SquatPot

Squatting Container-Based Toilet

For re.source sanitation

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Abstract

We were tasked with creating a container-based toilet design for users in rural Bangladesh. In Bangladesh, toilet users squat rather than sit, and use water for anal cleansing instead of toilet tissue. Our design adapts the traditional squatting toilet to allow for separation of liquid and solid waste streams by introducing a user-controlled lever mechanism. During urination and defecation, the lever remains down in the “open” position, allowing feces to remain separate and as dry as possible; when the user prepares to wash after defecation, he or she must pull the lever, triggering a flap which rises to cover the feces hole at the back of the squat plate. This allows for wash water to be diverted into the fluid hole at the front of the squat plate and into a biosand filter to be decontaminated.

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Introduction

We partnered with re.source, an organization that strives to deliver hygienic and aspirational sanitation service to some of the poorest urban households on the planet. Re.source recovers resources from waste to finance the delivery of in-home sanitation services which include household container-based toilets and a weekly waste collection service. Re.source targets extremely poor populations of people who live in urban settings, where sanitation and hygiene especially from human waste have tremendous scope for improvement. In previous work, re.source has implemented successful pilot programs of their container-based toilets and waste recovery systems in Haiti, a country where people use toilet paper to clean and sit on Western- style toilets. Re.source is now adapting their current toilet design for use in populations that squat rather than sit and use water for anal cleansing rather than wiping with toilet paper, a common sanitation practice in many parts of the world. Re.source is conducting a pilot study this summer in an urban slum in Bangladesh, which has a “squatting” and “washing” population. We were tasked with designing one of three squatting toilets to be used in this month-long trial period.

Due to the different sanitation practices in Bangladesh, the toilet design had to be modified significantly from what was previously implemented in Haiti. One of the main design constraints of a container-based toilet is to keep feces dry, because this makes the disposing and processing significantly easier. Dry feces are easier for waste collection services to transport and can be more cheaply transformed into fertilizer pellets or burned for energy production. The sitting toilets in Haiti use a very simple urine diverter to separate feces and urine, but managing squatting toilets’ pathogen-contaminated anal wash water adds an additional layer of complexity.

Our objective was to design a cost-efficient squat toilet that can divert feces, urine, and wash water in a manner that keeps feces dry for efficient processing and minimizes pathogen contamination.

In prior work on this project, we determined the best waste-management solution is to divert both urine and pathogen-contaminated wash water into a biosand filter. The biosand filter can be contained in a bucket underneath the squat pan, with a sieve at the bottom allowing the filtered liquid to infiltrate into the ground. Feces can be handled in the same manner as is currently done in Haiti, which involves dry storage in a second sealable bucket beneath the squat pan, which is collected weekly for processing. *Our primary goal was to design a mechanism for separating urine and wash water from feces that is aesthetically pleasing and requires minimal behavior change from users.*

Design Goals

Separate solid and liquid waste: As explained above, the key functionality requirement of our design is to separate liquid and solid waste. This means designing a mechanism that blocks or seals the squat pan's feces hole during washing and urinating, but allows it to be easily reopened for defecating.

Ease of use: In order to promote adoption of the toilet, it is important for our design to be very easy to use and require minimal user behavior change. In prior work on this project, we determined that it is best for the design to not require any moving or standing during use, in an effort to not disrupt users' current washing routines. This will lead to a design that is far more convenient and requires significantly less behavior change than any existing liquid diverting squatting sanitation solutions.

Aesthetically pleasing; Aspirational: In trials in Haiti, re.source found that aesthetics were very important in encouraging continued use of the toilet. The toilets resembled flushing porcelain toilets, and this resemblance to what was considered a luxury item added an aspirational quality to the product. This was a large factor in encouraging adoption. To achieve a similar effect with our squat toilet, we designed the plastic squat pan to resemble a porcelain squatting toilet. We designed and vacuum formed the squat pan in prior work on the project, and our mechanism designs need to be integrated with the existing squat pan design. Additionally, the mechanism should also strive to be aesthetically pleasing.

Ease of manufacturing and assembly, low cost: As a product intended for the developing world, costs should be kept as low as possible, and manufacturing should ideally rely primarily on processes that can be easily replicated abroad. The product will be manufactured in parts at Stanford and then shipped to Bangladesh and assembled there, so easy breakdown and reassembly is key. To conserve space in shipping, the toilet's outer housing (the frame) will be constructed on-site and will be customized to the particular site. As such, our mechanism should be designed to work with a range of housing materials and configurations, including both a large box that sits above ground and houses the waste containment buckets, and a flat frame that sits flush with the ground and requires waste containment buckets to be beneath ground.

Durable, repairable: The final product will serve as one of three squatting toilets for approximately one hundred slum inhabitants during a month-long user testing trial period. Toilet repair is included in the waste management service. Given this, wear and tear considerations are especially important. The design should be durable, and individual parts should be easily duplicated and replaceable to extend the toilet's life far beyond that of an individual part.

