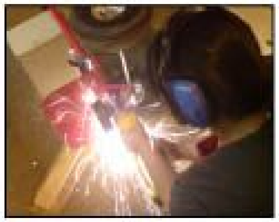
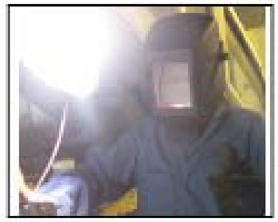
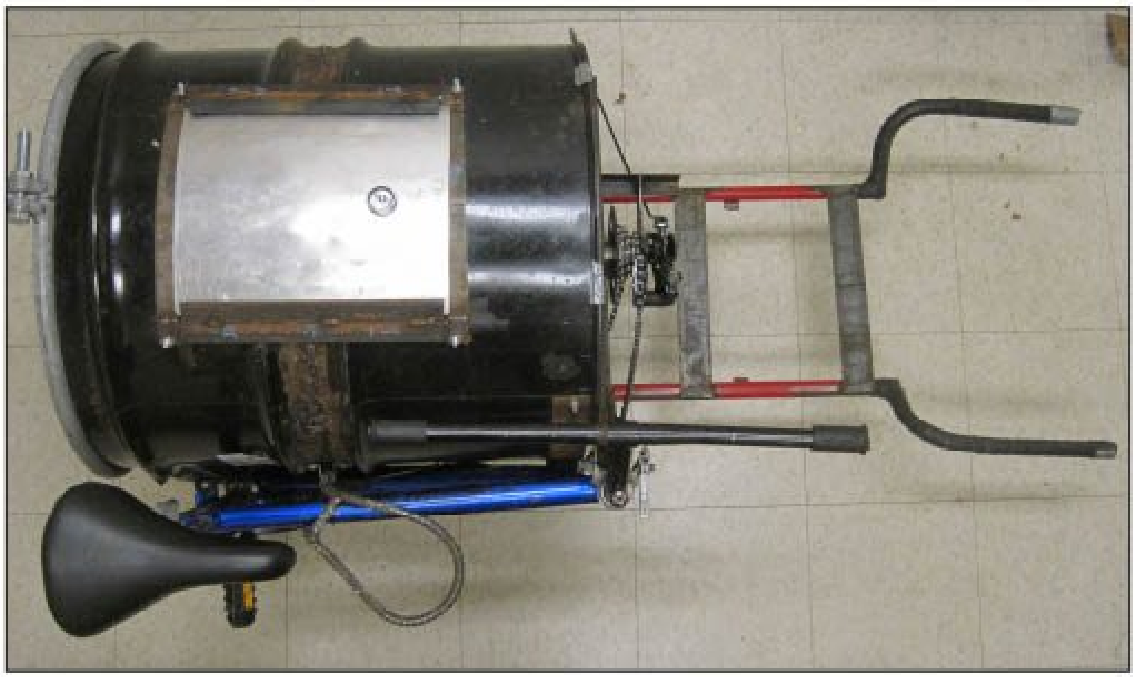
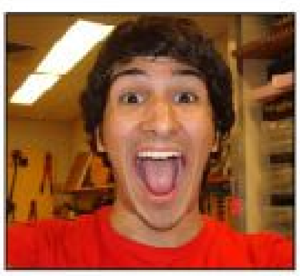
MOVILAVADORA
2.722 D-Lab: Design




Benji Moncivaiz **Connie Lu** **Brooke Jarrett** **Maysun Hasan**

Special Thanks to...

Nate Cooke
Victor Grau-Serrat
Gwyndaf Jones
Bernard Kiwia
Kathleen Li
Suprio Das
Dennis Nagle
Amy Smith
Lisa Tacoronte
Adam Talsma
Mike Tarkanian
and all other D-Lab mentors!

Also,
Nate and Jessica's office
That sleeping bag in the D-Lab lounge
"Brainstorming" walks
The M-Lab welding machine

Table of Contents

0. **Executive Summary**
1. **Prior Art**
   1.1 Washing Clothes
   1.2 Hand Washing and the Technology Gap
   1.3 The Washing Machine
   1.4 Human-powered Washing Machines
      1.4.1. Maya Pedal
      1.4.2. Radu Raduta
      1.4.3. Remya Jose
      1.4.4. Lisa Tacoronte
      1.4.5. Kathleen Li
      1.4.6. Adam Talsma
2. **Evolution of an Idea**
3. **Experimentation and Evaluation**
   3.1 De-watering Experiments
   3.2 Brief Prototype Testing
4. **Final Concept**
   4.1 Objective
   4.2 Design Specifications
   4.3 Our Design
      4.3.1. Outer Drum
      4.3.2. Inner Drum
         4.3.2.1. Frame
         4.3.2.2. Weave
         4.3.2.3. Assembly
         4.3.2.4. Reasonning
         4.3.2.5. Improvements
      4.3.3. Bicycle
      4.3.4. Mobility Structure
5. **Next Steps**
6. **Appendices**
   6.1 Pugh Charts
      6.1.1. Washing Method
      6.1.2. Drying Method
      6.1.3. Transport
   6.2 Visual Comparison between inner drums
   6.3 Design Specifications from Initial Planning
   6.4 Rough Line Item Budget

0. Executive Summary

Problem Statement
To design an economically-viable, human-powered washing machine that can be used by the average Peruvian woman entrepreneur. The machine must clean as well as or better than, and in less time than hand-washing, and be compact yet stable enough to be transported by foot in an urban setting.

Design Specifications
The *movilavadora*'s design specifications are divided into 6 major groups: form, portability, effectiveness, cultural acceptability, resource consumption, and economics. After reviewing interviews with Guatemalan women, our main concern was that the customer would not be comfortable pedaling the bicycle on the sidewalk. Therefore we aimed to accommodate their needs by reducing the *movilavadora*'s width so that it could be brought inside for more private use. We also aimed to transform the current bulky design into something easy to turn, to move long distances, and to stabilize for the wash mode. In order to be more financially viable, we also worked to reduce the materials and processes needed for the product. To reduce environmental impact, we aimed to increase the washer's efficiency so that less soap and water are needed. Overall we tried to balance people, profit, and planet for the most sustainable project possible.

Prior Work
Human-powered laundry machines have been designed and implemented at a small-scale in Peru, Guatemala, the Philippines, the US, and other countries. There are several crank-powered, compact machines that are commercially available and target bachelors, business women, and other single-serve on-the-go lifestyles. On the other hand, the bicycle-powered machine has adapted for many environments and many demographics (men, children, etc). To our knowledge, four MIT teams have also implemented bicycle-powered washing machines. All the models are horizontal axis washer, but that is where the similarity ends. One has used plastic for both the inner and outer drum, one combines a plastic inner with a metal outer, another uses a concrete basin with plastic inner drum, and the final uses sheet metal to construct both. The most recent design by Lisa Tacorante incorporates the seat into the design while the others rely on the user to find appropriately positioned seating.

Concepts Evaluation
The *movilavadora's* functions can be broken into different categories: washing method, de-watering method, power source, and portability. Our initial challenge was to make the 2009 *bicilavadora* more portable. However, we began by investigating each of these categories to ensure that the use of the 2009 *bicilavadora* would be a good foundation for the portable iteration. The main competing ideas were (1) the Hippo roller which de-waters using compression (2) the fold-up suitcase design that utilizes netting as the inner drum and does not provide a seat from which to pedal, and (3) the washing machine that is transported, powered, and dewatered by bicycle. After many Pugh charts, the 2009 *bicilavadora* won out in all categories except for the inner drum. The previous team designed a modular inner drum that is meant to be thermoformed and constructed for large-scale distribution. Thermoforming requires huge initial investments; therefore, this was an unacceptable solution for our intermediate technology.

Proposed Solution
Recognizing that the inner drum is a weakness in most pedal-powered machines, we decided to focus our attention on creating an inner drum from locally available materials. For us, it didn't make sense to give portability to a machine with fundamental flaws. We brainstormed local materials that could provide a strong, permeable inner drum. As a coastal town, Lima is home to many fishermen who are capable of making durable netting that could be used as part of the inner drum. The inner drum is made from wood and netting. As compared to the rest of the metal machine, this component can be easily removed, repaired, and replaced. This innovation is cheap as compared to plastic and rust-free

as compared to metal.

We based our design for the *movilavadora's* portable structure off of the common food carts found in Peruvian streets. Women sell tea and sandwiches from large, boxy carts that are pushed forward from gut height. Our design fits a dolly to the *movilavadora* so that the wheels act as transportation while moving from house-to-house and stabilizing shocks during wash cycles. The wheels are independent of one another, which allows for a small turning radius, and are large enough to manage a 5" curb drop-off.

Future Work

In general, our next steps concern market identification and product feedback. In particular, we will be coordinating with Limakids to determine how our project can work with their aims and needs. However, we believe that we need to expand beyond LimaKids in order to reach our targeted demographic. Before summer 2010, our team will draft a survey that will be used in Guatemala and Southern Peru by Connie Lu and Brooke Jarrett, respectively. We will collect data concerning work habits, typical income, etc. so that we can modify the design accordingly. If time permits, it would be best to build a prototype in order to gather specific feedback about user interface. In the fall of 2010, Benji Moncivaiz will use the *movilavadora* for his 2.671 class. Here, we hope to detail a standardized experimental procedure. This will then be used to establish baseline statistics for comparison to future prototypes.

