Team Project CDR

FABE 5200 Latrine Team A

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Executive Summary

In the developing world, many countries lack appropriate waste disposal methods, which often leads to open defecation. Open defecation results in water contamination and the increased spread of disease, and thus heavily contributes to negative health impacts for surrounding populations. One common solution to this problem is a pit latrine: a hole dug into the ground for the containment of human excretion. Pit latrines serve the purpose of sanitary waste disposal, and pit liners function as the infrastructural bearing for the latrine. The liner prevents against pit collapse and groundwater contamination. However, there are few pit liners in existence that provide safety and stability while also fitting the needs of end-users regarding cost-value, accessibility, and durability. As the target demographic for this product has low economic capital and typically lives in rural, developing areas, an effective pit liner solution must address these factors.

The pit latrine liner development method being proposed consists of a circular steel mold that fits 6 inches within the boundaries of a dug pit, and a soil-cement mixture that is poured around the mold. This solution is low cost, at 9.39 USD per liner; it is accessible, as materials for the liner can be locally sourced and no expertise is needed to construct the pit; and it is a durable solution, as ten people can use the pit for eight years before it is expected to fill. The mold is reusable, which can create income generating activities for individuals who purchase the mold to construct pits for others.

In order to ensure the validity of this product's design, numerous methods were employed including researching and performing equations for subsystems, assessing surveys from potential end-users regarding wants and needs for product implementation, and testing and evaluating the prototype developed.

Initial research showed that the desired pit shape should be circular, as the natural arching effect it produces makes it the strongest shape geometrically. The recommended depth and diameter of the pit is 3 meters deep and 1.8 meters in diameter. It was determined that the mold the team developed should be made from steel to increase its durability and should be 1.5 meters in diameter to fit within a 1.8 diameter hole. The ratio for the soil-cement mixture was determined to be 1-part cement to 6-parts sandy/silty soil. The cement grade required for the mixture is 42.5 MPa class N. Meeting these two requirements will allow the pit liner to withhold the lateral and downward forces of the soil, which typically cause pit collapse.

The pit latrine liner and mold product has demonstrated to be effective in pilot testing out of country. Further plans need to be made to form community partners and perform in-country testing, which will additionally require funding from NGOs, donors, and/or investors. Given the iterative design process being applied, in-country testing will inform further research and development. Upon reaching a finalized design improved on from end-user recommendations, the product will be ready for market roll-out in Ghana, and partnerships will be made with local cement and steel manufacturers, distributors,

and donors. Initial scaling will occur in Central Africa, with eventual plans for the product to reach India and South East Asia, resulting in global market penetration.

Results and Discussion

Framing the Design Challenge

Developing countries often lack plumbing and sanitation infrastructure; rural areas in particular face the largest challenges in accessing adequate sanitation mechanisms. One solution to overcome sanitation barriers is the use of a pit latrine. However, it is not uncommon for pit walls to collapse as the soil wears down in unlined latrines, causing a serious safety concern. Lined latrines are much safer in such cases (Reed, 2014). Unfortunately, the current methods and materials used to line latrines incur a considerable cost and require either the pit to be emptied or a new pit to be built every 2-10 years after it fills up (Mara, 2011). This is not economically feasible for many of the poorer communities with the greatest need for sanitary waste disposal. Therefore, the goal is to create a low cost and/or removeable liner system that can be reused in new pit latrines when the current pit fills up. The desired impact of such a solution would be to increase access to latrines in areas of need in developing countries, increase the safety of latrines in unstable soils, remove cost as a barrier for using a latrine, and reduce health issues from open defecation and water contamination.

Interviews

The intended end user of a pit latrine liner will be rural villagers in developing countries. Individuals are likely undereducated and reside under the global poverty line. The user's current reality is the use of unsafe latrines or open defecation in their community.

Since the pit latrine liner will be designed for developing countries, it is likely the users will not be the main customers buying the liners. Rather, it is more likely that the customers will be NGOs, non-profits, governmental agencies, and other organizations dedicated to helping improve sanitation in developing nations.

Due to the current lack of access to potential users and customers, the answers to these questions come from the notes and information collected by team member Dana Dosen during her trip to Kpando, Ghana, in 2019, to prototype a sustainable latrine as part of the FABE 5797 service-learning trip through OSU. In Ghana, large families are common in rural areas and a typical household, with typical households often including extended families. In rural areas, only about 2.1% of households have a flush toilet. The majority of households use a pit latrine, bucket and pan, or use open defecation (Ghana Statistical Service, 1993).

1. <u>What do you use as a toilet right now/Where do you go to the bathroom? </u>(Record all answers. Should be somewhat similar in each community. We are trying to just get a picture of what people do each day.

    - **ANSWER**: open defecation or poorly constructed pit latrines without liners (essentially just holes in the ground with wooden planks to squat on)

2. How often does it flood here? Do you notice water going from the ground into the hole or latrine when it rains? Do your latrines overflow when it rains? (Trying to see how predominate the flooding is and if latrine overflows from rainwater runoff or rising groundwater.)

    - **ANSWER**: latrines overflow and flood about once a year when it rains hard

3. Does anyone clean out the pit latrines you use? If so, who? How do they clean it out? (If there is a designated person who does this, we can try to talk to them and ask what that process entails.)

    - **ANSWER**: no – the latrines are covered and a new one is dug when the old one is full

4. What do you NOT like about the bathroom situation? What is bad about it or uncomfortable? (We want to record what they want changed.)

    - **ANSWER**: smelly, dirty, flooding, collapsing, animals get into structure and make it messy

5. What do you like about the bathroom situation now? What is good about it or comfortable? (We want to record what they are comfortable with so we can maybe incorporate that into the design. Answers might include proximity, privacy, ventilation, squatting, etc.)

    - **ANSWER**: prefer squatting rather than sitting western style

6. Is there a community bathroom? If so, who is responsible for cleaning it? (Trying to see if there is someone we could talk with about the removal process and gauge their comfortability with it.)

    - **ANSWER**: no – usually there is one latrine per household but households can be 8-15 people

7. Who cleans and maintains your pit latrine now? (See if people are saying the same person. If there is someone, see if we could talk to them about what the removal process would entail and if they would be comfortable with that.)

    - **ANSWER**: no one is assigned to this task… each family is responsible for their own latrine and so it differs

Resource Flow

In Ghana, the most common form of income-generating activity is agriculture and thus land and livestock are huge assets to the people (Winters, 2009). Common outflows include crops and livestock while common resource inputs include seeds, water, time, land, and livestock. Some rural household members work by providing non-agricultural services; in these cases, common resource outflows include time, education, expertise, and handmade products while common resource inflows include cash and food.

The proposed pit latrine liner solution will help increase opportunities for money inflows by providing individuals who purchase the mold the opportunity to construct latrines for others. Additionally, the simplicity of needed construction work for pit latrines with the proposed solution allows individuals without prior construction experience to potentially benefit from income generation activities. This allows for an increase in usable assets for individuals in addition to increased access for individuals unable to build pit latrines themselves in-country.