Approaches Considered

We considered three potential design approaches for separating solid and liquid waste and prototyped each before selecting a final design to pursue for our high-fidelity product. We referred to the three different designs as the "Lever," "Slider," and "Frying Pan," and each is explained in more detail below.

The Lever

Figure 1: The Lever prototype, in the "closed" position (left) and "open" position (right).

The Lever design features a plug attached to an axle that rotates. Both the plug and axle are beneath the squat pan, and one end of the axle is attached to a lever that comes up through a slot in the frame. The user can pull the lever while squatting, which rotates the axle and causes the plug to swing upwards and seal the feces hole, preventing wash water from falling through. The lever will usually be in the sealed position. The user can squat, urinate, move the lever to the open position before defecating, and then move the lever back to the closed position before washing.

We prototyped this concept in wood as shown in Figure 1 above. We experimented with multiple options for the sealing “plug,” including an upside down round silicone bowl (pictured in Figures 1 and 2), a tapered rubber plug, and a wooden flap with a gasket. We found that each worked reasonably well, but that the silicone bowl worked the best. Consistent and extensive use during the summer pilot program might lead to slight variations in the seal’s alignment. The silicone bowl offered the most forgiving fit, as its domed shape enabled a water-tight seal even with slightly varying orientations. In a higher-fidelity iteration of the Lever, we planned to cast our own flatter, domed silicone plug to seal the final product.

We anticipated that the Lever design would also require a locking mechanism to keep the lever and plug in the sealed position. We identified many potential locking mechanisms, including using magnets, lining lever’s slot with silicone at the point of sealing to require more force to push/pull the handle in/out of locking position, putting a weight at the top of the lever handle to hold the seal in place using gravity, and shaping the plug so that it holds itself in place, eg. with a groove that fits around the edge of the feces hole. We found that the silicone plug in our prototype remained in place without a locking mechanism, and anticipated that if our final design did require a locking mechanism, a weight at the end of the lever’s handle would be sufficient.

The Slider

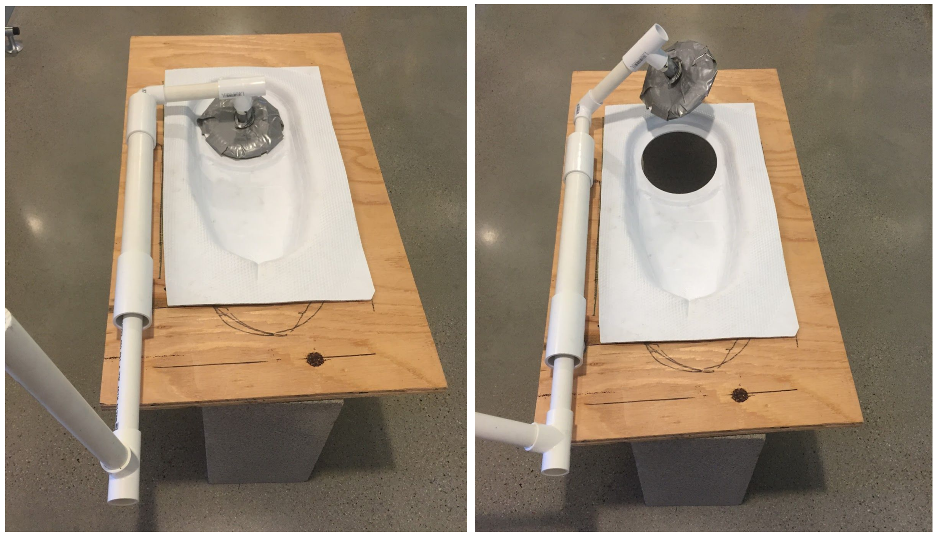

Figure 2: The Slider prototype, in the "closed" position (left) and "open" position (right).

The Slider design features a mechanical seal attached to a "slider" that pivots and slides back and forth in an outer sheath. The mechanical seal uses only the force of gravity, which will likely result in less wear and tear than the Lever's plug. The slider allows the user to pivot and slide the mechanical seal backwards off of the feces hole before defecating, and then slide it forwards again to cover the feces hole before washing. Unlike the Lever, the Slider's mechanism is above the frame, and is visible to the user.

We prototyped this concept using wood and PVC as shown in Figure 2 above. We experimented with multiple options for the mechanical seal, including a reversed plug (pictured in Figure 2), a collar with a lid (pictured in Figure 3 below left), and a collar with a slightly larger lid that only has a lip on the back side to allow the lid to slide back without needing to be pivoted upwards (pictured in Figure 3 below right). The second two options provided the most consistent seal. The lid completely covers the feces hole, preventing wash water from falling into the hole, while the collar prevents wash water from slipping under the lid into the hole. In a higher-fidelity iteration of the Slider, we planned to 3D-print a collar and lid with an attachment to easily secure the lid to the end of the slider.