1. Prior Art

1.1 Washing Clothes

Three major components are required in clothes washing: water, chemical surfactants and mechanical agitation. Heat speeds up the removal of soil from the clothing, but it is not absolutely essential for most types of soiled clothes. During washing, clothes are first submerged in water and chemical surfactant, and the mixture is mechanically agitated. The mechanical agitation lifts most dirt particles from the clothes into the water. Chemical surfactants surround and loosen stubborn particles from fabric, and keep them suspended particles suspended in the water. After a period of mechanical agitation, the water and suspended dirt particles are drained. The clothes are then again submerged in clean water, and mechanically agitated to lift remaining dirt and chemical surfactant. This rinse water is then drained. Rinse water can be reused. Finally, either wringing or fast, vigorous spinning dries the wet clothes.

1.2 Hand Washing and Technology Gap

There is large technology gap between traditional hand washing and electric washing machines. In communities around the world, many cannot afford to buy electric washing machines, which cost at least two hundred US dollars. Even if people had the initial purchasing power, many times they cannot afford the electricity required to operate these machines. The lack of sufficient water pressure in many developing countries also deteriorates utility of most electric washers. Thus, it is very common for women to wash clothes by hand. Washing clothes by hand costs very little monetarily, but is an extremely time consuming process. Moreover, repeated washing is harmful to hands due to prolonged exposure to harsh chemical surfactants combined with deliberate agitation. Cold weather makes hand washing especially painful. The chemicals and agitation causes dryness and cracking of the skin that makes it difficult for women to do other daily activities. If clean water is not easily available, women often wash laundry in contaminated waters, which can cause infections through the broken skin. Additionally, the posture required for hand washing clothes can cause back pains, also hindering their daily activities. In both Peru and Guatemala, and most likely in many other countries, some women earn their livelihood by washing clothes by hand for wealthier households. For these women especially, the effects of harsh chemicals and agitation are magnified because they wash clothes very frequently. Moreover, the fact that hand washing is time-consuming means that their productivity and income are narrowly limited.

1.3 Washing Machines

Many types of washing machines have been invented and used, but the two designs that have proven to be most effective are the vertical axis (top-loading) and the horizontal axis (traditionally front-loading) machines. In the vertical axis washer, clothes are fully submerged in water and the vertical drum rotates back and forth to separate and agitate clothing. In the horizontal axis washer, the drum is only filled to approximately one-third of the full volume. The horizontal drum rotates continuously in one direction. Fins on the side of the drum pick up the clothing and drop them back down, agitating and separating the clothes. Recently, horizontal axis washers have become more popular because they use significantly less water and potentially less power than vertical axis washers. Rotating the drum in a single direction uses rotational momentum in its favor, whereas turning the drum back and forth requires a significant amount of impulse to change the momentum with each switch in direction. However, it has been recognized that the horizontal axis drum needs to be significantly stiffer and more robust to withstand the large amount of force that the pounding of wet clothes exerts on the drum walls. Moreover, horizontal axis washers generate more vibrations than vertical axis washers do.[1] The understanding of the relative benefits and disadvantages of vertical and horizontal axis drums that has been gathered during the development of electric washing

1 Raduta, Radu. "Design for Dissemination of a Low Cost Washing Machine for Developing Countries." Bachelors Thesis, Massachusetts Institute of Technology, Cambridge, 2008.

machines can be translated to human-powered washing machines.

1.4 Human-Powered Washing Machines

Illustration 1: Household electric washing machine converted to pedal power (via exercise bike.)

Image Credit: http://www.humboldt.edu

Illustration 2: WonderWash hand-cranked washing machine is marketed for campers, single people, and business people and washes up to 5 pounds of clothes at a time.

Image Credit:http://www.dallasnews.com

There have been many efforts to create human-powered washing machines. Some of these efforts have arisen out of environmental awareness, and several technologies have been focused on application in developing countries. At Humboldt University, two human powered washing machines have been built. Both of these adapt household washing electric machines to pedal power (Illustration 1). While most examples of human-powered washing machines have been pedal powered, there is at [2]least one machine that is hand-crank powered. The *WonderWash* is a small plastic washing machine that washes up to 5 pounds of clothes and is powered by a hand crank (Illustration 2). Commercially at less than $50 per unit, the *WonderWash* is targeted at campers, single people and businesspeople because of its portability and compact form.

1.4.1 Maya Pedal

The NGO *Maya Pedal* in Guatemala attempted its first bicilavadora in 2005. This bicilavadora had a vertical-axis and top-loading (Illustration 3). It tended to rip clothes and was hard to power, and as a result the project was abandoned.

Illustration 3: *Vertical-axis bicilavadora built by Maya Pedal. Image Credit: Raduta, 2005.*

[2]http://www.laundry-alternative.com/wonderwash.htm

1.4.2 Radu Raduta

The bicilavadora development was picked up again in 2006 when Radu Raduta and several other MIT students helped to continue the project at *Maya Pedal*. This MIT team worked with *Maya Pedal* to build a proof-of-concept horizontal axis washer solely out of materials that could be found in Guatemala (Illustration 4). The MIT team first constructed a prototype on campus, and won an International Technology Award from the IDEAS competition in 2005 (Raduta). They were successful in building a very similar protytype at Maya Pedal as well, and materials were locally available, but some materials were not locally abundant.

Illustration 4: Horizontal-axis bicilavadoras built by MIT team and Maya Pedal in 2006. Left is original MIT prototype design. Similar prototype was built at MIT for IDEAS competition. Right is local adaptation from original design. Image Credit: Raduta, 2005.

Radu continued to look thoroughly into washing clothes and the mechanisms of washing machines in order to continue the bicilavadora project as his master's thesis in 2007. In this thesis, Radu focused primarily on the large-scale dissemination of the bicilavadora and on the design of the inner drum. Radu suggested a business model that was inspired by International Development Enterprises' (IDE) model of centralized manufacturing with local assembly. The inner drum of the bicilavadoras would be made in a centralized factory setting, and a kit containing only the parts necessary to build the inner drum would be sold at local markets by stand owners who currently sold chemical washing powders. Radu suggested a marketing partnership between the bicilavadora and a specific brand of chemical detergent. The partnership would be mutually beneficial, Radu believes, because the chemical detergent company would distinguish itself from a large field of competitors with a "novel way to promote…products" and the bicilavadora company would "increase adoption rates and further promote their brand.[3]" The consumer or a middleman would be instructed on how to assemble the parts, and to devise a system to catch water and secure the drum. In designing the inner drum, Radu explored different materials that could be used to make the inner drum and developed a functional and easily transported shape for the final inner drum. Radu ruled out metal for the inner drum because metal corrodes easily. He also built a test inner drum entirely out of relatively water-resistant (oily) wood, but found the construction to be "expensive, cumbersome and exceedingly heavy." See Appendix. He settled on making the drum from ABS, thermoformed into the shape he investigated.

3 Raduta, Radu. "Design for Dissemination of a Low Cost Washing Machine for Developing Countries." Bachelors Thesis, Massachusetts Institute of Technology, Cambridge, 2008.

1.4.3 Remya Jose

A student named Remya Jose in India also engineered a clothes-washing machine that consisted of a cylindrical drum made out of wire mesh inside of a custom-welded aluminum box casing. Pedals on either side of the washing machine directly drive the turning of the inner drum, and the seat is detached (Illustration 5). Remya's father brought the original designs to an engineering workshop for manufacturing, and it appears that Remya's family has been using the resulting washing machine. Remya's story and the technology she created received attention from the Indian government and a legal firm, which helped Remya submit her design for patenting. However, it seems that the patent never came through and the design has not been disseminated commercially.

1.4.4 Lisa Tacoronte

Lisa Tacoronte built a bicilavadora using one of the ABS drums designed by Radu during the winter of 2009. This bicilavadora was implemented during a D-Lab: Development trip at an orphanage called *Sagrada Familia* in Lima, Peru. When we visited a year after the implementation, the bicilavadora was in use, although not well maintained. The bicilavadora was extremely well received, and very useful in helping with the huge volume of laundry at Sagrada Familia (there are approximately 800 children who are housed and schooled at this orphanage). The community requested that D-Lab students bring more of the ABS drums and build more bicilavadoras, but had not taken the initiative to find alternative inner drums or build additional bicilavadoras on its own. For whatever reasons, this model seems to be the most well known bicilavadora, and has been documented in many news channels like CBS.[4]

Illustration 6: Lisa Tacoronte standing among the kids at La Familia Sangrada with her bicilavadora. Image Credit: Gwyndaf Jones, 2009.

4 See: http://web.mit.edu/newsoffice/2009/itw-bicilavadora-0219.html
http://www.cbsnews.com/stories/2009/04/22/eveningnews/main4962435.shtml

1.4.5 Kathleen Li

Kathleen Li also built a pedal-powered washing machine during a trip to India in summer 2009. Because it is relatively inexpensive to have local craftsman make custom parts in the community where Kathleen was working, the inner and outer drum, as well as several other parts were manufactured to order, primarily out of sheet metal. Unlike Lisa's design, this washing machine had a detached seat (See Illustration 7). One employee at the NGO where the washing machine was built likes using the machine to wash her clothes regularly, but it is unclear whether it has been used extensively by the community as intended.

Illustration 7: A woman testing out the machine. This is a still taken from a video. In it, the chain falls off several times. Image source: Li, 2009.