Planning

In order to ensure sufficient progress was made this semester, the team created a Gantt chart project plan that is also in the form of a work breakdown structure. This project plan spanned the entire semester and included start and end dates for subtasks and deliverables.

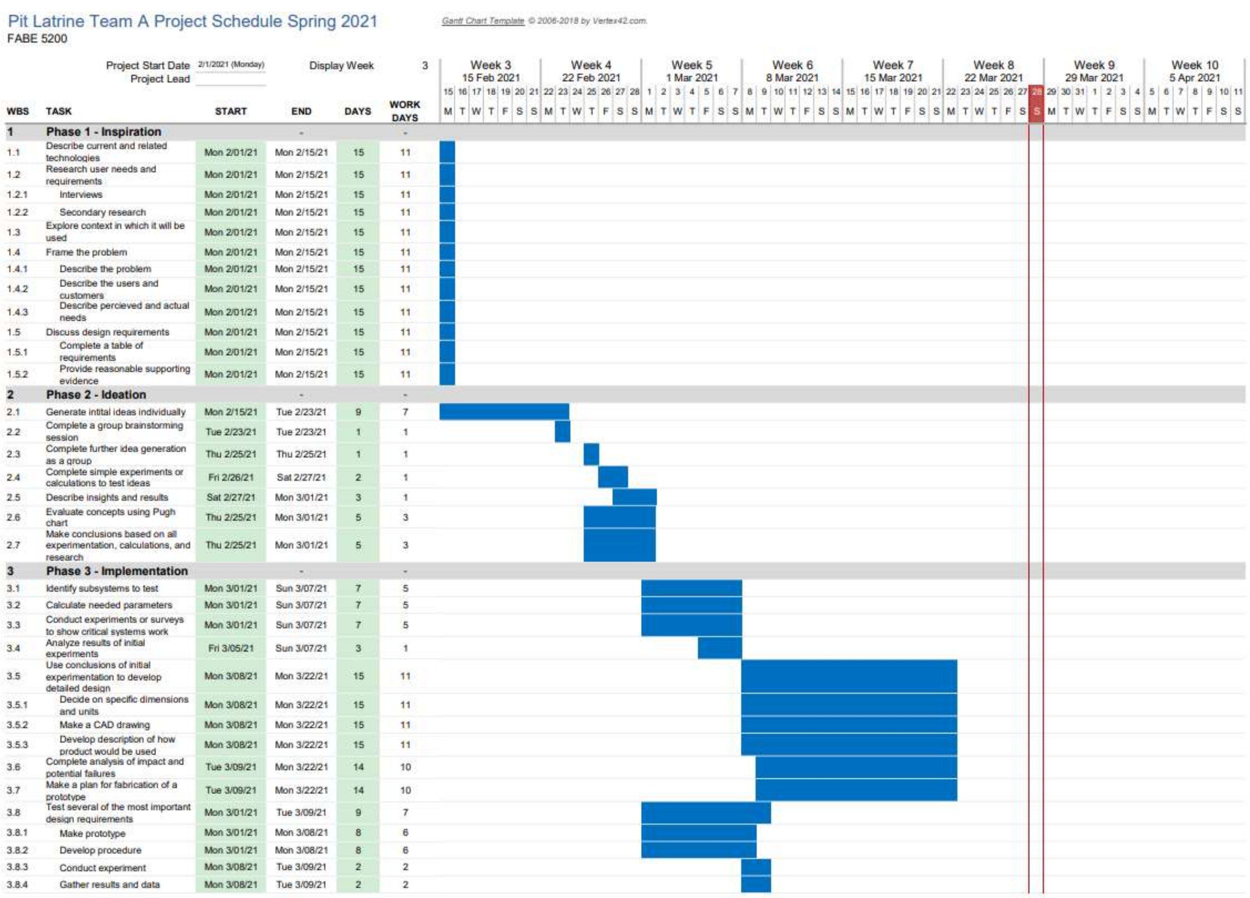


Figure 1: Team project plan (part 1)

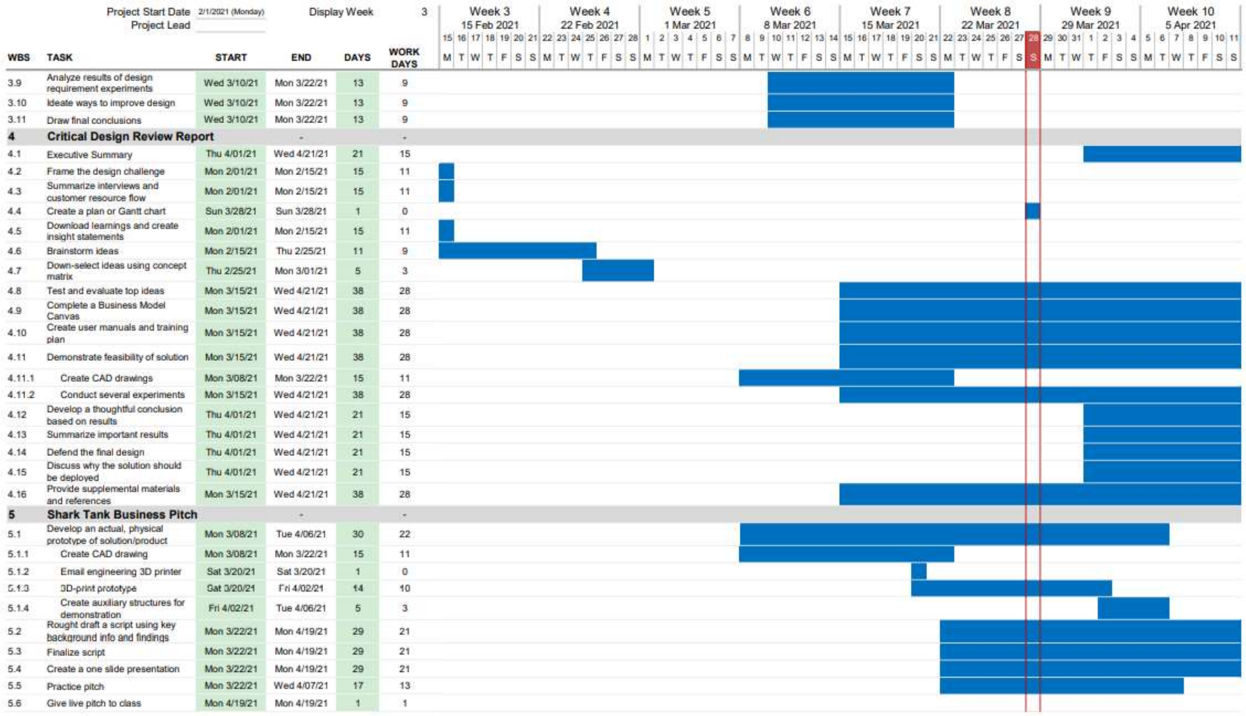


Figure 2: Team project plan (part 2)

Learning Download and Insight Statements

Because the team was unable to conduct actual interviews or visit the regions where the design was being developed for, the team instead downloaded their learnings by discussing the facts and impressions gathered from their research during the inspiration phase. Based on their findings, a few key insight statements were determined:

- Open defecation is detrimental to human health and safety.
- There are many existing latrine construction technologies, but no single one is broadly used or appropriate for use in a wide variety of situations.
- Affordability is a key deterrent to increasing access to pit latrines in developing countries.
- Most people care about basic functionality rather than advanced/add-on technology.
- Cleanliness is a defining quality of any toilet experience.