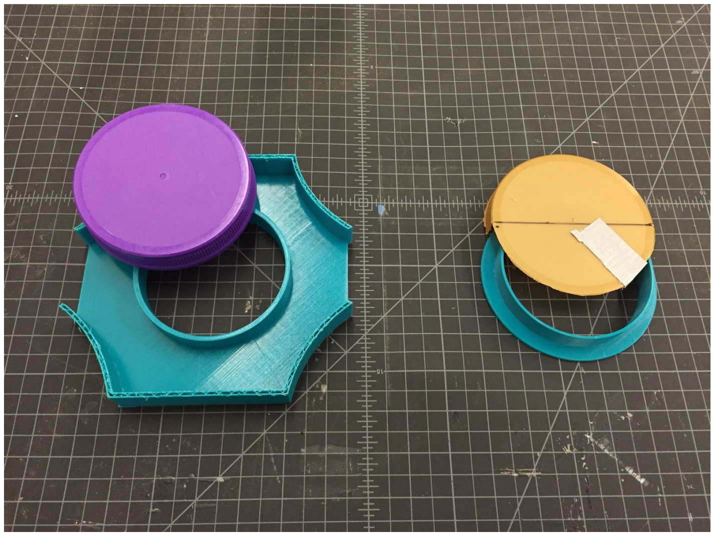

Figure 3: Mechanical seals: collar with full lid (left) and collar with half lid (right).

The Frying Pan

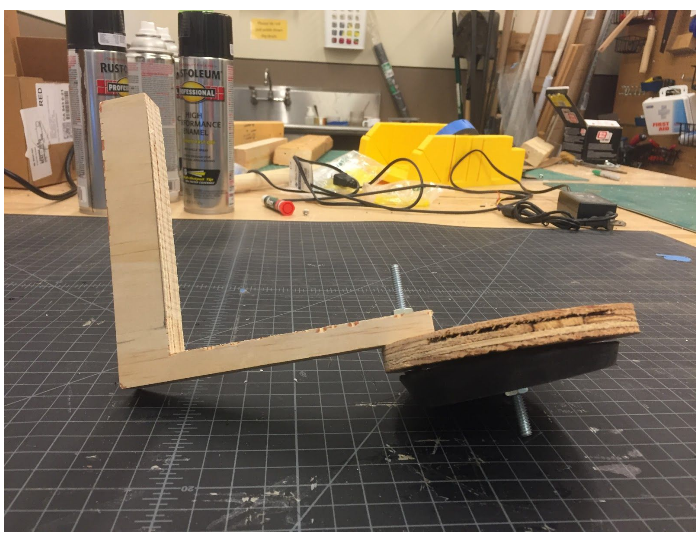

Figure 4: The Frying Pan prototype.

The Frying Pan design is a simplified version of either the lever or the slider. It features either a plug or a mechanical seal, but instead of using a mechanism to place the seal over the feces hole, the user simply puts the seal in place by hand using a handle attached to the seal. The design includes a leash that connects the seal/handle to the toilet platform to eliminate the risk of it getting lost. We prototyped this design using wood and a rubber plug seal, pictured in Figure 4 above. In a higher-fidelity iteration of the Frying Pan, we would 3D-print an ergonomic handle and an attachment to easily secure the handle to the seal.

We felt this concept was important to consider as it is significantly simpler than the other two options. It would be easier to manufacture at scale and would pose less risk of failure in the field. However, it has a significant usability challenge in that users would have to touch the handle to position the seal, which may come in contact with contaminated wash water or urine. This potential for discomfort and disgust in handling the frying pan is an important consideration. Additionally, maneuvering the seal into the feces hole using the handle may be difficult to do without moving or standing up, which violates one of our key design goals. During prototyping, we found it somewhat difficult to hold a squat while maneuvering the lid. However, this result may not be reflective of our users' attitudes and capabilities, as we are not practiced squatters.

A number of different handle shapes and locations could be explored to both promote ease of maneuvering and minimize the handle's contact with wash water and urine. We identified a designated lid resting location during user defecation as a means of alleviating some discomfort with handling the lid. Users could store the lid in a circular depression at the back of the toilet, which would contain the contaminated lid to a single area and reduce ambiguity as to what users should do with the lid while defecating, making its use more intuitive. The Frying Pan concept is similar to some non-diverting pit squat toilets currently in use in many parts of the world, which led us to think some users may be more comfortable with the design than we would otherwise anticipate.