1.4.6 Adam Talsma

Adam Talsma, William Chin and Josh Geltman built a pedal-powered washing machine prototype at MIT in Spring 2008 through CityDays, and implemented an improved prototype in Tambo de Mora, Peru the following summer. The washing machine had a detached seat, simple steel frame, and plastic barrels for the inner drum (see Illustration 8) The CityDays team was able to find appropriately sized plastic barrels, but it has been noted in Radu's thesis that even when a few barrels can be obtained, the supply is likely to be too limited to accommodate scale-up. The construction process for this washing machine is very well-documented. However, the washing machine, as far as the team is aware, was not used after they left Tambo de Mora.

Illustration 8: Nested Drums. Image Credit: Talsma, 2007.

2. Evolution of an Idea

The *movilavadora*'s functions can be broken into different categories: washing method, de-watering method, power source, and portability. Our initial challenge was to make the 2009 *bicilavadora* more portable. However, we began by investigating each of these categories to ensure that the use of the 2009 *bicilavadora* would be a good foundation on which to base our modifications. The following table compartmentalizes our brainstorming sessions and research by category.

Washing	De-Watering	Power Source	Portability
Water agitation	Hang wringing	Bicycle Pedal	Backpack / Briefcase
Scrubbing by friction	Pressing together (direct)	Crank	Bicycle
Impact (rotational)	Pressing together (rollers)	Sewing pedal	Push cart / wheelbarrow
Impact (pounding)	Spin	Rolling drum (ie Q-Drum)	Rolling washer
Pressurized air through material	Heat	Motor	
	Whip effect	Manual shaking	

Using a Pugh chart for each category, we concluded that spin washing, press de-watering, and backpack transportation were the best solutions (power source was not discussed in detail until later in the design process). These Pugh charts can be found in Appendix 6.1. Despite the results, certain ideas and methods continued to persuade us in ways that the numbers could not. For example, in our discussion about press de-watering, our visual concept of pressing revolved around a single piece of clothing. Thus we put a plus next in this cell. If one considers an entire mountain of clothes, however, the press de-watering becomes a less effective option.

Therefore, over Spring Break 2010, each team member was tasked with detailing an integrated design that combined his or her favorite components of wash, de-watering, power, and portability structure. The resulting ideas, their benefits, and disadvantages are described below:

(1) A Hippo roller which de-waters using compression. The handles for pushing/pulling the machine fold out to become the base of the machine during wash mode. The method for powering was not yet developed.

Benefits: Simplicity. Many parts are multi-functional.

Disadvantages: Instability and locking complications. Having the handles function as both a pushing device as well as a stand has advantages, but it is not optimal for creating a stable base. The members would need to be rigidly connected to the

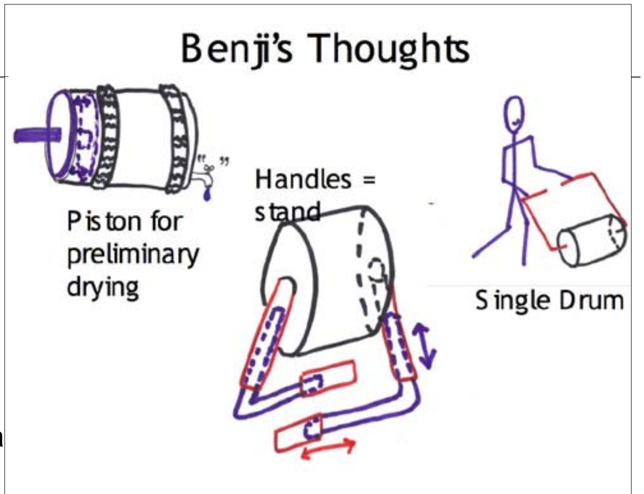


Illustration 9: Computer sketch of the Improved Hippo Roller concept. Image Credit: Moncivaiz, 2010

drum while also having the capacity for rotating. This would be difficult to achieve without a thoroughly engineered member, which would likely be expensive.

---

(2) A collapsible suitcase design that utilizes netting as the inner drum. The pedals would fit on top of the suitcase and be detached for wash mode. The user would need to find his or her seating from which to pedal. In wash mode, the handle would fold over to prevent the machine from sliding out further.

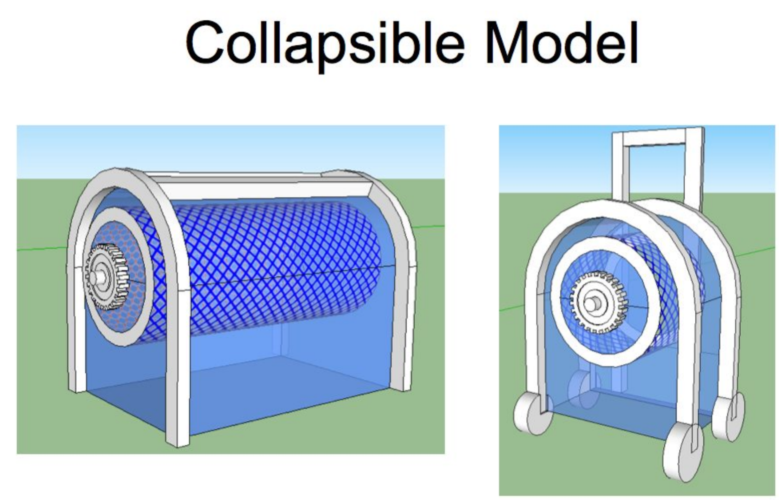


Illustration 10: Sketch up model of the collapsible concept

Image Credit: Hasan, 2010

Benefits: Compactness. Unhindered travel is optimized for those who need to walk and take the bus. This is a likely situation since the washing woman will probably not live in the same high-income bracket neighborhood as her client.

Disadvantages: Sealing issues and abundance of moving parts. Each of the sections would need a tight seal against other sections when expanded to wash mode. As a result, the manufacturing would need to be fairly precise to ensure proper alignment of pieces against one another. Moving parts are inherently vulnerable points especially if they are used often. Sheer friction and repeated use would significantly weaken the machine. This would possibly result in a shorter expected lifespan.

---

(3) A washing machine that attaches to the back of a wheelchair. The seat detaches from the wheelchair, using the front casters and metal back legs (originally the armrests). The drum is placed between the wheels which act to stabilize the drum as it spins (not reflected in diagram). The entire thing is powered by hot water pressure that pushes the suds of soap through the cloth.

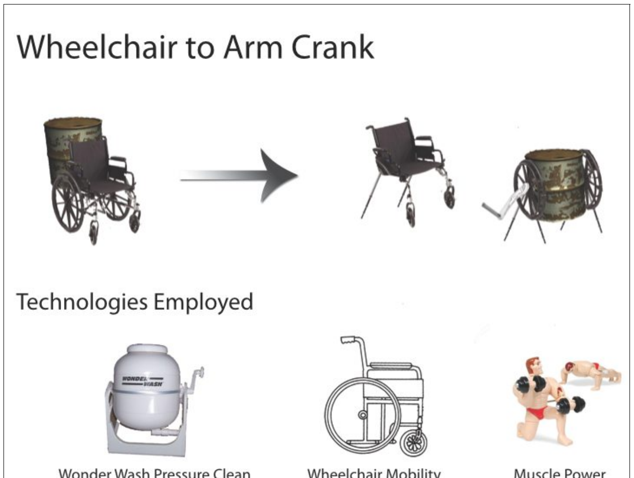


Illustration 11: Diagram of wheelchair idea, Image Credit: Jarrett, 2010

Benefits: Compactness and ability to carry washing accessories. The wheelchair could be used to stack laundry, detergent, or other related items.

Disadvantages: Use of an expensive wheelchair with an able-bodied person. Modifying a wheelchair is not ideal. It would be best to take the basic components of a wheelchair (seating, push cart handles, and wheels) and design around local materials. Additionally the wheelchair is an unnecessary transportation mechanism if the person is already capable of walking.

(4(4) Building off of the Q-Drum concept, this design is suspended off the ground. The bicycle wheels support the drum, turn it, and allow it to go over rough terrain. Here, the clothes would be washed/dried as one walks. The ends of the handles have two pegs on which the drum can be centered. Each peg creates a different gear ratio, allowing for a transition between wash and transportation modes.

Benefits: Simplicity of using a single drum instead of requiring inner and outer drums.

Disadvantages: Being required to walk in order to wash.

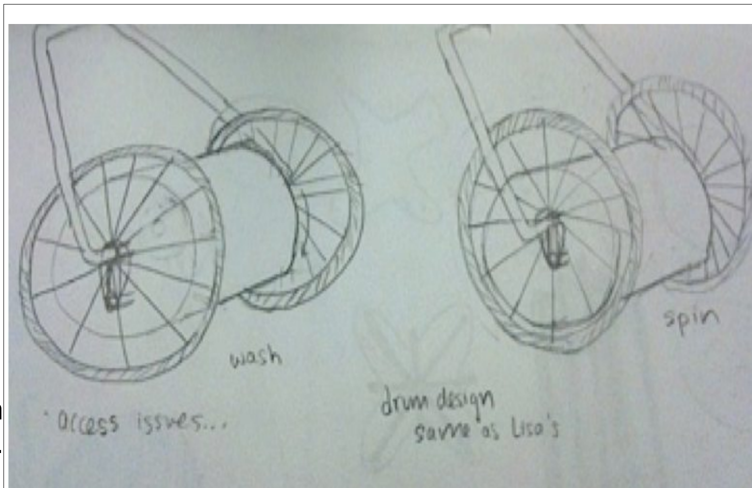


Illustration 12: Sketch to describe the transition between wash and spin modes.