Brainstorming

Initially, the team took 10 minutes to individually generate ideas related to the identified problem scope and statement and to write or sketch them on sticky notes. After individually generating ideas, the team came together and put their individual ideas on a white board to see similarities and differences. The team then conducted a second iteration of group brainstorming to organize ideas and combine some of the individual ones to form new ones. The team then used 25 bisociation topics to come up with new ideas and reiterate strong ideas already generated.

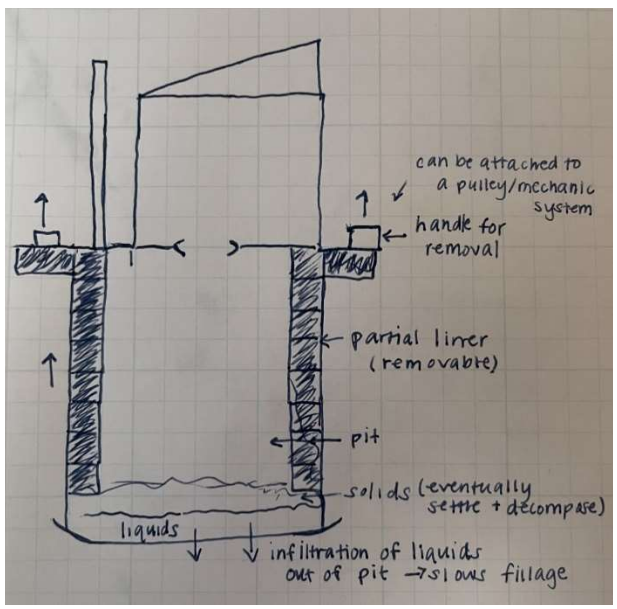
After the brainstorming sessions, the team compiled a list of ideas that merited further exploration, research, and experimentation.

- Mold for cement liner to be poured directly into hole (mold and cement)
- Bottom of pit liner stays in the ground (either biodegradable or detachable) for easier removal or no bottom at all for liquid drainage
- Circular pipe with threading (knurls) to screw into ground then dig out inside during construction
- Having complete walls pieces that can disconnect from each other for easier removal
- Elevated removable cylinder piece with permeable bottom
- Having struts between walls to provide additional stability

From these ideas, four designs were further expounded on, discussed, and chosen to move forward with into concept evaluation and testing.

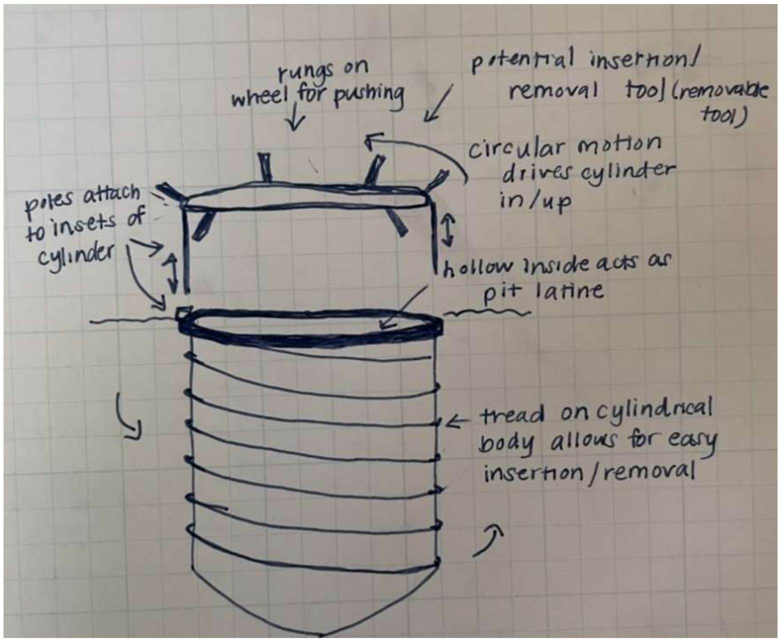
Design 1: No Bottom

This design includes a pit latrine of any shape where the outer material is removable because there is either no bottom piece or a separate permeable/biodegradable bottom.



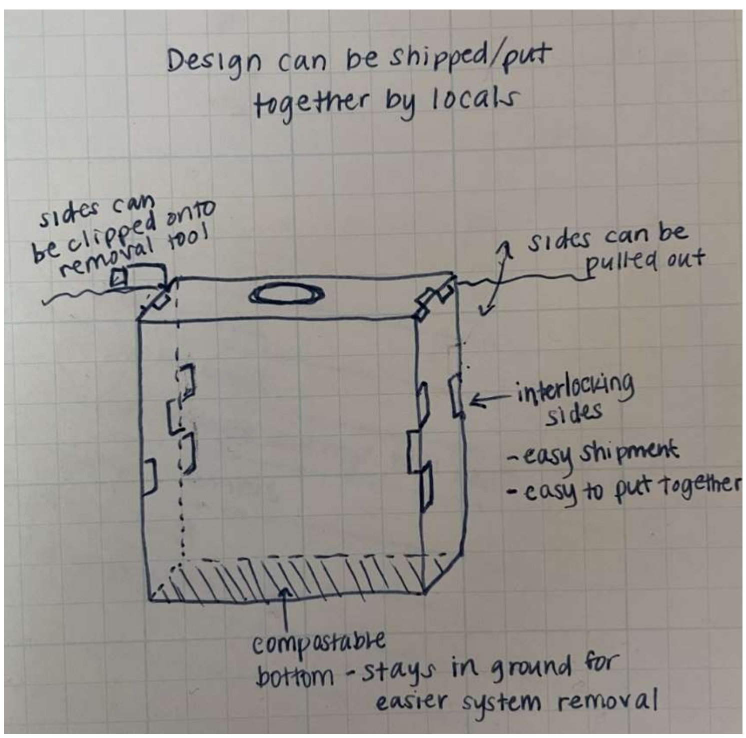
Design 2: Screw In

This design includes a cylinder pit latrine where the entire body is in one piece with a threaded exterior similar to a screw. The body of the pit latrine can be spun into and out of the ground for removable use.