Final Design Approach: The Lever

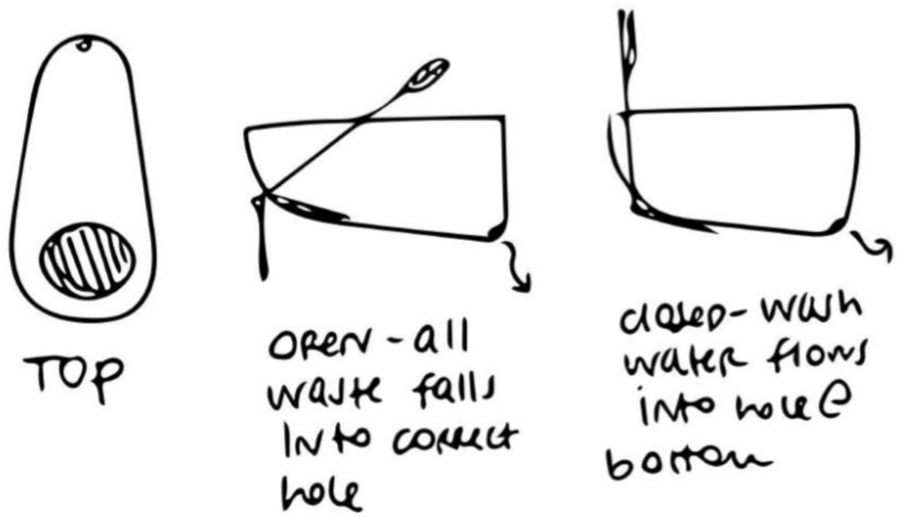

Figure 5: A conceptual explanation of the lever concept: Open - all waste falls into correct hole; Closed - wash water flows into hole at bottom.

After testing the prototypes described in the preceding section, we arrived at the following evaluation of each approach. We were surprised to find that each prototype achieved our primary design goal of effectively sealing the feces hole. The Lever is the most aesthetically pleasing design, and its relatively simple mechanism doesn’t require any amount of maneuvering precision from the user. The silicone plug may wear out over time, but is easily replaceable. The Slider’s sealing mechanism is more durable and does not require force to be held in place, but the design is overall less aesthetically pleasing. Its seal would also likely require 3D-printing to manufacture, which is expensive and difficult to scale. The Frying Pan is cheapest and easiest to manufacture and poses the lowest durability risk, but is a significantly less elegant design with regard to human factors, and is also less aesthetically pleasing.

Based on the evaluation outlined above, we decided to move forward with the Lever as our final high-fidelity SquatPot. Our primary motivation was that based on re.source's work in Haiti, the aspirational design goal is very important for encouraging users to adopt the toilet, and the Lever's aesthetic is closest to that of a porcelain squat toilet. The lever design is intuitive, and in housing the mechanics below the toilet platform users interface only with the handle opening and closing the silicone seal, which mimics a luxury toilet user's primary interaction with the toilet's flushing lever. As described in the preceding section and pictured in Figures 6 and 7, the final design features a domed silicone-casted seal attached to a lever mechanism that locks in place using a top-weighted handle. The lever axle is positioned in the middle of the squat pan so that the handle is easily accessible from a squat in both the open and closed positions. Each part is described in more detail below, and detailed drawings can be found in Appendix A.

Figure 6: The SquatPot in the open position (left) and closed position (right).

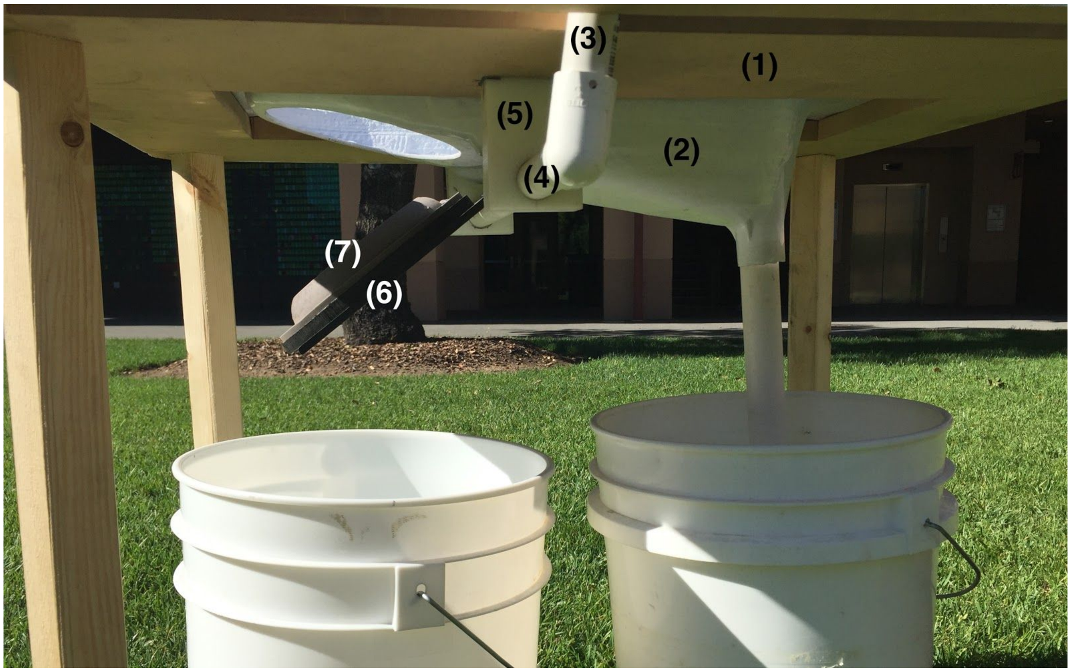

Figure 7: The SquatPot with individual parts labeled.