Image Credit: Lu, 2010

(5) A washing machine that is transported, powered, and dewatered by bicycle.

Benefits: Ease of transportability.

Disadvantages: The device is bulky and would require some fairly complicated mechanisms for engaging and disengaging the chain between wash and transportation modes.

Photo of bicycle-powered ice cream push cart removed due to copyright restrictions. See http://www.hollywire.com/the-news-dump/change-the-world-one-hot-dog-taco-and-cupcake-at-a-time

The inner drum has varied across all of the bicycle powered machines that have been described so far. Please see Appendix 6.2 or a visual comparison between the variations. Previous designs have incorporated a number of materials such as ABS, wood, plastic water barrel, sheet metal, and metal mesh (resembling chicken wire). We immediately ruled out ABS since it is not financially sustainable on a small-scale. The plastic water barrel is only available in certain parts of Peru and cannot be depended on for consistent sizing. Sheet metal will rust, but there are methods of preserving it such as using varnish or car body coatings. We decided against this alternative for environmental and health reasons. We decided on using a combination of a mesh (metal / rope) and wood for our inner drum design. Being locally available, easy to work with, and cheap, these materials were ideal for the conditions in Peru.

The derailleurs are another weakness in the 2009 *bicilavadora* (Tacoronte's) design. This system is not immediately intuitive to someone who has never ridden a bike before. This is a likely scenario in Peru where women are not often found riding bikes. The system is also not easy to build around due to the precision and knowledge necessary to install the derailleur successfully. If it breaks, the women will need to seek help for repairs. To top it all off, the chain must wrap around as the bike folds into transportation mode. For these reasons, we tried to come up with a good alternative to the derailleur. The retro-direct is the best alternative at this point. However, we decided not to pursue the retro-direct since we knew it would involve expensive, unusual gear ratios. Additionally, time was limited and so we were forced to prioritize.

The five ideas from Spring Break inspired a final concept. Based off of several experiments that are detailed in section three, we shaped this concept into our final design which is described in section four. This design incorporates the idea of the pushcart, wheels as stabilizers, fishermen's rope for the inner drum, and bicycle power.

3. Experimentation and Evaluation

3.1 De-watering

Hand wringing is one of the hardest stages in hand washing clothes, thus removing water after a wash cycle is one of main challenges in creating a good washing machine. We tested different methods of de-watering our clothes by using a small towel which we wet to saturation. From its soppy state, we measured the amount of water we were able to remove using different methods. Our standard test was hand-wringing, for which we folded the towel and twisted it to remove the water for 30 seconds.

Most modern day washers use a spin cycle to remove water after a wash. In order to simulate the spin cycle of a washer the towel was suspended inside a mesh pocket inside of a bucket and was manually spun around on the vertical axis as fast as possible. A similar test was also preformed while spinning on the horizontal axis.

Illustration 14: Different methods tested for de-watering. Wringing by hand (right), horizontal axis spinning (middle), and vertical axis (left). Image Credit: Lu and Jarrett, 2010.

A method to remove water before the introduction of a spin cycle was a press. We tried three methods of press drying (see Illustration 15. First, the towel was placed between two planks of wood and full body weight was put on it by stepped on it. The stepper rocked back and forth for about 30 seconds and then measured the amount of water that is in our flat bin. The second was similar but the towel was pressed mechanically by clamping towel between two planks until it would no longer tighten. Finally, using a 4” diameter cylinder, we rolled over the folded towel four times back and forth and measured the amount of water squeezed out.

Illustration 15: Different methods tested for de-watering. Vertical pressing via weight (right), vertical pressing via clamp (middle), and pressing with roller (left). Image Credit: Moncivaiz and Hasan 2010

The results of these are as follows:

	Hand Wringing	Vertical Spin	Horizontal Spin	Human press	Mechanical Press	Rolling Pin[6]
Tester	Jarrett and Lu[1]			Hasan and Moncivaiz[2]		
Test 1	610mL	450mL[3]	500mL[5]	720mL	720mL	600mL
Test 2	580mL	485mL[4]	380mL[3]	800mL	800mL	620mL
Test 3	540mL	n/a	n/a	800mL	800mL	650mL
Mean	576.6mL	445mL	472.5mL	773.3mL	773.3mL	623.3mL

[1] Weight of water used to measure the amount of water removed, using 1mL/g as the conversion factor.
[2] Volume of water used to measure the amount of water removed, in mL.
[3] Was spun for 20 seconds.
[4] Was spun for 30 seconds.
[5] Was spun for 25 seconds.
[6] The cylinder was somewhat hollow so full force could not be applied.
Illustration 16: Final Results from testing.

3.2 Brief Prototype Testing

As part of our experimentation, we did two informal tests to determine how our machine worked. Due to time constraints, we were not able to use the machine multiple times. Instead, we used these moments to quickly identify obvious issues and to better understand the design challenge from the user's point of view.

Our first prototype testing occurred early on in the process. We wanted to see how well the 2009 bicilavadora was able to wash clothing. We learned that the outer drum needs a clever way to seal all of the holes that are made for bolted connections. We first tested the inner drum with a window screen that we stapled at as many points as possible along the radius. It tore in under fourteen minutes of washing and spinning. Then we tested two kinds of ropes. We were able to determine appropriate spacing between the ropes through iterative wrappings and found that the polyethylene rope was superior to the others tested. The final realization was that the drain took more than 15 minutes to drain, adding a significant amount of time to the washing process.

The second test occurred on the night of May 7th, 2010, the dawn of our presentation. We washed and dried a full load of laundry to test the drum's effectiveness as a washing machine. This brought our attention to many other flaws in the design. First, the machine continued to leak. While filling, water poured out generously. Once it had filled a decent amount, however, the springs of water ebbed to a slow drip. We hypothesize that this is due to an auto-seal from the weight of the water placing pressure on the inner tube washers. Since the leaks appeared again once the drum was being emptied, we think that this is sufficient evidence to prove our theory. Improvements could be made by using plumber's epoxy on permanent holes, but we do not yet have detailed ideas of how to seal it temporarily without using o-rings or other expensive parts. Another issue was the distance between wrappings. Despite calculating the distance needed between each turn of the rope, small items like socks and underwear still fell through. We later noticed that one shirt sleeve had even torn. In conclusion, we would need to either decrease the distance between each wrapping or “cross-tie” additional rope perpendicular to the main wrapping, as well as cut down the bolts so that no loose sleeves catch. There is no way of knowing when clothing falls through the cracks unless one opens the drum. Hopefully this will not be an issue once the inner drum's rope spacing has been perfected.

From simply using the machine, we realized other user interface issues. We would like for our door to move more smoothly so that it does not inconvenience the customer. Additionally, a stop needs to be added so that the chain automatically lines up for easier gear changes. Easier gear changes can also be aided by keeping the *movilavadora* in low gear when ending each dry cycle so that the next wash cycle starts up quickly and without effort. This should be mentioned in whatever guide accompanies the machine. Finally, we would like to point out that the bottom derailleur confused and frustrated us on several occasions. In our opinion, any attempt to change this part of the system would greatly improve the design.

4 Final Concept, Execution, and Criticism

4.1 Objective

To design an economically-viable, pedal-powered washing machine that can be used by the average adult Peruvian woman entrepreneur. The machine must clean as well or better, and in less time than hand-washing and be compact enough for travel by foot in an urban or peri-urban setting.

4.2 Design Specifications

A detailed version of the design specifications can be found in appendix 6.3. The *movilavadora*'s design specifications are divided into 6 major groups: form, portability, effectiveness, cultural acceptability, resource consumption, and economics. After reviewing interviews with Guatemalan women, our main concern was that the customer would not be comfortable pedaling the bicycle on the sidewalk. Therefore we aimed to accommodate their needs by reducing the *movilavadora*'s width so that it could be brought inside for more private use. We also aimed to transform the current bulky design into something easy to turn, to move long distances, and to stabilize for the wash mode. In order to be more financial viable, we also worked to reduce the materials and processes needed for the product. To reduce environmental impact, we aimed to increase the washer's efficiency so that less soap and water are needed. Overall we tried to balance people, profit, and planet for the most sustainable project possible.

Since we spent so much time on planning and building our prototype, we have not yet had sufficient time to measure our machine's capabilities. Thus the design specifications acted more as guidelines than hard requirements. There are certain things that we can assume work the same as Tacorante's 2009 model such as “water requirement” or “blacksmith capability” since there has been no modifications to the outer drum. The other areas of our design specifications require further investigation to ensure that they meet the standards we originally set out.

We can, however, compare basic differences between the *movilavadora* to an electric washer.

	Bicilavadora	Typical Washing Machine
Cost	$ 308 USD	$ 700-2,700 USD
Spin RPM	165 RPM	1000[1]
$Time_T$	42 Minutes	30-90 Minutes
Capacity	67 Liters	113 – 128 Liters
Water Use	424,000 Liters	1,900,000 Liters

Illustration 17: Comparison to a typical electric washing machine.

The comparison for cost is based on a one-time investment and is not adjusted for the lifetime of each product since there is not sufficient data on how long the *movilavadora* lasts in the field. However, we can make a rough estimate that the *movilavadora* would last 3 years before needing to be repaired based on the year-long,intensive stay that La Familia Sangrada has given Tacorante's 2009 model. The typical washing machine, on the other hand, tends to last approximately 7 years based on Consumer Reports' website.[5] Thus, the *movilavadora* costs $100/year. This cost is identical to less expensive washing machines. More expensive washing machines would cost $390/year.