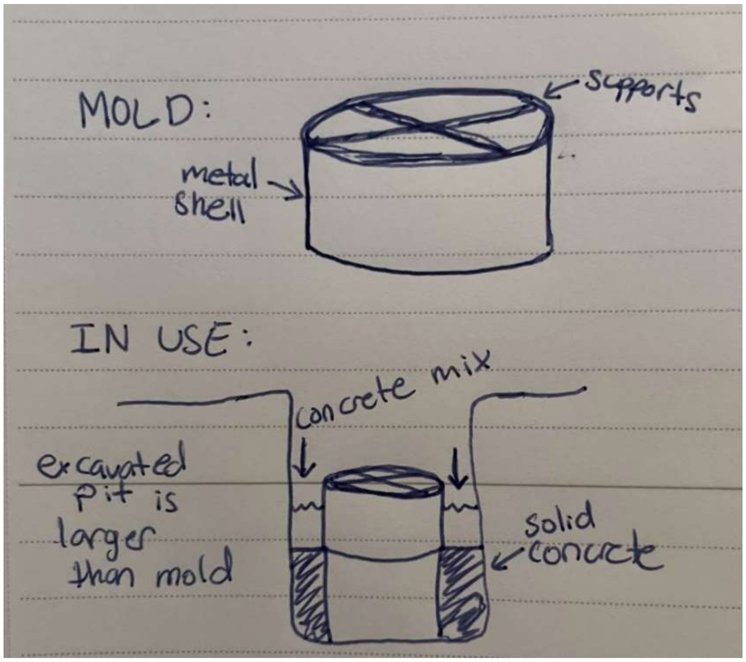
Design 3: Clip Together

This design includes walls that are shipped individually to the site for assembly. The walls interlock and/or snap together for easy assembly and disassembly.



Design 4: Soil-Cement Mold

This design method of constructing a pit latrine involves excavating a large pit and using a mold placed first at the bottom of the pit to pour cement for a liner directly in the excavated hole. After each layer is set, the next layer can be poured.



Concept Matrix

	Criteria	Baseline	No Bottom	Screw In	Clip Together	Soil-Cement Mold	Current Pit Latrine	Totals	Rank
			Designs						
1	Affordabilty	4	+	0	+	+	0	3	1
2	Reusability	3	+	0	+	+	0	3	1
3	Permeability	1	0	0	0	0	0	0	
4	Stability	5	0	+	0	0	0	1	4
5	Size	0	0	–	0	0	0	-1	9
6	Durability	2	0	+	0	+	0	2	3
7		0						0	
8		0						0	
9		0						0	
		Totals	2	1	2	3			
		Rank	2	4	2	1			

Figure 3: Concept Matrix for Brainstormed Latrine Designs

Detailed Soil-Cement Mold Design

In order to decrease the cost and expertise needed for pit liner construction, a portable, reusable cement mold can be used to form the walls of a pit latrine. This design allows a cement-soil mixture to be poured around the formwork after a pit is dug, creating rigid walls that prevent the pit from collapsing during use. The design of the mold includes a hollow cylinder with thickness of 5 millimeters and a height of 0.5 meters. There will be two perpendicular struts that intersect in the middle of the mold to provide both support and resistance against lateral forces directed inward as the cement dries, and a place for constructers to grasp the mold while holding it in place. These struts will be placed at a height of half of the cylinder, 0.25 meters. In order to construct a pit latrine, a hole will be first be dug with a depth of 3 meters and a diameter 1.75 meters as the soil-cement mixture is prepared. The mold will then be placed into the bottom of the hole and cement will be poured between the outside of the mold and the walls of the hole. The mold will be left in the hole for 15 minutes to allow the concrete-soil mixture to partially cure and maintain its shape. The mold will then be lifted 0.5 meters, and more cement will be poured on top of the already drying cement. This process will be done 6 times in order to create a 3-meter hole.

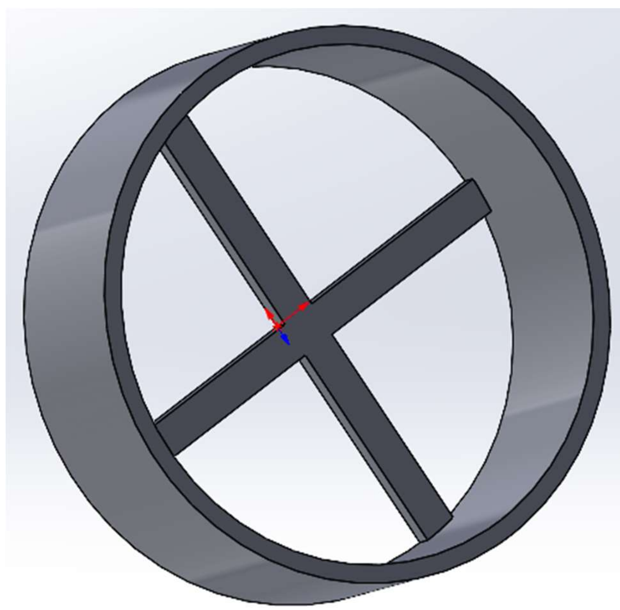


Figure 4: Top angled view of mold

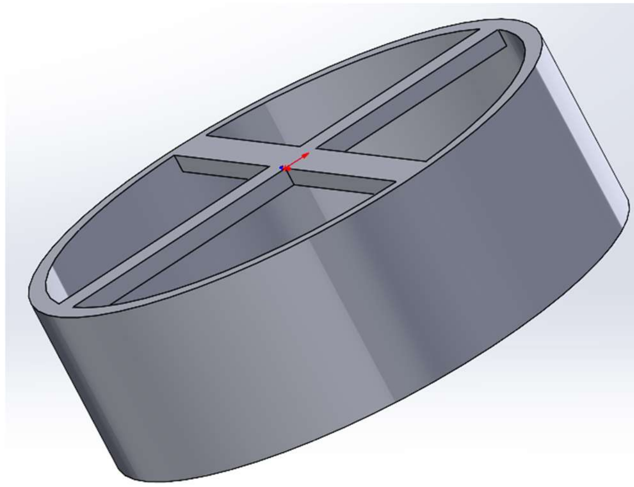


Figure 5: Side angled view of mold

Prototyping, Testing and Evaluation

Testing

To begin testing the concepts generated surrounding the prototype, the team identified subsystems that required further evaluation in order to determine the feasibility of the product. These subsystems include pit shape, pit and mold dimensions, lateral and downward forces, cement strength and concrete ratios, and the necessary thickness of concrete liner.

<u>Pit Shape:</u> The two main options for pit shape are circular or rectangular. While rectangular pits are easier to construct, circular pits are more stable because of the natural arching effect of the ground around the hole. Additionally, circular pits do not have any sharp corners to concentrate strain. Given that this product is being designed for areas with more unstable soil types wherein pit collapse is more likely, a strong pit shape is necessary to achieve durability. Therefore, it was decided that the shape of the pit, the liner, and the mold would be circular.