The SquatPot is made primarily from plastic and PVC, which we chose for its durability, resistance to water and corrosion, and ease of cleaning. It is comprised of seven main parts, numbered correspondingly in Figure 7 above: (1) the frame, (2) the pan, (3) the handle, (4) the axle, (5) the anchors, (6) the flap, and (7) the plug. The frame can be made from whatever material is readily available (the frame we built to demonstrate functionality is made from wood). The pan is made from vacuum-formed Styrene with a reusable mold that was made out of wood on the ShopBot, a wood CNC router. The handle is PVC, and attaches to the axle with a PVC elbow. A 6" steel rod is secured inside the tip of the handle with a screw as a locking mechanism (the additional weight in the handle holds the lever in place). The axle, anchors, and flap are made from Delrin. The axle is turned down at the ends to fit snugly into the PVC elbow, and is milled flat in the center so that the flap can be attached securely with screws. The plug is cast silicone, which was made with a reusable 3D-printed mold, pictured in Figure 8 below. We prototyped the custom shape with model magic, and went through two iterations of printing and casting before arriving at the final shape, all of which are pictured in Figure 8. The final shape is hollow to conserve silicone material and reduce cost, and features a flat outer ring with holes for screws to ensure a secure attachment to the flap.

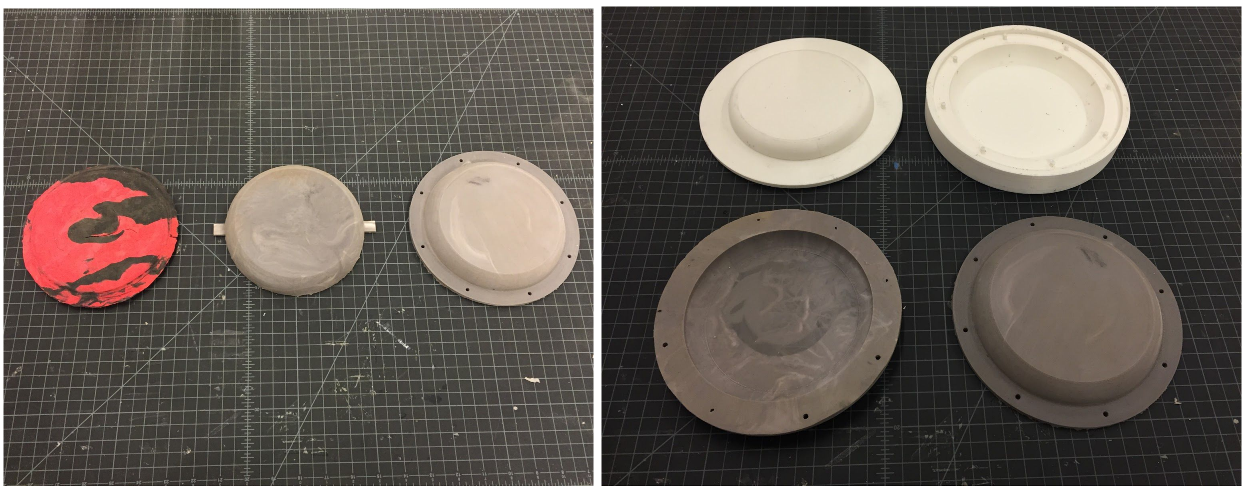

Figure 8: Prototyping seal shape (left), final seal and 3D printed mold (right).

The SquatPot's screw-based assembly allows for easy breakdown and reassembly, important for product shipment and transportation to urban slums. The modular assembly enables re.source's envisioned distribution model of shipping lever mechanism parts from Stanford to field sites, where hired labor can assemble the mechanism and attach it to a frame constructed on-site from locally available wood or another cheap alternative. The use of PVC piping, which is locally available in Bangladeshi markets, reduces the number of parts that need to be shipped from abroad and enables cheaper, locally-sourced maintenance. Additionally, the screw-based assembly reduces maintenance costs by enabling replacement of individual mechanism parts instead of the whole mechanism.