Since our design is meant to be more affordable and portable than an electric washer but more

5 http://askville.amazon.com/Average-lifetime-clothes-washer/AnswerViewer.do?requestId=9178005

effective or faster than washing by hand, we can only comment that it achieves an equal or better financial viability as well as vastly improved portability. Observations in the field are needed to obtain reliable data about normal hand washing habits and to gather feedback on the current design's cultural acceptability, performance, user interface, and maneuverability.

4.3 Our Design

The machine can be broken up into five major groups: inner drum, outer drum, bicycle, portable structure, and connections. This section will describe the components in each with dimensions included in pictures, their reasoning, and the specific areas needing improvement. Many of the basic components of the *movilavadora* had already been fabricated so our team does not know all of the exact steps of their construction. To learn more, please contact Lisa Tacoronte or refer to the materials inside the folder marked “1PriorArt/2009_Tacoronte_DLab.”

Bicycle power was chosen over two other alternatives: the hand crank and the sewing pedal. Legs are one of the strongest parts of our bodies so we are able to pedal more quickly and powerfully than we would be able to do with our arms. Additionally, the bicycle is ubiquitous in Lima, Peru. This means that bicycle parts should be abundant. Again, this prefabricated bike frame can be ordered straight from companies at a wholesale price. Getting them straight from a factory ensures quality and consistency as opposed to buying them recycled. This reliability allows us to manufacture much quicker than if we needed to measure and remeasure to account for variabilities that are inevitable with handmade products.

4.3.1 Outer Drum

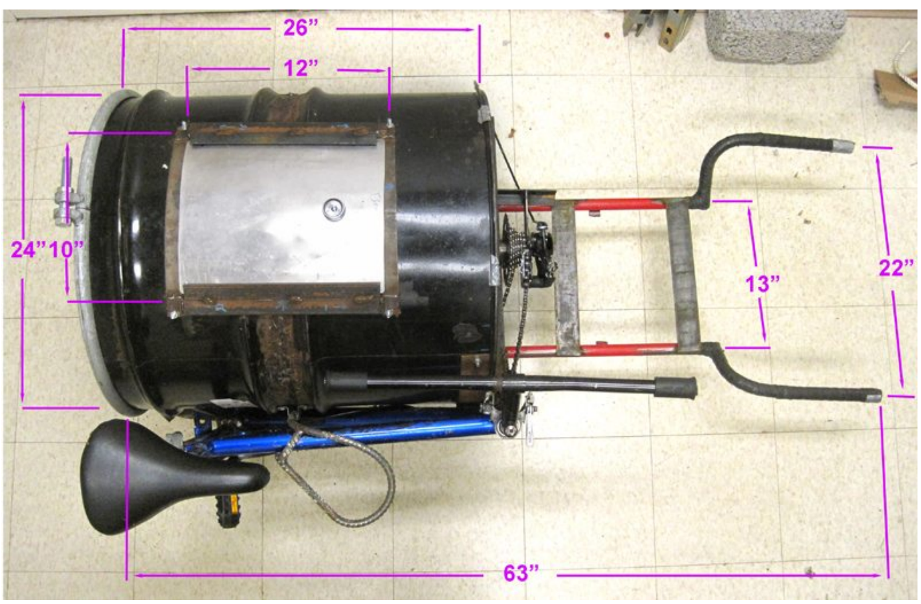


Illustration 18: The final machine with dimensions. Image Credit: Lu, 2010.

The outer drum is made with a used 50-gallon drum. A middle section is cut out and the drum is re-welded together. Special care should be taken to ensure that the weld is made leak-proof and straight. Holes are made on the flat, circle sides of the drum and a door is cut out. The door is made by gently bending a piece of thin iron stock to match the curve of the drum and then attaching a bike cup to it. The door is lined with a frame made of t-iron. As can be seen in the illustration below, an long piece of thin flat stock is welded onto the inside of the t-iron to hold and guide the door.

Afterwards, the sleeve bearings should be attached to angle iron and centered on the flat side of each drum (see illustration 26). These will support and hold the inner drum's axis. Whenever something needed to be connected to the outer drum, we opted to use bolts as opposed to welds for simplicity and to avoid weakening it unnecessarily. These holes were closed by pushing the bolt through a layer of bicycle inner tube and a washer on either side of the drum and tightening to seal.

The drum was chosen because it is heavy enough to provide the washer with significant stability. Unlike Talsma's 2008 version made of nested plastic barrels, the 50-gallon drum does not need to be bolted to the ground for use. We tried to reduce our environmental impact in two ways: (1) As a top loading design, the *movilavadora* uses 1/3 of the water needed for top loaders, and (2) Using recycled parts such as the oil drum. Finally the oil drum was chosen because the volume is large enough to accommodate most family's needs.

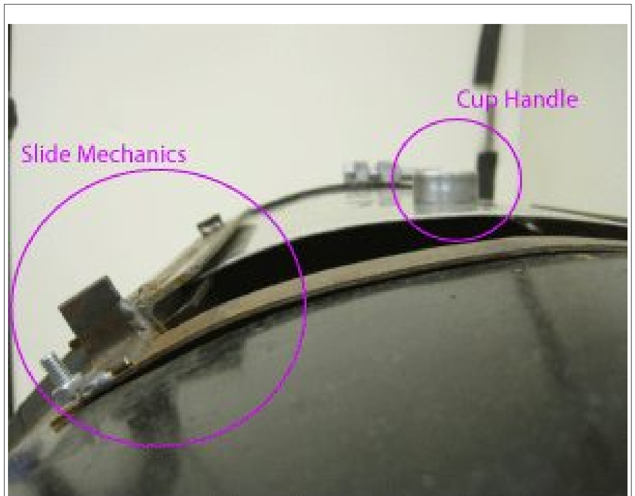


Illustration 19: Detailed look at how the door sits on the frame. The knob made from the bike knob is also visible on the right. This was accomplished by placing a washer inside and cutting a bolt to length. This way the bolt does not catch on the frame. Image Credit: Lu, 2010.

Improvements can be made. Despite the use of bicycle inner tubes to line the holes needed to bolt, there is still leaking. The use of silicon sealant or plumber's epoxy would be useful here. The door also needs to be made more exactly to prevent leaking. This could also be fixed by adding round rubber tubing to the door's edges for a tighter seal against the slides. Although we were losing water out of these holes quickly, the drain did not evacuate the inner drum quickly enough. This could be fixed by enlarging the hole or using a siphon system that removes water from the top door. A siphon would also help solve the issue of the drain's height. Where it is currently attached, there is no clearance or height for someone to hold a bucket underneath it. Finally, the drum is not very aesthetically pleasing. It is not immediately obvious what the *movilavadora* is meant to do unless told or shown. This could be easily rectified by painting “Lavadora” on the side.

4.3.3 Inner Drum

We chose to focus on design for affordability and manufacturability for the inner drum. The inner drum’s components are currently made out of wood planks (2 X 4s and 1 X 1s), ¼” plywood, ¼” polyethylene rope, and hardware as mentioned below.


Illustration 20: The inner drum. Image Credit: Lu, 2010.

4.3.3.1 Frame

To begin construction, we cut two circular pieces of ¼" thick plywood to serve as ends of the inner drum. A 3" difference in diameter between the outer and inner drum left 1.5" of space all around the inner drum when inside the outer drum. These plywood circles lie parallel to the circular part of the outer drum. A heavy metal collar and a small piece of sheet metal were placed at the center of either side of each plywood circle, to provide a robust connection between the *movilavadora* drive axis and the inner drum. The metal collar has three screws that can be tightened to secure the drive axis, without having the axis go through the inner drum. Both ends of the drive axis were extended through a sleeve on the outer drum. One end was connected to the bike chain via a freewheel. A freewheel was attached by first welding a cup (which had matching threads to the freewheel) onto the pipe coming from the inner drum. The weld was ground down in order to allow the pipe to easily slide in and out of the sleeve bearing on which the inner drum rotates.

The wood planks were cut to length and secured, becoming the ribs/fins of the inner drum. The ribs/fins were screwed in the circumference of both circle plywood pieces, and oriented so that they would move the clothing around during the wash cycle. Three 2 X 4s and three 1 X 1s were used, because we felt that three fins were sufficient for cleaning purposes and we wanted to maximize the space inside the inner drum in order to be able to wash more clothing. The length of the planks is important because if they are too long, the inner drum will not fit inside, and if too short, too much "wiggle" room is allowed for the inner drum to shift back and forth when inside the outer drum. This makes it difficult for the chain to stay on the drum consistently. Since we did make the mistake of cutting the 2 X 4s too short, we compensated for missing length in the assembly process, as described later.

4.3.3.2 Weave

We notched the wood planks every ¾". The notches maintained the spacing between the ropes, and therefore allowed us to save on the amount of rope used and improve the affordability of the inner drum. The rope was tied around one of the 2 X 4s, and woven around the drum, using the notches as guides. We pulled the rope as tight as we could to ensure that the maximum strength in the rope could be utilized to maintain the shape of the rope "cage." We went around for 1/3 of the way spiraling the rope down the sides of the drum. Then, in order to provide access into the inner drum, we created a hole in the weaving. We changed directions by swinging around a 2 X 4. When we reached the other side of the hole, we turned around the adjacent fins and then repeated the process. After the width of the hole is created, a continuous spiral was adopted for the final 1/3 of the way down. Care was taken to maintain the rope always parallel to itself and parallel to the ends of the inner drum, so that we did not have unnecessarily large holes. To make the rope more taut, we cross-tied additional lengths of rope down the middle of each "panel."

