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ARBORLOO CONCRETE BASE DEVELOPMENT

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ABSTRACT

Although toilets are something we take for granted in our day-to-day lives, providing access to adequate sanitation in developing countries is an ongoing challenge. One basic solution to ensuring the proper disposal of human waste is a simple concept called an arborloo—a moveable slab over a shallow pit that can be relocated when the pit is full. Our team made multiple improvements to the traditional arborloo base slab. By utilizing slab and dome geometries and a lightweight concrete mix composed of recycled, lightweight materials—including coconut shells and husks and ground Styrofoam—we have created a saleable product that is more easily adapted than the previous do-it-yourself process. The average weights of the slab and dome, 43.5 and 31.0 pounds, respectively, allow the arborloo to be lifted by inset rebar handles and carried comfortably by two people for long distances. With a cost of only $3.83 for the slab and $3.78 for the dome, the potential for this product to be adapted is great. This product will aid in improving the quality of drinking water and reducing related illness while also providing jobs and economic growth in the community.

BACKGROUND

An Arborloo is a simple and affordable technology for improved sanitation—a moveable slab over a shallow pit that can be relocated when the pit is full. The full pit is covered with soil and the pit compost can be used to promote the growth of a tree. In Haiti, where sanitation coverage has dropped from 26% in 1990 to 17% in 2010 [1], improving sanitation is crucial, especially in preventing illness caused by unsafe drinking water.

The standard arborloo design that was developed by Peter Morgan has been widely adopted in Africa, but there are still several shortcomings. The traditional “Peter Morgan” Arborloo, developed for use in Africa, takes two days to install on-site while the concrete cures. This 3'x3' rebar reinforced concrete base is heavy, consisting of a 2:1 ratio of sand to cement and weighing upwards of 190 pounds. If the base were to be sold as a product, transporting such a large, bulky object on foot or by donkey from the urban areas where they are produced, through the mountains, and to the rural areas where they are needed would pose a great challenge in Haiti. Also, the aesthetics of the current design, with a shelter made out of woven palm fronds and sleeping mats, is not considered appealing. Generally, there is not a perceived need to purchase and maintain Arborloos.

One way to make concrete lighter is to reduce the density. Lightweight concrete, such as that used by the RIT concrete canoe team can have a density of less than 62 lbs/ft^3 compared to the standard concrete density of approximately 140 lbs./ft^3 [2]. This low density is achieved by replacing the standard fine aggregate (less than ¼” diameter), sand, with Poraver, recycled glass beads. Although Poraver is extremely lightweight and has desirable strength characteristics, it is not a realistic lightweight solution due to its high cost. Instead, the team decided to use a testing-based approach to investigate non-traditional materials.

PROCESS

The team followed an engineering design process, which involved benchmarking, brainstorming, concept selection, and multiple iterations of prototype development, testing, and design refinement. A list of desirable attributes for our final design (Table 1) was developed in conjunction with our customer and guide, Sarah Brownell. These attributes were categorized based on importance in order to prioritize our subsystem development.

Very Important	The system supports the user over an arborloo hole 18-20” in diameter, 3-4 feet deep The system costs less than \$50-\$100 to users (at production level quantities). The system is lightweight and moveable (by donkey or person walking for up to 6 hours) The system can be installed in less than 4 hours. The system can be installed with simple hand tools. The system confers social status to the owner.
Important	The system is safe to use for users (falling, tripping, slipping, and moving to new hole). The system keeps pests out of the pit. The system looks “modern” in a Haitian context. The system is welcoming and comfortable. The system can be financed in parts.
Less Important	The system is a product, not a DIY project. The system resists weather and pest damage. The system minimizes environmental impact throughout the lifecycle.

Table 1: Customer Requirements

In order to verify that our design meets these customer needs, a set of engineering requirements were developed as testable quantitative measures. The most significant engineering requirements that we identified were purchase cost (less than \$50), load support (marginal of 270 lbs.), waste hole coverage (with a diameter of 20 in.), and weight (heaviest piece less than 100 lbs.). The complete list of the 15 engineering requirements with marginal/ideal values and the direction of improvement are presented in Table 2.