The SquatPot costs $100.64, with an additional $89.43 in initial overhead for the reusable 3D-printed silicone mold (see Bill of Materials in Appendix B). This price tag is reasonable for the project's current scale and level of funding. It is also relatively simple to manufacture. With the exception of the axle and squat pan, all parts can be purchased or built by hand using common power tools. A mill is required to flatten the axle, but in the absence of a machine shop an alternative solution could likely be found. The squat pan requires vacuum forming, which is difficult to replace with an alternative process. However, the sitting toilets in Haiti also require a vacuum-formed part (the urine diverter), and in the initial trials the parts all were manufactured in Stanford's Product Realization Lab and shipped to Haiti. In the future, manufacturing for both toilets can be streamlined with scale, allowing for a cheaper product and faster manufacturing times.

Evaluation of Approach

The SquatPot seems to achieve our design goals outlined previously quite well. Most importantly, it seals reliably. Our testing of the seal is pictured in Figure 9, and Figure 10 shows that the part of the plug below the seal is completely dry. It is easy to use, it resembles an aspirational porcelain squat toilet, it is relatively inexpensive and easy to manufacture, and its parts are durable and easily repairable. Of all of these design goals, it seems the aspirational quality is the least effectively achieved. The Lever design was the most aesthetically pleasing of the concepts we considered, but nevertheless it is difficult to convincingly mimic a porcelain toilet with low-cost materials and manufacturing processes.

Based on prior research, we know that users will want to cover the feces hole while washing and urinating to distance themselves from the feces and minimize odor. We therefore think it's likely that this toilet will be used correctly; users are incentivized to cover the feces hole while washing, decreasing the likeliness that we will run into the issue of user non-compliance.

Of course, the ultimate test for each design goal will be when the product is used with high volume in the field by seasoned squatters. We may find that it wears down or breaks far too quickly after continued use, that it is not intuitive to use for experienced squatters, that it requires too much behavior change, or that it is not aesthetically pleasing enough to encourage continued use.

Figure 9: Testing the SquatPot's seal.

Figure 10: The seal works very well, as evident by the dry area below where the plug interfaces with the edge of the feces hole.

Recommended Future Work

Squat pan: The current squat pan has a flattened section around the feces hole which creates a ledge on the underside of the basin. This ledge prevents the flap from sitting flush with the feces hole. This ledge is not required for the squat pan's functionality, and could instead be smoothed into a continuous decline. With a continuous decline, the lever flap could rest flush against the feces hole, reducing the thickness of the plug and flap required to seal the feces hole, thus reducing the product's weight and cost. For these reasons, we recommend re-forming the squat pan to remove this ledge. The ledge is pictured in Figure 11 below.

Figure 11: The ledge at the back of the squat pan prevents the flap from sitting flush with the feces hole.

Lever axle: To counter increased internal moments on the lever axle and flap due to the thicker, heavier flap required to bring the plug flush with the feces hole, we constructed the lever axle out of a solid Delrin tube instead of a hollow PVC pipe. However, if the ledge described above is eliminated, hollow PVC tubing may be enough to support the resulting lighter flap. We recommend investigating this option, as PVC is a cheaper material readily available in local Bangladeshi markets and is therefore preferable to Delrin. A thicker PVC pipe may also be more durable than the current Delrin axle, and could potentially withstand more wear and tear.

Cover material dispensing: Container-based toilets often utilize cover material (usually sawdust) to trap feces odors and keep away flies. Users are expected to dump a cup of cover material into the feces hole after defecating, in lieu of when one would normally flush. The current toilet design requires multiple user behavior changes: activating and deactivating the seal, and then also adding cover material after defecation. The most successful product will require the fewest behavioral changes. A future toilet design could incorporate a mechanism that automatically adds an appropriate amount of cover material after defecation. This mechanism could be mechanically coupled with the lever mechanism to time cover material release with the opening and closing of the feces hole. In combining these two steps into a single behavioral change, users are more likely to adopt behavioral changes needed to effectively use the toilet.

Adapt to field testing: After evaluating the SquatPot in the field and assessing how well it achieves our outlined design goals after continued use, we recommend adapting the design to better achieve any lacking functionality or aesthetics. It is difficult to predict what improvements will be necessary prior to field testing, but we anticipate that the aesthetics of the silicone plug may be a concern, along with its durability and the durability of the axle, as those parts are subject to the most stress during use. We recommend future work in experimenting with ways to strengthen both the axle and silicone plug, which could include investigating alternative shapes that may better handle repeated stress.

To improve aesthetics, we recommend experimenting with different colors of silicone for the plug, and potentially making the design even flatter. We also recommend that the frame built on-site be constructed with aesthetics in mind, so that the complete squat pan and frame assembly appears luxurious. Additionally, we recommend further investigating the Slider and Frying Pan as alternative design options, and potentially also taking those to a higher fidelity to be able to incorporate in field testing as well, and compare and contrast the different designs more accurately.