4.3.3.3 Assembly

Normally, the inner drum and drive axis can simply be placed into the outer drum, through the sleeves. However, because we cut the planks too short, metal “washers” (made of pipe larger than the pipe used as the axle) were installed on either side of the collar that supports the inner drum. One washer spaces the inner drum’s collar and the sleeve, and the other spaces the inner drum freewheel and the sleeve. Please see illustration 21.

Illustration 21: The sleeve that holds the inner drums axle. Image credit: Lu, 2010.

4.3.3.4 Reasoning

We chose to construct the inner drum out of wood and rope because these materials are cheap and readily available. We chose to use rope because fishing expertise (and, therefore net-making knowledge) is common in Peru, and we believe that local net-makers can improve on our design. Because the materials are widely available, the inner drum is easily replaceable and repairable. There is legitimate concern that wood would rot because it is getting cyclically exposed to water and air. However, if there is sufficient ventilation to air-dry the wood quickly enough, it will likely stay robust. We do realize that in the field, the user should not have to worry about where to put the *movilavadora* so that the inner drum does not rot. Thoughts on this improvement is expounded on below.

4.3.3.5 Improvements

Future improvements to the wood construction include making the 2 X 4 structure easier to push through water (for example, drill holes into the board). This way, when washing, the force needed to spin the fins through the water is decreased and the person does not have to work as hard to push the inner drum through the water. It would be ideal if the only resistance were coming from the clothing being forced through the water. Also, we would recommend using a more oily and durable wood. Pine, which most planks are currently made of, is too wearable. We believe that an oily wood, such as cypress, would improve the lifetime of the inner drum dramatically. The wood poses another problem. It splinters very easily because it is softened by the exposure to water. Residues are left on the clothing. If the pine were replaced with a harder wood, this problem may be solved as well.

When the U-shaped bracket that serves to secure the folded bike was attached, nuts and bolts were used. These nuts and bolts protruded into the drum and began to hit the door of the inner drum when we started spinning. With every hit, the door became looser and looser. Currently, the way to secure the inner drum’s door is simply by tying it in position with rope. A more clever and quick-change type of system to open the door of the inner drum should be considered instead of simply tying it in place.

The collars that make the transition from the plywood circles to the pipe axle are specialized hardware. It would be ideal to come up with a way to connect the inner drum to the chain (we did it with a collar and pipe) so that no specialized pieces such as the collar were used. Efforts can be aimed at figuring out a different way to mate the pipe to the plywood circle.

Because of the current arrangement of the rope, socks and underwear escape through the inner drum during the spin cycle. Once they fall out, they get caught or torn on bolts protruding through the outer drum. Clothing is most likely to escape from the edge, near the circular plywood. One would think that simply putting the ropes closer together would easily solve the problem, but the problem with this “solution” is that the wood between the notches in the wood will get thinner and thinner. Care must be taken to ensure that the strips left between notches is stable and will not simply fall off with any sort of reasonable load. One solution could be to increase the amount “cross-tying” done, increasing from the current one to a possible three times.

4.3.3 Bicycle

Bicycles in Peru are typically made of cheap steel and sold for new at as little as $ 40 USD. Since specific parts of the bike are needed, it would be best to strike a deal with a local manufacturing company so as to create demand for those specific pieces rather than a wasteful demand for the entire bike. But the frame can be taken from a bicycle that is no longer functioning as well. This reuses materials that might have otherwise been thrown away. The back part should be cut off as indicated in illustration 22.

Illustration 22: Cut on the line and leave a bit of material on the bottom of the frame, behind the bottom bracket, so that there is ample material remaining to weld the stand to. Image Credit: Jarrett, 2010.

The bicycle needs to be attached to the outer drum at an angle as seen in

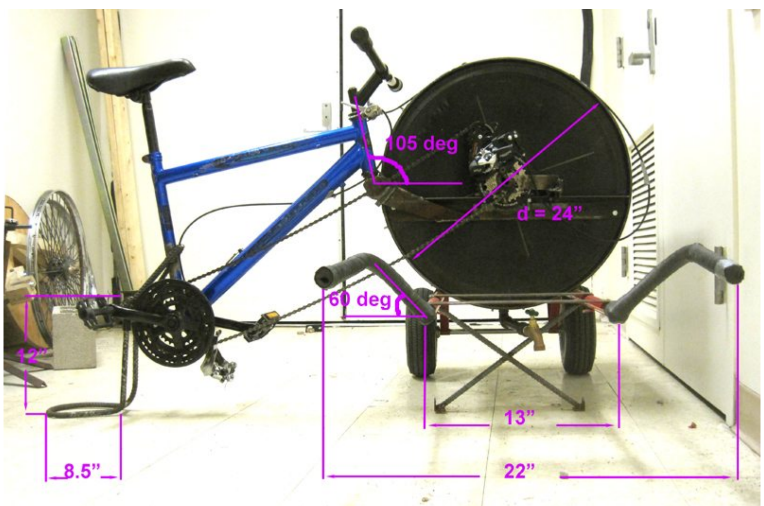


Illustration 23: Side view of the movilavadora in washing mode with dimensions. Image credit: Lu 2010.

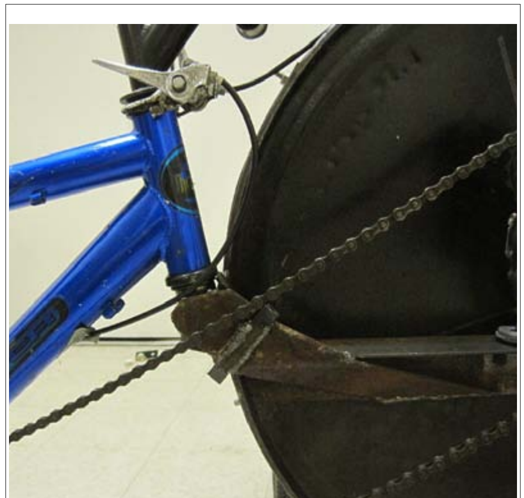


Illustration 24: Close-up of the bike to drum connection. Photo Credit: Lu 2010.

illustrations 23 and 24 This is so that the pedals do not hit the ground. This connection is made by welding the tube from the bike's fork at the angle necessary such that the rest of the bike can rotate about this fixed point. This is reinforced by welding on all sides. A close up is shown in illustration 24.

The chain connects from the bottom bracket of the bike to the freewheel on the inner drum's axle. After the freewheel has been attached, the derailleur can be installed. The derailleur system should be fit on the *movilavadora* upside down as seen in illustration 24. The L-piece in illustration 26 is made from two pieces of angle iron. The derailleur is one of the most challenging parts of the design, but the tension in the shifters is somewhat forgiving of imprecise welds. The L shape should be brought as close to the free wheel as possible, otherwise it will need to be bent to reach further gears.

The detachable stand/lock needs two tubes to be welded onto the bottom of the bike frame, perpendicular to ground as seen in illustration 27. These tubes are capped by welding flat stock to the tops. An appropriately sized piece of rebar should be taken and bent into a “U” shape so that the arms of the “U” are sized to slide into the tubes at the back of the bike frame. This distance should be the same as the distance from the outside of the top tube to the outside of the inner drum as seen in illustration x so that the stand can double as a lock. After measuring the height from the caps to the

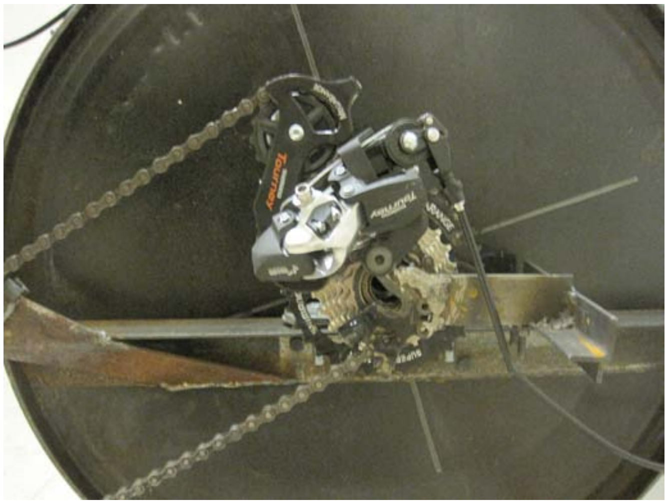


Illustration 25: Upside down derailleur. Image credit: Lu, 2010.

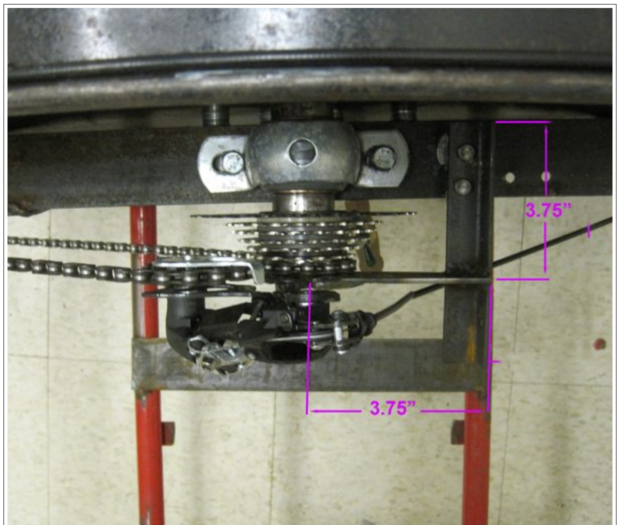


Illustration 26: Top view of the derailleur with dimensions. Image credit: Lu 2010.

ground, one should add a few 1/16ths of an inch on to account for the elasticity of the steel. This new height should indicate where to bend the bike stand/lock to make a foot on which it sits as seen in illustration 28.