Importance	Function	Engr. Requirement (metric)	Unit of Measure	Marginal Value	Ideal Value
9	Minimize	Purchase Cost	\$	50	25
9	Maximize	Load it can support	lbs	270	450
9	Minimize	Time to assemble	hours	2	1
9	Minimize	Weight of heaviest assembled piece	lbs	100	80
9	Minimize	People needed to move heaviest assembled piece	qty	2	1
3	Maximize	Hole diameter it covers	in	18	20
3	Minimize	Squat hole widest point	in	9	11
3	Target	Tripping hazards	in	6	N/A
3	Minimize	Hand tools needed to assemble	qty	3	0
3	Maximize	90% of Users find easy to clean	%	90	100
3	Maximize	Lifecycle	Kg CO_2	27	27
3	Maximize	90% of Users find comfortable	%	90	100
3	Maximize	90% of Users find visually appealing	%	90	100
3	Maximize	Pieces for available upgrade	qty	2	3
1	Maximize	Static coefficient of friction against ground	-	0.5	0.6

Table 2: Engineering Requirements

The concepts we considered focused on the different slab geometries that could be used to achieve high strength with minimal volume and thus comparatively minimal weight. Methods of reducing the weight carried by a single person by dividing the slab into multiple pieces were also considered. The following geometries were considered and evaluated using the Pugh selection process: hollowed dome, hollowed cone, segmented oval, a crossed “X”, a cross-hatched “#” constructed from four beams, a simple square, and a triangle. Our selection criteria corresponded to the customer needs and all concepts were compared against the datum of the Peter Morgan arborloo.

The focus of our structural analysis was to see how well each shape performed during different loading scenarios. We used the finite element analysis software ANSYS to apply two different loading scenarios to evaluate the magnitude of stress to expect and how shape distributes the stress. We performed this analysis on five slab shapes: circular, triangular, square, hollowed out dome, and hollowed out cone.

The results of using ANSYS will largely depend on the mesh used, so it was essential that it was accurate. The mesh is how many different elements we split our geometry into in order to do an analysis, generally the more elements its split into the more accurate the software. After consulting with experts, we came up with a two-layer mesh that has a separate mesh around the hole, as shown in Figure 1 below. This separate mesh is to prevent a point load, which results in unrealistic stress values. After we had meshed the shapes we had to constrain the shapes around the outermost edge. Two different loading situations were used to simulate the loading: two feet standing beside the waste hole and another of a person sitting on a bucket nested in the waste hole. The scenario with the bucket was the worst case between the two loading cases because it causes more of a cantilever effect since the force is further away from the support. A key result of this analysis was determining the thicknesses needed for the desired strength of our final geometries. The locations of the maximum stresses were identified, which were useful during construction and can be seen in Figure 2 below in red for the dome. We were also able to see that the dome diffuses the stress rather well due to its geometry; tensile forces are lessened as the surface slopes downward from center to edge. As tensile stresses are absorbed by compressive strength, the dome is utilizing concrete's most advantageous characteristics.