Conclusion

The SquatPot was quite successful in accomplishing our design goals. After thoroughly evaluating three potential design directions, we are confident that our final design is well-suited to the project's goals, and are very pleased with the result. The SquatPot is a cost-efficient squat toilet that effectively separates urine and wash water from feces, is relatively aesthetically pleasing, and requires minimal behavior change from users.

Appendices

Appendix A: Part Drawings

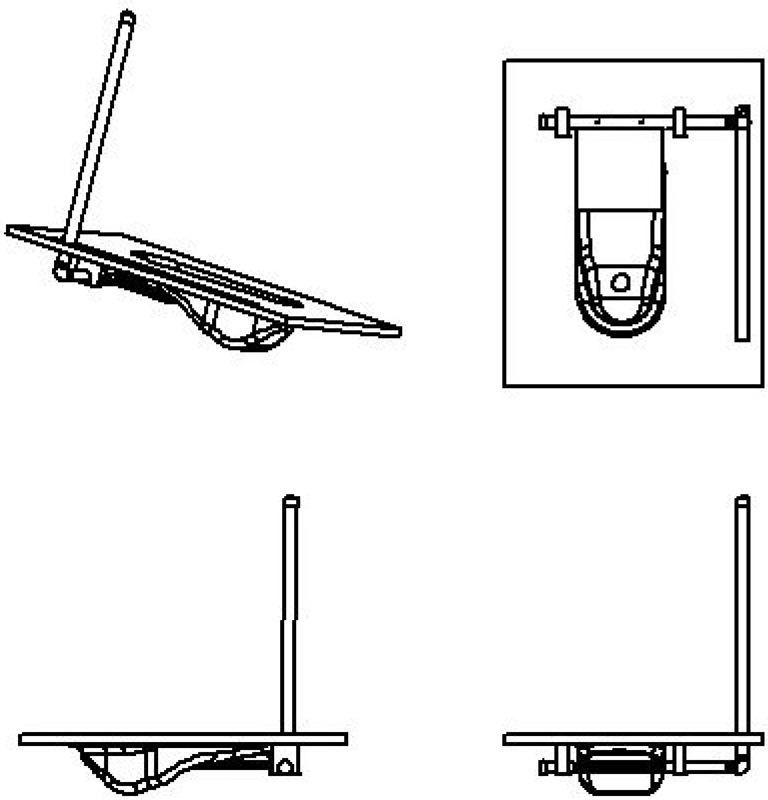

Figure A1: Pan, frame, and lever mechanism assembly drawing. From left to right, top to bottom: iso, bottom, left, back.

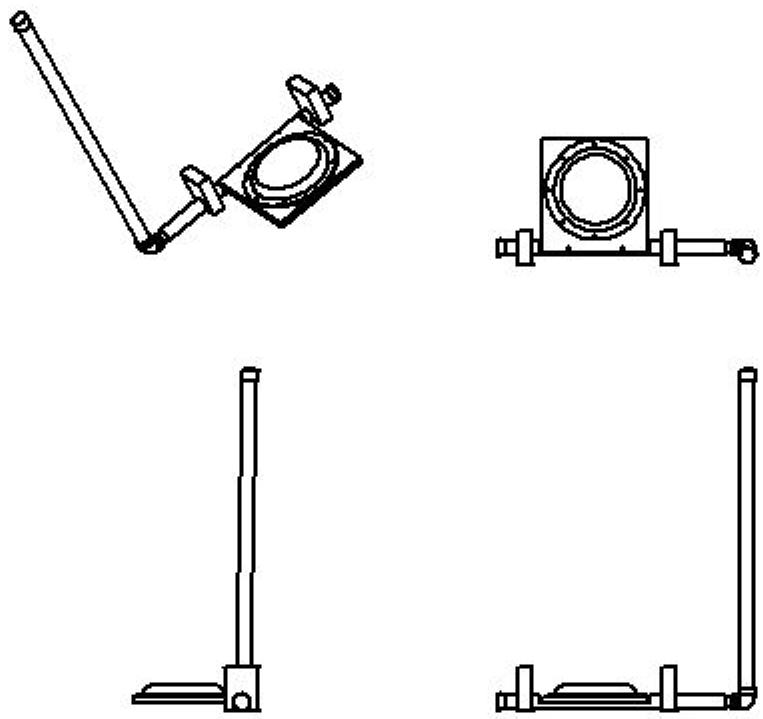

Figure A2: Mechanism assembly drawing. From left to right, top to bottom: iso, top, left, back.