<u>Pit and Mold Dimensions:</u> It is usually advantageous to dig the pit as deep as possible, but this depends on soil conditions, cost of lining and the level of the groundwater. In sandier soils or areas where groundwater is high, the pit should be shallower but with more cohesive, stable soil with high compressive strength, deeper pits can safely be excavated and used. The bottom of the pit latrine should be at least 2 meters above the water table. The number of users and projected years of use should also be taken into account when designing a latrine for a certain pit lifetime. A final consideration when determining depth is that pits ought to be deep enough to leave some space of separation between the user and the waste to limit disease transmission and odor. Taking all these factors into account, a 3 meter depth will be the recommended depth for this design as it is the most common standard size used in for a single family home and is generally considered safe, even in less stable soils.

The recommended final diameter of the pit is 1.5 meters. This gives a total volume of 5.3 m^3. To determine the longevity of this pit latrine volume, assumptions were made surrounding the people per household and the waste created per person per year. For a household of 10 people whom accumulate 0.06 m of waste per person per year, the latrine will last for approximately 8 years with these dimensions. This is an acceptable pit latrine lifetime for this project. Due to the procedure of construction, the initial pit latrine hole must be dug slightly larger than the desired 1.5 meters in diameter. This is because the liner will be poured with cement from the outside of the mold to the soil wall. The desired thickness of the concrete liner is 5 inches. Therefore, the original hole dug out for the pit latrine should measure 1.75 meters in diameter.

Lateral and Downward Forces: Downward forces that will be acting upon the soil surrounding the pit latrine are unpredictable and therefore hard to determine. Previous calculations from Phase 2 show the common force impact of different variables to soil. Those are reiterated below.

$$Pressure\ (psi) = load(lbs) \div area(in^2)$$ Pressure (psi)=load(lbs)÷area(in2)

$$1\ psi = 6.89476\ kPa = 0.00689476\ MPa$$ 1 psi=6.89476 kPa=0.00689476 MPa

Table 2: Examples of Ground Pressure Exertion

Object	**Ground Pressure (MPa)**	**Ground Pressure (psi)**
Human male	0.055	8
Motorbike	0.62	90
Human in stiletto heels	3.250	471

Information gathered from: https://en.wikipedia.org/wiki/Ground_pressure

Lateral forces from soil are necessary to determine as they define the cement grade needed to ensure pit stability and prevent collapse. The horizontal effective stress is an important design component and is often expressed as a portion of the vertical effective stress using the coefficient of lateral earth pressure at rest K_0.

K_0 is correlated to the friction angle that represents failure condition as a strength parameter.

To effectively determine lateral earth pressure, an understanding of an OCR profile of the operating soil is necessary which cannot be determined without in-person testing. Assumptions were made and values were derived using established geoengineering values.

Friction angle

$\gamma = \frac{1}{2}\cdot\cos^{-1}\cdot\frac{\mu\cdot\sigma_n}{K} = \frac{1}{2}\cdot\cos^{-1} f$ (friction angle)

Loose fine sand (from table online): $\phi = 28^\circ$ - friction angle

K_0 = coefficient of lateral earth pressure at rest

$K_0 = (1-\sin\phi)\frac{1+2/3\sin\phi}{1+\sin\phi}$ where $\phi = 28^\circ$

$K_0 = .6773$

$K_{0(OC)} = K_{0(NC)}\cdot OCR^{(\sin\phi)}$

- cannot determine OCR w/out OCR profile

Based on $K_0 = .6773$,

earth pressure maximum increase = <u>73 kPa</u> (obtained from online graph)

1 MPa = 1000 kPa

The profile of the soil is operating 73 kPa = 0.73 MPa acting on all tangential points.

<u>Cement Strength and Concrete Ratios:</u>

- 32.5 MPa – strength between 32.5 (min) – 52.5 N/mm^2
- 42.5 MPa – strength between 42.5 (min) – 52.5 N/mm^2
- 52.5 MPa – strength minimum is 52.5 N/mm^2
  - Strengths after 28 days – compressive strength
  - Class N: ordinary early strength

Given the compounding effects of earth pressure, 42.5 MPa grade class N cement is necessary.

Cement grades and classes define concrete grades.

- 42.5 MPa class N strength produces grade C30 and C40 for concrete.

Mix ratios are typically defined by cement – sand – aggregate

- Acceptable ratios for grade C30 and C40 are 1:3:6 and 1:2:4

Grade 30 should be the minimum usage for the pit latrine liner. It is used for rigid pavement work (road laying).

Thickness of Concrete Liner: The minimum recommended thickness for a fully bonded concrete layer suitable for load carrying capacity is 4 – 5 inches (100 – 125 mm). Load-carrying capacity may act as a boundary for the lateral forces of the earth.

Increasing the thickness from 4 to 5 inches boosts load-carrying capacity by 50%.

It is recommended the concrete layer be 5 inches thick to withstand the lateral/downward forces from the soil.

To further investigate the team's design, two additional experiments were created to test the feasibility of the concrete mixture and the size of the mold. The experimental procedures and results are as follow.

Concrete Solidify Test:

Procedure: Obtain concrete mix and soil. Mix concrete and soil with selected ratio. Use a tin can or metal prototype to act as the mold. Pour concrete into a bucket surrounding the mold and start a timer. Every minute gently lift the mold up to determine if it has solidified to the point where it can hold its shape. When it can hold its shape, completely lift the mold, and stop the timer. Observe the concrete mix and record any dripping or sliding. Repeat the experiment lifting the mold at different times to find a close approximation for the time it takes the mixture to hold its shape

Results:

Iteration	Observations
Layer 1: 5 min solidify time	Some sliding from top edges. Slight sticking to metal mold when extracting.
Layer 2: 15 min solidify time	No sliding or dripping. Metal mold pulled out with ease and no sticking occurred.

Strut Placement Test:

Procedure: The struts will provide maximum support for the mold at 90-degree angles. Use painter's tape and a tape measure to map out a circle on the ground of the selected mold diameter. Tape down two struts perpendicularly through the circle. Have different sized individuals stand within the struts. Use a straight vertical object to ensure when standing within the structs the individual's hips, and shoulders still fit within the boundaries. If the individual cannot fit, repeat experiment, and widen the angle between the struts.

Results: the team quickly realized that a mold diameter of 1.5 meters was plenty of space for more than one individual to maneuver around within.

Evaluation

Based on research, calculations, and testing, the team made many conclusions that effect the design and final prototype. The pit will be circular with a recommended depth of 3 meters and final diameter of 1.5 meters. This means that the mold will be 1.5 meters in diameter. However, because of the technique being employed to construct the liner, the original pit will need to be excavated to be ~1.8 meters in diameter to allow room for pouring the liner. The process of construction is feasible for low-skilled workers.