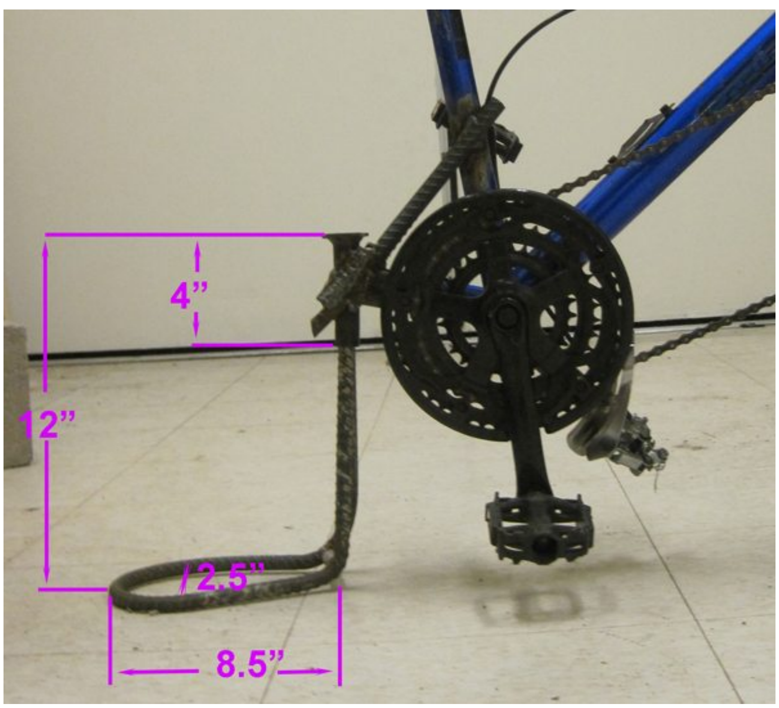


Illustration 27: Close-up of the removable stand with dimensions. Image credit: Lu 2010.

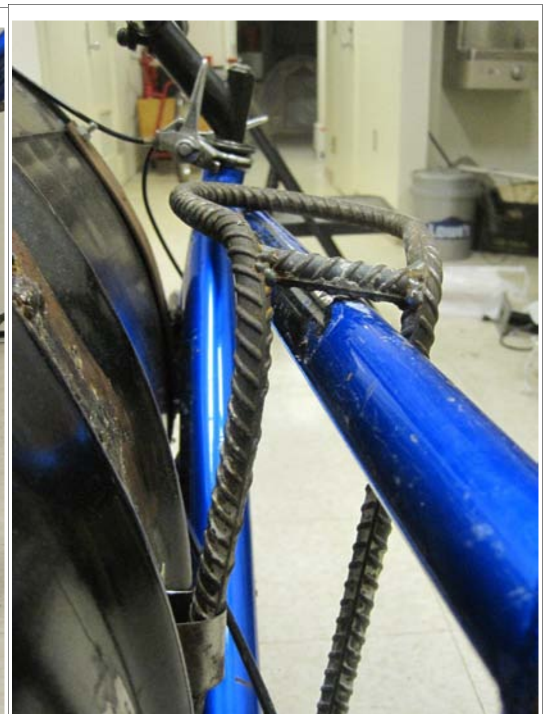


Illustration 28: The removable stand doubles as a lock when the movilavadora is in transportation mode. Photo credit: Lu 2010.

There are other benefits to using a bicycle. The machine relies on pedal power as opposed to fossil fuels. Unfortunately it is unlikely that enough people using electric washing machine users will switch to the *movilavadora* for a measurable benefit for the environment. The machine works without the derailleur, which is a fussy and complicated part of our design. This means that the manufacturer could opt out of using it in order to make it affordable to people with lower incomes.

The bicycle will be the main user interface once our product is disseminated. Once the machine was assembled, we had limited time using it as it might be used on the field. Based off of these short experiences, we are already able to see needs for improvements:

- •The seat is uncomfortable after prolonged use. This may be an issue given that the women are likely to work often and without breaks. This can be fixed by adding cushioning or replacing the seat altogether.
- •The bike handles are not located in a very ergonomic position. One needs to hunch over and lean on the palms. By doing something similar to the handles on the dolly, it may be more comfortable.
- •The transition presents a number of issues:
    - ○ The rotation of the bike is not constrained during transition from transportation to washing mode. It just keeps rotating. There needs to be a physical stop so that the chain is fed into the derailleur straight.
    - ○ The chain bends a bit when folded up for transportation mode. The tension could be relieved by somehow increasing the chain's length before folding so that it sags and turns instead of bending on its inflexible axis.
    - ○ The pedals have to be in a certain position for the transition to be successful. When the pedal is rotated correctly, it does not rub against the wheels. The method for transitioning needs to contain as few steps as possible.
- •The derailleur can be finicky to install and is non-intuitive to non-bike users. We should further develop the retro-direct or consider other alternatives to the derailleur. Additionally, a low cost yet durable way needs to be developed to keep the derailleur housing in place. It is currently stuck on with duct tape. It works, but something more permanent would be nice.

4.3.4 Mobility structure

The innovation of our design is adding mobility to the bicilavadora. This is accomplished by attaching the drum to the frame of a dolly as seen in illustration 29. There are four connections made with bolts and washers. We chose to connect at points rather than flat stock such that deformities that occurred would be isolated and not rip off sections of the outer drum.

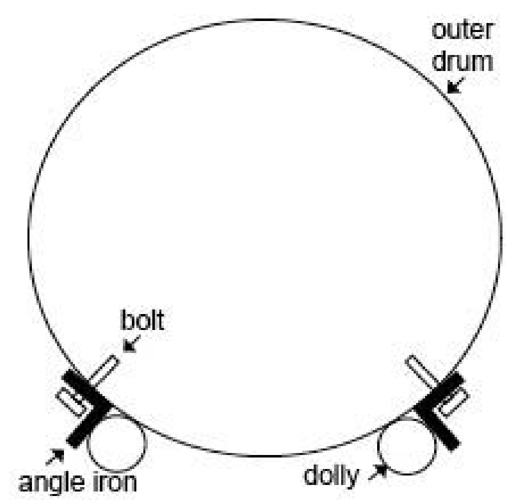


Illustration 29: Diagram of how the drum attaches to the dolly. The angle iron is welded onto four points on the dolly and then, the drum is bolted down. A washer is cut from a bike inner tube to seal on either side of each nut. Image credit: Jarrett 2010.

The dolly was serendipitously found in D-Lab and was chopped up to fit our needs. We kept the wheels, removed most of the lateral supports, and altered the handles to be more comfortable to push and pull the movilavadora across different kinds of terrains. The dolly was also modified to accommodate the removal of the inner drum for maintenance or in case something that has fallen between the ropes needs to be retrieved.

The main structure of the dolly is two parallel bars on which the drum rests. The wheel's axle provide one point of lateral stability. The laundry basket holder and the feet of the drum provide further support. We made the feet of the drum's bike-side lower than the height of the wheels, as seen in illustration 30, so that the water would drain out more effectively than in a flat surfaced barrel. Then, the original handles were cut and reattached. The new arrangement provides 22” of space so that someone can walk between them comfortably as seen in illustration 23.

The dolly provides many benefits. While the wheelbarrow is easily maneuverable, the lack of balance makes it a much more difficult task to man for long distances. On the other hand, a cart design would be more expensive and possibly over stable. Two wheels offer a good balance between these two options. The center of mass is low enough that our system feels ultra-light, but the handles are low enough to offer enough control over the machine. And with two independently moving wheels, the turning radius is not compromised noticeably.
Mobile business such as knife-sharpeners and fruit smoothie makers are common in Peru. The movilavadora's structure is also a “push-cart” technology that is identical is functionality to the aforementioned mobile businesses. Instead of biking with the washer, as one might do with a cycle rickshaw, a woman can comfortably walk with the machine, just like other businesses.

Illustration 31: movilavadora from the side with dimensions. Note the tilt downwards which helps the water drain to the spigot. Photo credit: Lu 2010.

In the future, it would be better to start our dolly from scratch, using local materials like angle iron, flat stock, and rebar. In this way, we could reduce our costs considerably. For example, we estimate that our $ 80 USD dolly could have been made for under $ 10 USD in almost any metal shop near Lima. There are two other issues with this prototype's structure: the outer drum door is difficult to remove while the oil drum is bolted to the dolly and the structure is not as easily moved in tight spaces as we would like it to be. If we had started from scratch, it is unlikely that we would have come across these two issues since we would have designed for them. However, working with a pre-existing object meant that we had to modify it to our needs instead. What if we could invent a way to fold the pedals in or to rotate the drum for transportation mode such that the bicycle sat on top of the outer drum instead of folding to the side? Obviously, further improvements are possible!

4. Next Steps

In general, our next steps concern market identification and product feedback. In particular, we will be coordinating with Limakids to determine how our project can work with their aims and needs. However, we believe that we need to expand beyond LimaKids in order to reach our targeted demographic. We would also like to identify and observe other house-to-house businesses. If there are other cart-based services that we could model ourselves after, it would be useful to document their business models for later reference.