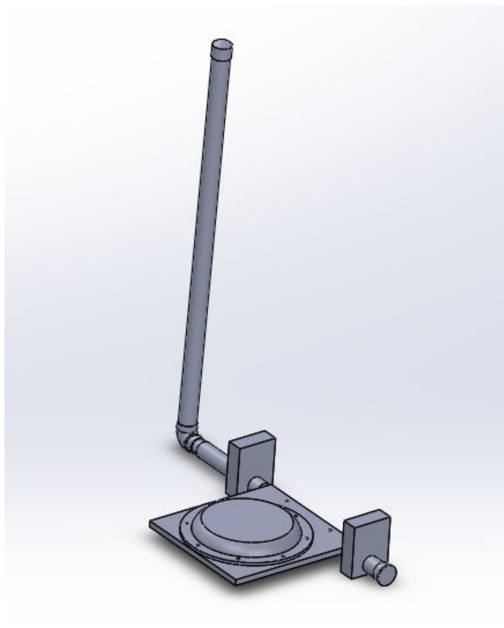

Figure A3: Mechanism assembly model.

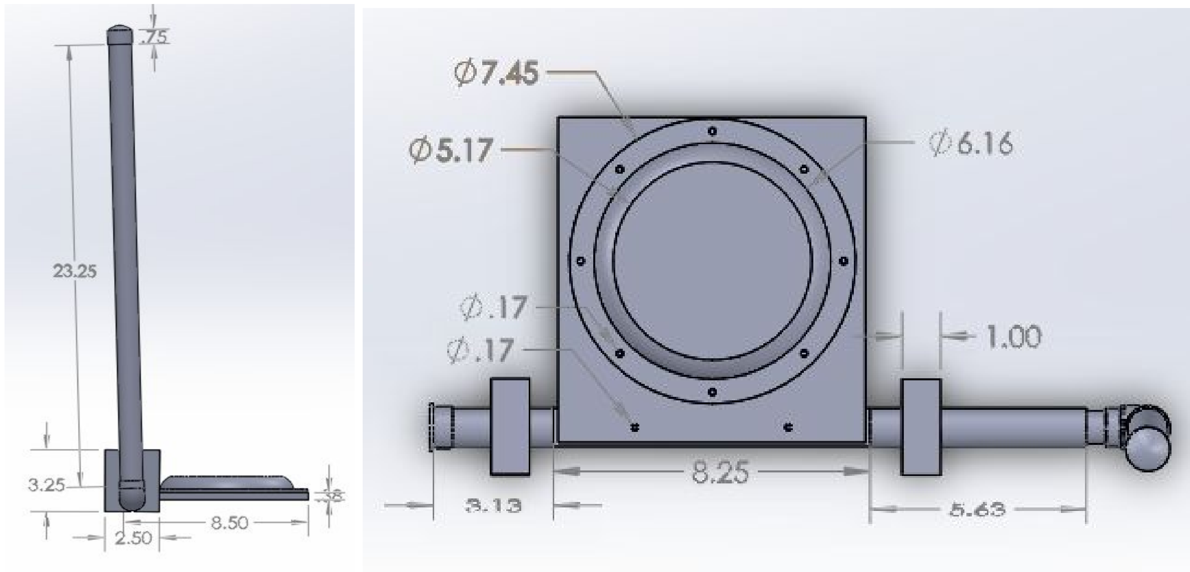

Figure A4: Mechanism assembly model with dimensions.

Appendix B: Bill of Materials

Item	Supplier	Supplier Part Number	Quantity	Price ea.	Total Price
Medium Density Fiberboard 3/4"x24"x48"	Home Depot	354221	1	12.48	12.48
Medium Density Fiberboard 1/2"x24"x48"	Home Depot	279388	1	9.95	9.95
VPC 3/4"x24" pvc sch. 40 pipe	Home Depot	254518	1	1.24	1.24
Charlotte Pipe 3/4" pvc sch. 40 socket cap	Home Depot	188174	1	0.46	0.46
Charlotte Pipe 3/4" pvc sch. 40 plug	Home Depot	612723	1	0.84	0.84
ABS Sheet 3/8"x8.5"x8"	TAP Plastics		1	8	8
ABS Sheet 1/4"	TAP Plastics		1	5	5
Multipurpose O1 Tool Steel	McMaster	89905K13	1	6.96	6.96

rod 3/4"dia x 1"					
Elbow 90 pvc 40- 3/4x1/2	Ace Hardware	46363	1	0.99	0.99
1"x3.25"x2" HDPI	TAP Plastics		2	5.11	10.22
1" dia x 18" delrin rod	TAP Plastics		1	10.43	10.43
Hillman 8-32 x 1-1/4" Machine Screws	Ace Hardware	8282482	6	0.15	0.9
Hillman 8-32x1/2" stainless steal machine screws	Ace hardware	825474	8	0.1	0.8
Silicone cap mold 3D print	PRL		1	89.43	89.43
Smoothsil-940 silicone (g)	PRL		530	0.05	26.5
High Impact Polystyrene sheet 0.1"x24"x24"	Amazon	B004DZOVZ8	1	5.92	5.92
	Overhead	**Per Unit**			
Total	**$89.43**	**$100.67**			