The cement purchased to create the compound mixture should have a strength of 42.5 MPa, or grade 42.5N. The cement should be combined with a ratio of 1-part cement to 2-parts sand to 4-parts aggregate. This will create a concrete mixture of grade 30, which will be able to withstand lateral earth forces being applied. The thickness of the concrete layer should be a minimum of 5 inches or 0.127 meters to ensure against pit collapse, given the drastic increase in structural strength from adding an inch layer of thickness.

A metallic material works for a mold. The concrete mixture does not stick to the metallic mold if it is given an appropriate time to solidify. The mold can be easily removed, and smooth edges remain in the concrete. The time needed for the concrete to cure enough for the mold to be safely removed is at least 10-15mins.

There are many testing iterations that this design must further undergo before implementing a completed design. From proof-of-concept research, the current design meets all the major requirements for the pit latrine liner to meet the standards of the problem definition. The largest concern regarding the current design is the unpredictable nature of the lateral forces posed by varying soil types. Depending on the exactly where the pit latrine is to be built, the lateral forces can change dramatically. Without building a full-scale model, this concept is difficult to test and draw major conclusions from.

Final Prototype

The final prototype is 3D printed which is extremely useful because the exact dimensions of the design could be used. The final 3D printed prototype is useful to find areas of improvement because it was able to actually be put in a simulated hole and tested on its stability. The team found that the prototype held firm and was easily able to be lowered and lifted into the hole. Additionally, the physical and tactile presence of the prototype helped the team to realize that the interior struts may need to be rounder in order for the mold to be more ergonomic and useable.

Figure 6: Top view of 3D printed prototype

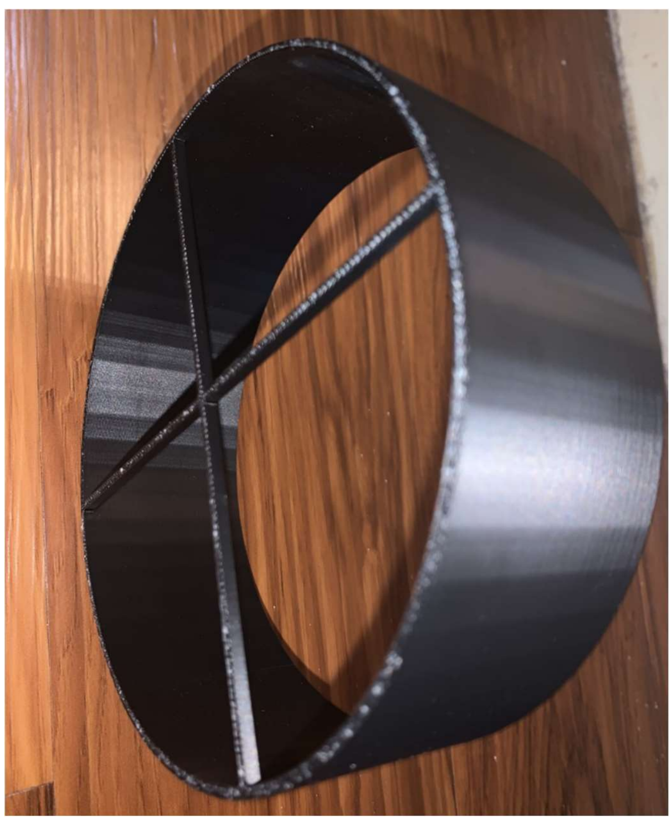


Figure 7: Side view of 3D printed prototype

Business Model Canvas

Key Partners

For this project to be successful there are many people that need to be on board. First, expert engineers are needed to check the concept, as well as explain the concept to others. Next, donors/ investors are needed to launch this design by funding manufacturing as well as compensating other partners needed for the project. In-country organizational partners such as non-profits and government agencies are needed in addition to in-country guides for in-country trips to make sure everything is safe and up to code. Lasty, but potentially most importantly, villages willing to try the product are needed in order for the team to understand its plausibility and any design flaws that will result in non-adoption of the technology.

Key Activities

Although it's easy for a company to get carried away and want to have the largest scope possible, it's important to narrow the focus by creating a business plan. As it relates to the development of this product, that includes iterative research and development for a soul-cement mold design in order to improve the design as much as possible. Before the design can be finalized and taken to market, pilot designs and in-country testing should be implemented and preformed to assure the acceptability of the product. It is also crucial to connect with non-profits and government agencies to gain in-country partners and create in-country manufacturing and distribution networks.

Key Resources

There are many resources that are crucial to the development of this design. Human resources include expert engineers and in-country partners. Money provides tangible resources that include research equipment, raw materials to construct the mold, manufacturing equipment, and transportation.

Value Propositions

The pit-latrine design creates value in many avenues. The design significantly reduces health risks which will bring value to healthcare systems. Since the design includes an easily reciprocated product, locals can be trained to reuse the mold in multiple locations. This allows microbusinesses to emerge that can use the cement mold method as a source of income. Additionally, having a functional pit-latrine will save residents time in the day from walking to use the bathroom.

Customer Relationships

The relationships a company establishes with its customers and relations partners contribute heavily to the success and long-term viability of the business. In order to build a trustworthy company, it's crucial to have more than just a selling and buying relationship, but rather a partnership with a feedback aspect. It is crucial to build rapport, check in, visit/ interview, and provide maintenance for and with end-users. It is additionally important to make sure distributors are satisfied and upholding agreed upon term through maintaining frequent connection. With Design Outreach/ other non-profits regular updates on progress will be required which requires consistent communication. Relationships built with DO and Non-profit organizations will be vital to maintain due to their ability to assist with achieving wide product acceptability and distribution. It is the intention of the creators of this product to touch base often with the Ministry of Health and other relative regulatory government offices to facilitate clear communication on facts, impacts, and team intentions.

Channels

Strong communication is imperative for a company in order to establish strong relationships. In order to generative investment income, the company will reach out to potential investors via email to provide them an opportunity to hear the team's business pitch. For non-profit customers, such as Design Outreach, seminars/ conferences will be held, in addition to reaching out via email about presentations. Given that countries differ widely in terms of which modes of advertising are effective, the channel of communication will differ based on the location of diffusion. For end users in Ghana, communication will revolve around travelling acting groups sharing how to use the product as well as the product's benefits; additional communication channels include word of mouth and billboards in main cities. For donors there will be emails and online advertising. For government officials there will be phone calls, emails, and visits.

Customer Segments

The team aspires to gain a clientele including but not limited to Design Outreach, end users, Ministry of Health (regulatory government offices), other non-profits, and in-country stores/shops.

Cost Structure

The costs incurred will include monitoring and evaluation as well as raw materials, manufacturing costs, advertising costs, testing and R&D costs, as well as distributing/shipping costs.