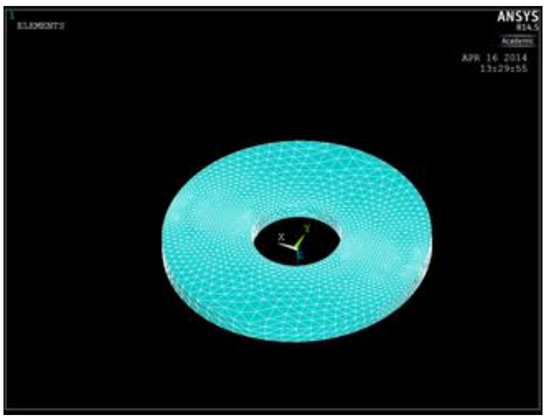

Figure 1: ANSYS Slab Model Mesh Area

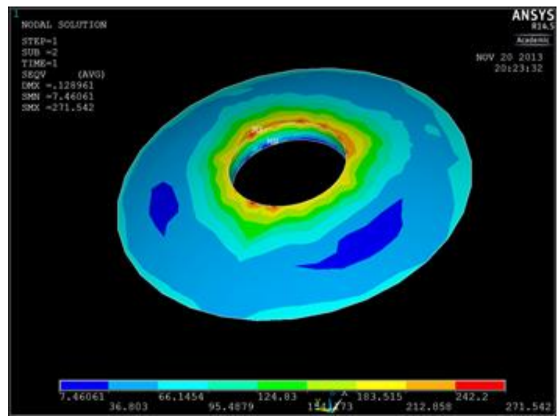

Figure 2: ANSYS Stress Plot of Dome

With an understanding of the strength requirements, we were able to focus on creating a lightweight concrete mixture. We explored lighter materials to replace those in the standard concrete mix of cement, sand, and limestone aggregate. We also tested mixtures with fly ash and slag, which are cement substitutes; however, we calculated that the cost of shipping these materials to Haiti exceeded that of cement and these materials were later excluded.

Of an extensive list of possible aggregate materials, we performed compression tests in mixtures including the following: Styrofoam, plastic beads, rubber mulch, limestone gravel, coconut shells, and sand. The compression testing was performed per ASTM C-39[3] and consists of applying a compressive axial load to molded cylinders at a consistent rate until failure occurs. Cylinders are sized 4" x 8" and compressed by two blocks, with one cylinder tested at a time. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross sectional area of the specimen. After testing various mixture prototypes (detailed in Table 3 below) we were able to determine that out of the aggregates we had tried that Styrofoam, coconut shells, and sand were able to give us a mixture that is light, inexpensive, and provides adequate strength.

The costs for materials in Table 3 were assumed based on June 2013 Haiti storefront prices, except for rubber mulch which was estimated based on US costs. Labor rates for preparing the materials were included and assumed to be \$6/day for unskilled labor and \$10/day for skilled labor based on standard 2010 rates for rural areas [5]. Processing and assembly times were estimated based on time studies of our process. Shipping costs were also included and based on volume of space occupied in a 20 foot shipping container traveling from Miami to Cap Haitien, Haiti (\$3700 for storage and loading, excluding customs fees).

Our ANSYS analysis indicated that our failure mode would be due to tension caused by cantilever loading and not due to compression. To combat this inherent weakness, we experimented with different types of fibers and mesh materials as means of tensile reinforcement by constructing a test specimen sized 4" x 4" x 14" and performing a flexural test per ASTM C-78 [4]. This test method consists of simply supporting a beam and applying a force at two equidistant points on top of the test specimen to determine the flexural strength of concrete. Results are calculated and reported as the modulus of rupture. The three materials we decided to test were coconut husk fibers, composite fibers used in industry, and a mosquito net mesh. After multiple trials, [Table 3] we concluded that the coconut fibers offered the best tradeoffs between cost, manufacturability, and strength.

As a means of reducing weight, we experimented with a product called Glenium, which reduces the amount of water needed in a mix. Glenium is used in a small amount and is inexpensive for one arborloo. It saves about 1.5lbs of pounds of water per arborloo, and allows the mix to reach its strength at an earlier duration than standard concrete. The reduction in water has the effect of reducing the weight of the concrete.