Before summer 2010, our team is drafting a survey that will be used in Guatemala and Southern Peru by Connie Lu and Brooke Jarrett, respectively. We will collect data concerning work habits, typical income, etc. so that we can modify the design accordingly. If time permits, it would be best to build a prototype in order to gather specific feedback about user interface. In particular, the data could be used to create a cost-benefit analysis. This would further our design by knowing where we can cut our costs and what tradeoffs would be acceptable.

In the fall of 2010, Benji Moncivaiz will use the *movilavadora* for his 2.671 class. Here, we hope to detail a standardized experimental procedure. This will then be used to establish baseline statistics for comparison to future prototypes. In hopes that our document will serve as instructions for creating more pedal-powered washing machines, it will be brought to Peru and Guatemala to be reviewed by random samples of welding shops to survey whether they believe they would be able to copy the design based off of the information given. If there are negative responses, we will determine what is missing in order to complete this document.

Appendix 6.1: Pugh Charts

Pugh Chart for Washing Method

	Spin agitation	Washboard	Impact	Turbulent H20
Cleanliness	0	+	+	+
Gentleness	0	-	-2	-
Capacity	0	-	-	-
Water requirement	0	0	-	-
Initial force requirement	0	-	0	0
Steady-state power requirement	0	-	-	0
Active pedaling time	0	-	+	+
Cost	0	+	-	-
Blacksmith capability to manufacture	0	+	-	-
Capital required for manufacturing (machinery req'd)	0	+	0	0
Durability	0	-0.5	-	+
Ease of maintenance	0	0	-	-
TOTAL	**0**	**-1.5**	**-7**	**-3**

Pugh Chart for Drying

	Spin	Press	Wring
Dryness	-	+	0
Force Necessary	+	+	0
Time to drain and dry	+	+	0
Cost	0	+	0
Blacksmith capability to manufacture	+	0	0
Capital req'd to manufacture (machinery req'd)	+	-	0
Durability	-0.5	0	0
Ease of maintenance	-	0	0
TOTAL	**1.5**	**3**	**0**

Pugh Chart for Transport

	Bike	Backpack	Suitcase	It Rolls	Push-oven
Compactability	0	+	+	0	-
Cultural acceptability	0	+	+	+0.5	0.5
Distance	0	-	-2	-	-1.5
Turnability	0	+	+	+	-
Stopping time	0	+	+	+	-
Stability while standing	0	+	+	-	0
Stability while moving	0	+	-0.5	+	-0.5
Maximum safe speed for travel	0	-0.5	-	-0.5	-
Max weight for feasible transport	0	-	-	0	+
Cost	0	+	+	0	-
Blacksmith capability to manufacture	0	-	0	-0.5	0
Capital required for manufacturing (machinery req'd)	0	0	0	0	0
Durability	0	-0.5	-	-	+
Ease of maintenance	0	0	0	-2	+
TOTAL	0	3	0.5	-2.5	-3.5

empty page for fun

Appendix 6.2: Visual comparison between inner drum designs

Image removed due to copyright restrictions.
Still image from video clip, see full video at
http://www.youtube.com/watch?v=VhlUVdbU9Lk

Illustration 33: Wood from Radu Raduta for Guatemala (2005)

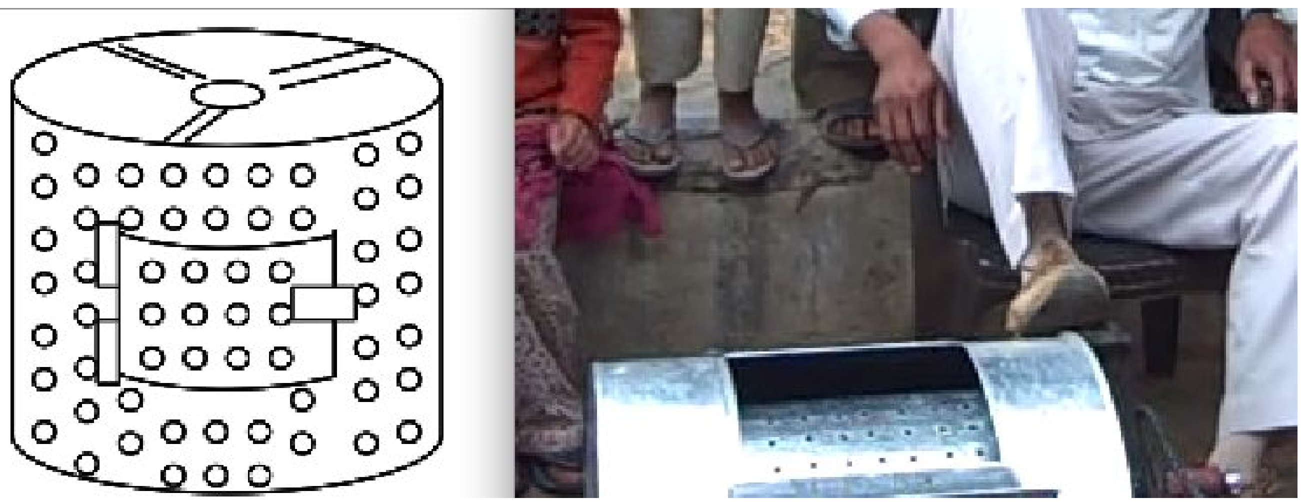


Illustration 34: Sheet Metal from Kathleen Li in India (2009)

Illustration 35: Plastic Barrel from Adam Talsma in Peru (2008)

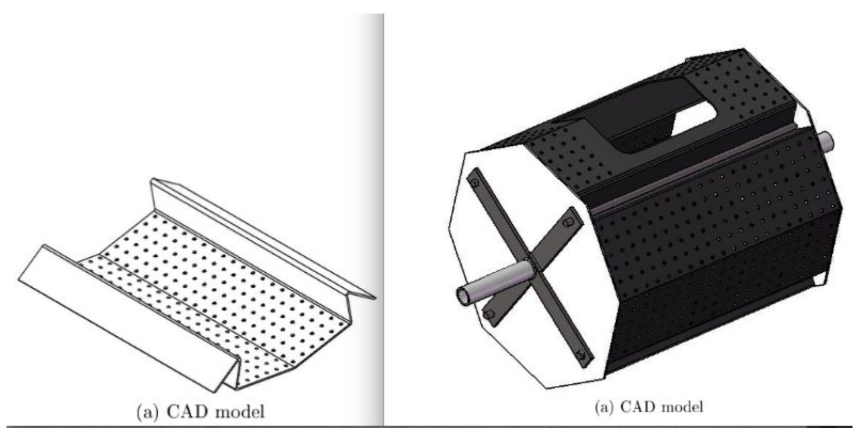


Illustration 36: ABS from Radu Raduta for Peru (2005)

Appendix 6.3: Design Specifications from Initial Planning

BASIC SPECS			
Design Specification	**Metric**	**Ideal**	**Acceptable**
Cost	USD	Pays itself off in three-months	Pays itself off in six-months
Blacksmith capability to manufacture	yes/no	yes	yes
Ease of manufacturing	Time	4.5 hours	10 hours
Capital required for manufacturing (machinery req'c	USD	1500 USD	1500 USD
Durability	Time Until First Critical Break	At least 2 years longer than payback period	At least 6 mos longer than payback period
Ease of maintenance	Number of Hidden Parts	0	2
EFFECTIVENESS			
Design Specification	**Metric**	**Ideal**	**Acceptable**
Cleanliness	Remain in Color Saturation	>90%	>80%
Gentleness	# of Buttons Lost / 10 loads	0	<1
Dryness	(Dry Wt / Wt Post-Process) / Std	greater than one	equal to one
FORM			
Design Specification	**Metric**	**Ideal**	**Acceptable**
Weight (loaded and unloaded)	Kilograms	<25 kg & 10 kg	<30 & 15 kg
Dimensions	Meters	Can comfortably clear a Peruvian doorway by >6 inches	Can comfortably clear a Peruvian doorway by >1 inch
Capacity	Weight of Packed Clothing	>15 kg	>8 kg
EFFICIENCY			
Design Specification	**Metric**	**Ideal**	**Acceptable**
Water requirement	Liters	<15	<18.3
Initial force requirement	Newtons	<225	<338
Steady-state power requirement	Watts	<45	<65
Active pedaling time	Time	15 minutes	25 minutes
Time from water collection to clothes on drying line	Time	1.3 hours	2 hours
Water Evacuation (drain time)	Time	7 minutes	10 minutes
PORTABILITY			
Design Specification	**Metric**	**Ideal**	**Acceptable**
Turnability	Radius of Turn	0 meters	1 meter
Stop time	Time	2 seconds	3 seconds
Stability (while standing)	Newtons Required to Topple	<450	<225
Stability (while moving)	Newtons Required to Topple	<450	<225
Maximum safe speed for travel	Meters per second	1.5x as fast as speed-walking	at least half the speed of speed-walking
ERGONOMICS			
Design Specification	**Metric**	**Ideal**	**Acceptable**
Culturally acceptance	Interviews	85% positive	70% positive
Ease of loading and unloading	Time Required to Load/Unload	<20 seconds	<30 seconds

Appendix 6.4: Rough Line Item Budget

Group	Cost (USD)	Notes
Bicycle	70	Cheap yet functional
Outer Drum	10	Cost listed online for recycle, empty
Inner Drum	28	Directly Calculated
Mobile Structure	40	Directly Calculated
Total	**148**	
Real Cost	**148**	This total excludes labor and things we received for free