Revenue Streams

The revenue streams derive from investors, donors, end-users, and shops/stores that will stock the product (distributors). The viability of the business will depend on having a positive revenue stream after three years of product launch.

Roadmap

YEAR		
JANUARY	**FEBRUARY**	**MARCH**
Initial Research and Testing	Initial Research and Testing	Procurement of initial donor funding Establishment of community partner for testing
APRIL	**MAY**	**JUNE**
In-country testing with community partner	Further R&D based on results from in-country testing	Finalizing of product Establishment of supplier/manufacturer partnerships
JULY	**AUGUST**	**SEPTEMBER**
Procurement of initial implementation funding Establishment of distributor relationships/ in-country employees	Initial implementation/ market roll-out of product - Limited to Ghana	Needs assessment for scaling up Analysis of implementation mechanisms
OCTOBER	**NOVEMBER**	**DECEMBER**
Development of strategic mass-marketing & scaling plan	Procurement of funding from investors/donors for scaling	Establishment of cross-country business partnerships and/or plan for the creation of production facilities

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Resource Assessment

The resource assessment has been conducted by separating needs into phases. The phases considered include planning/design, during which the overall design of the product is explored and prototyped; community testing, during which prototypes are tested in community for functionality and community acceptance; product development, during which the iterative design process is implemented and any necessary changes to the product design are integrated; manufacturing, within which the product is manufactured at a rate necessary to meet expected initial distribution; distribution, which involves establishing a mechanism to distribute the product to clients (to include last mile distribution); and post-implementation testing, during which testing will be conducted after implementation to ensure the product is working as it should.

Planning/Design

- Time/Money: research, prototyping, initial testing
- Expert Engineers

Community Testing

- Community partnership in-country
- NGO partnership/Donors
- Money: travel expenses
- Expert engineers
- Community development practitioners (necessary if language/cultural barrier is significant and engineers cannot fill this role)

Product Development

- time/money: adjustments to design
- Expert engineers

Manufacturing

- Donors
- Business partnerships in-country for:
    - Cement
    - Customized metal framework

Distribution

- Transportation: hire local employees to distribute product
- Business partnerships in-country with local markets and stores
- Local masonry experts/concrete mixers for latrine construction

Post-implementation testing

- time/money: travel expenses
- Community partners/users willing to give feedback

The biggest identified resource gaps include community partners willing to test the product prior to product dissemination and donors/NGOs willing to financially support the development of the soil-cement pit latrine model. Additional partnerships need to be established with local businesses to ensure manufacturing and distribution needs can be met. There is potential that local masonry experts and concrete mixers will need to be hired in order to provide customers with the option to have their pit latrine constructed for them.

Partnerships to Build

The partnerships to build, established in the key partners section, include expert engineers, donors and investors, in-country organizational partners, and community partners or villages. It is necessary to first assemble a secondary engineering team capable of cross-checking the validity of our design and design process. There is potential to collaborate with Design Outreach to fulfill this need, given their humanitarian engineering experience and success and the connections of team members to members of the Design Outreach firm. Initial product testing will require an in-country community partner set in Ghana due to the tailoring of the initial pit latrine mold design to this country. Due to Ohio State's partnerships with numerous communities in Ghana through service-learning trips, the team may take advantage of established connections by contacting the humanitarian engineering department at the university. It is additionally necessary to acquire funding for travel and testing, which will require the support of donors and/or non-governmental organizations (NGOs). The team should look to partner with NGOs specializing in humanitarian sanitation efforts. Potential examples for collaboration include the Centre for Affordable Water and Sanitation Technology (CAWST), PSI: WASH, and CARE. The team meets the parameters necessary to apply for Elrha's Humanitarian Innovation Fund, which supports organizations and individuals to expand and share innovative and scalable solutions to challenges facing effective humanitarian assistance. The aforementioned constitute immediate needs to further development.

Upon receiving funding and implementing testing, the team will need to establish in-country suppliers capable of supporting manufacturing and distribution needs. It is not expected that this will be necessary until 1 to 2 years after testing. Partnerships should be formed with Dagote Cement, which is the largest cement supplier and distributor in Central Africa and has operations in ten African countries, providing an ease in transition upon scaling of distribution. There is a need to find a company capable of producing and/or repairing metal molds in-country. The leading East and Central Africa steel production company is Zenith Steel. However, this company specializes in structural steelwork, and it is currently unknown whether they have the production capabilities to produce the mold designed by the team. Steel-work manufacturers may need to be explored while in-country. The final key partnership to build is that of a network of local employees. Employees hired by the team will have the responsibilities of last-mile distribution of molds (if necessary) and pit latrine construction (if requested by user). Multiple partnerships will later need to be established with local businesses such that the product can be sold in markets.

User Manuals and Training Plan

User Manual: Given the simplicity of both the design of the mold and construction of the pit latrine with the pit latrine liner mold, the user manual itself will be simple. In order to overcome potential barriers of literacy and language, the manual will feature mainly pictures capable of completely demonstrating the methodology to be used for construction. Captions to pictures may be included in local languages. The user manual will appropriately reflect the users it is intended for, and therefore the first model of the manual will feature pictures of individuals from our community testing partnership in Ghana. Pictures of individuals will not be featured without their consent. The manual will be printed on paper and laminated to avoid barriers to technology, reduce the cost of user-manual production, and increase the durability of the manual. The pictures below outline the basic steps of what will be included in the manual. More research needs to be conducted to ensure that all images, symbols, and colors used in the final draft of the user manual are considered culturally appropriate by the end users.

