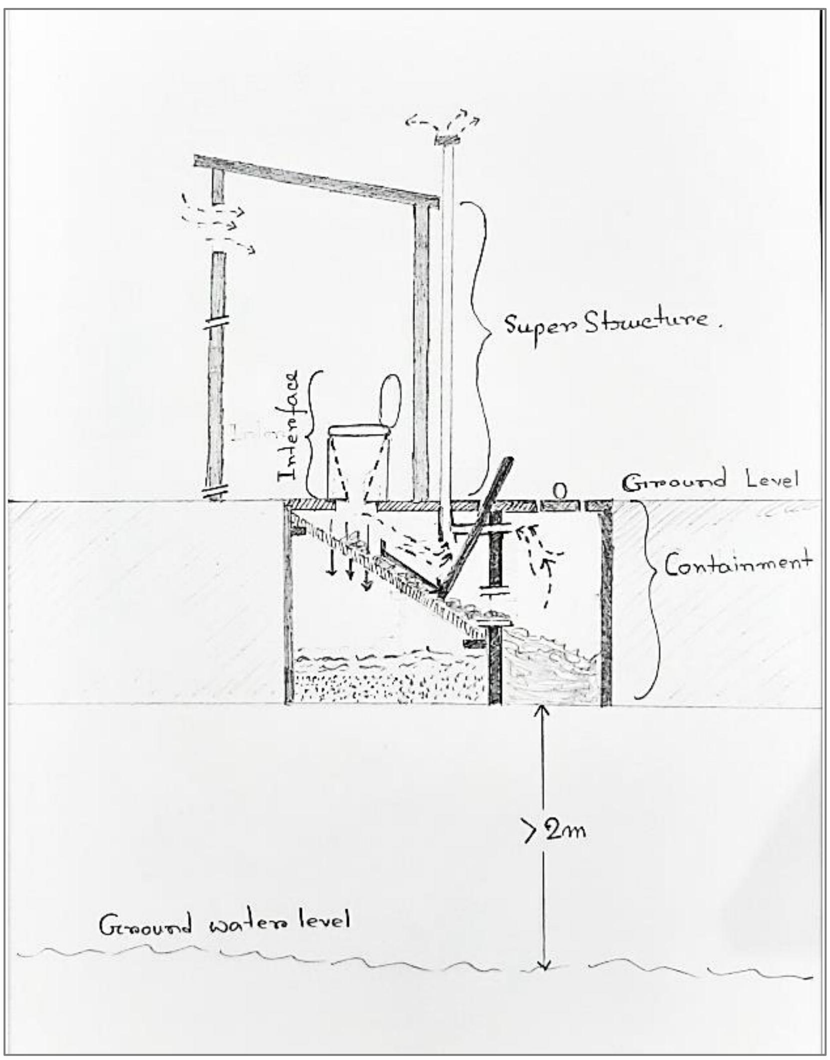


Fig. 8 illustrates the Integrated Single-Family Sanitation Solution

Affordability remains one of key factor for lower adoption toilet usage in rural areas. While government and NGO funded initiatives have been successful in making localized impact, the universal and mass adoption remains limited in various parts of the world. In proposed solution, each of the 3 components are specifically designed to break the barrier of affordability limit of $45 per household toilet in Sub-Saharan Africa. Our designed achieved overall capital cost of $43.22 (Containment – $20.53; Interface – $6.69; Super-structure – $13.95; Miscellaneous-$5.0) for construction and installation of one household toilet thereby promising sustainability and self-adoption.

Innovative approach of use of plastic bottles in building the super-structure and containment goes beyond cost by creating sustainable environmental impact. Careful selection of locally available materials (e.g. bamboo and used plastic bucket made interface) at negligible cost helps in limiting the cost of construction. Self-installable unit by using locally available materials, using regular tools reduced skilled labour cost significantly.

Multiple smaller design innovations ensured adequate standard of safety and hygiene in-spite of low-cost solution. Segregation of liquid and solid waste using bamboo sieve, storage of liquid and solid waste in separate chambers, ventilated pit etc. are aimed to maintain high standard of hygiene during usage of toilet and disposal of solid and liquid waste. On-site waste management e.g. drying and decomposition into manure, is made possible to ensure minimum maintenance cost and safe waste management.

Common practices of sitting (western style) is kept intact while designing the interface. Such approach promises higher adoption toilet usage in all age groups and physically disabled people in rural area. While bottled made super structure has kept the cost low, it additionally provided a well build unit with adequate safety. Bamboo made door with locking system ensured privacy while accessing the toilet.

While entire unit is designed as integrated system, the most of components in interface and superstructure are kept modular for ease of replacement without any need to dismantling the overall structure.

We believe such system will go a long way in providing a sustainable, affordable and hygienic sanitization need of Sub-Saharan rural population. We are happy to call it ***"HapiLoo"***.