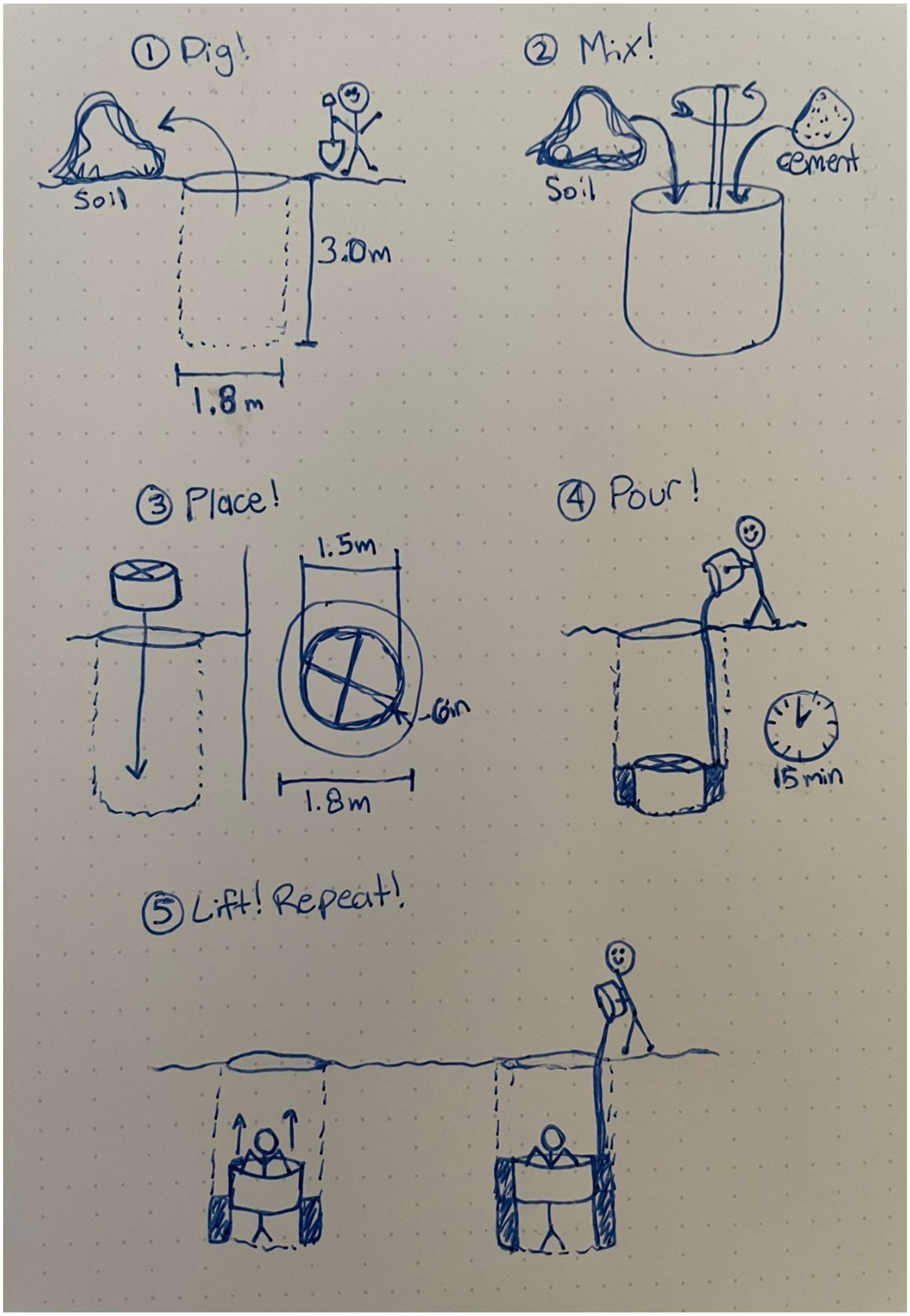

Figure 8: Example User Manual

Training Plan: Initial trainings for prototype testing will be conducted by the engineering team in-country with community partners. User manuals will be distributed. There is no need for an initial robust training plan, as individuals should be capable of performing pit latrine construction based on the information provided in the user manual.

Upon product expansion and scalability, a team of in-country employees will need to be hired in order to assist with pit latrine construction when necessary/requested by customers. Employees with backgrounds in construction and/or masonry will be sought out. Employees will require initial training consisting of constructing a pit latrine in the field with an experienced partner first. After successfully completing the construction of a pit latrine, employees will be provided with the user manual in case instructions are forgotten. The previous experience of employees in the realm of construction will prevent the majority of potential mishaps, due to the simplicity of the design of the pit latrine liner mold. Employees will be given a steel mold that can be reused and will receive cement from the key partnership established with Dagote Cement. Yearly optional training will be offered in the event that employees need a hands-on training refresher course.

Proposed Business Structure and Funding

There are multiple phases of development that the business must go through to reach substantial growth, and the financial investments needed will increase with each phase. Initial investments of $5000 will constitute enough financial leeway for the team to conduct research, product prototyping, and simple tests, which describes the initial design stage. Initial investments may be supported by university grants, research funding, and direct team member contributions.

The team will then require funding for further testing in-country and research and development. Two weeks of travel will initially be needed to construct and test the product, with monthly follow-up evaluations being recommended after implementation. All-inclusive travel costs to Ghana for a team of 4 for two weeks will be around 12,500 USD. An investment of $25,000 during the in-testing and R&D phase will fully support incurrent costs. This phase will require investments from donors and/or NGOs.

The implementation phase will result in manufacturing and distribution costs. Initial implementation is expected to be limited to villages in Ghana. The goal of initial implementation is to expand from product use in one village to product use in a minimum of 20 villages. Manufacturing costs for the pit latrine liner mold and materials include the direct materials cost of 9.39 USD per liner. The cost of producing the steel mold is currently unknown due to its need for customization but expected to be under a dollar once the price is distributed over multiple customers due to the reusability of the mold. It is expected that 1,000 pit latrine liners will be constructed during initial implementation, requiring that 10,000 USD be invested in order to meet production needs. Marking up material costs to $13 per pit latrine provides a profit line of $3.61 per liner materials distributed, while still keeping the product affordable. This results in a total of 12,610 USD of return profit, such that end-users will cover production costs. Additional funds from donors/NGOs will be needed to supplement salaries for expert engineers and local team members hired for pit latrine materials distribution and construction.

The final phase of production is scaling. It is expected that product expansion will occur first in Central Africa, with the goal of later expanding into India and South East Asia. This phase will require entering into partnerships with cement suppliers, steel manufacturers, and distributors. The firm will need to employ locals in every distributing country for the construction of pit latrines. An estimated 500,000 USD investment will be necessary to achieve economies of scale. This investment will be partially funded through contracts with distributors and profits for end-users. The remaining sum will need to be garnished from donors, investors, and/or NGOs.

Conclusions and Recommendations

The team's soil-cement pit-latrine liner mold design will offer a safe waste-disposal mechanism for a 10-person household for over 8 years. This longevity can be increased further with the addition of chemical and biological additives that expedite the decomposition process of waste. The simplicity of this solution creates accessibility for individuals, as advanced knowledge of masonry or concrete-work is not needed for construction. The soil-cement mold is also cost-effective. The average price of construction is $9.39 USD; comparatively, the average cost of pit latrine construction in West Africa ranges from $15 to $25 USD. Furthermore, this product has income generation potential because customers of the mold can provide pit latrine construction services to neighbors and nearby villages in need of latrines. Since the mold is made of metal, it can be reused to build other pit latrines once the original one is filled, which removes additional cost associations and promotes sustainability. By locally sourcing cement and utilizing already dug-up, local soil, the soil-cement mixture being used results in a durable and safe pit latrine liner. Through testing and evaluation, the team has proved that the soil-cement mixture is strong enough to withstand the lateral soil forces that cause many unlined pit latrines to collapse.

The Pit Latrine Liner Mold is a simple yet effective design. This design should be deployed because it is effective, safe, and cheap. Since this mold is easy to use, the people needing a pit latrine can implement it themselves. This mold has the potential to change the lives of millions of people not only because of the pit latrine itself but also because of the economic growth it can cause.

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