	Mix Percentage (Dry Weight)							**Other**				**Estimates for Peter Morgan Style Arborloo (1,256 in^3)**		
	Cement	Fly Ash	Slag	Rubber Mulch	Coconut Shells	Sand	Styrofoam	Glenium (in^3/in^3 wet mix)	Water-Cement Ratio	Reinforcement Type	Reinforcement Amount	Cost	Cured Weight (lbs)	Tensile Strength (psi)
Standard Mix	33.3	-	-	-	-	66.7	-	-	0.25	None	-	$ 3.50	79.06	345 [c]
Haitian Mix	33.3	-	-	-	-	66.7	-	-	0.25	None	-	$ 3.50	-	245 [c]
Mix 7	22.4	6.2	7.9	15.3	-	47.9	0.30	0.0020	0.74	None	-	$ 41.69	55.75	70 [c]
Mix 8	27.7	-	-		23.7	48.6	-	0.0016	0.45	None	-	$ 18.79	83.38	260 [c]
Mix 9	14.9	4.1	5.3	10.2	20.8	44.7	-	0.0016	0.74	None	-	$ 51.87	85.50	408 [c]
Mix 10	35.7	-	-	-	30.6	32.9	0.82	0.0016	0.39	None	-	$ 26.34	73.38	460 [c]
Mix 11 [a]	36.4	-	-	-	22.3	41.2	0.09	0.0018	0.37	None	-	$ 5.81	63.66	245
Mix 12 [a]	36.4	-	-	-	22.3	41.2	0.09	0.0018	0.39	Bird Net	2 layers	$ 6.32	63.56	309
Mix 13 [a]	36.4	-	-	-	22.3	41.2	0.09	0.0018	0.39	Industrial Fibers	16.2 g	$ 6.96	61.17	178
Mix 14 [a]	36.4	-	-	-	22.3	41.2	0.09	0.0018	0.39	Coconut Husks	8.2g	$ 5.81	61.50	239
Mix 15 [b]	33.3	-	-	-	-	66.7	-	-	0.25	Bird Net	2 layers	$ 4.01	79.06	272
Mix 16 [b]	33.3	-	-	-	-	66.7	-	-	0.25	Industrial Fibers	16.2 g	$ 4.65	77.10	401
Mix 17 [b]	33.2	-	-	-	-	66.7	-	-	0.25	Coconut Husks	14.7 g	$ 3.51	78.05	467
Mix 18 (Slab)	33.2	-	-	-	14.5	51.9	0.12	0.00100	0.20	Coconut Husks	14.7 g	$ 3.83	58.72	439
Mix 19 (Dome)	33.2	-	-	-	21.6	44.6	0.18	0.00120	0.26	Coconut Husks	14.7 g	$ 4.58	52.30	403

[a] Mixes 11-14 were from the same batch except for added reinforcements
[b] Mixes 15-17 were from the same batch as standard mix except for added reinforcements
[c] Tensile values estimated as 20% of compression strength given by ASTM C-39

Table 3: Mixture Compositions and Test/Cost Results

Multiple test plans were developed to evaluate the performance of our designs and ensure consistent, quality procedures were used in our testing. In order to make sure that different batches of concrete mixtures were comparable, we measured slump (per ASTM C-143 [6]), a measure of the consistency and workability. We also recorded the wet weight/density of the mixtures to compare to the dry mixtures and assess the quality of the cure.

Multiple tests were conducted in accordance with the engineering requirements. The tests outlined below were carried out to evaluate the performance of our designs as they relate to the high importance customer needs. In addition, measurements were performed to assess tripping hazards, compressive strength, tensile strength, and determining the pieces available for upgrade.

<u>Load Support / Impact Tests</u>: This test involves setting a sheet of plywood with a 22” diameter hole in the center on top of bricks. The concrete base is then made concentric with the plywood hole and a 5 gallon bucket is placed inside the squat hole of the concrete base. Next, known weights are added in increments (starting off with larger increments and get smaller as the test goes on). Any signs of failure (if any), such as cracking, are observed after each new weight is added. This test is used to make sure the base is strong enough to support the people using it. Also, if the base is able to hold 500 lbs and not show any signs of failure, a weight of 200 lbs is taken and dropped from 6” above the hole to simulate impact loading. This test is done to make sure children or people jumping on the base won’t break it.

Size / Weight Tests: These tests involve recording the dimensions (outside/ inner diameter, inside/ outside thickness, height, width) of the concrete base using a tape measure. A sheet of plywood with a 22" diameter hole in the center is placed on the ground and the arborloo is placed concentrically around the hole. Measurements from the outside diameter of the base to the diameter of the plywood hole are made in 6 spots (roughly 60 degrees apart) to determine how well the base covers the waste hole and assess how much of the base is touching the ground. The squat hole is also measured in a similar manner. The weight was simply recorded using the machine shop scale.

Lift and Carry Test: The concrete base is placed on the ground and one person tries to pick it up. If the base can't be picked up with one person, another person is added. This process is repeated, adding as many people as needed, but one at a time, until the base is picked up. If the base is able to be lifted, the base is to be carried by however many people to the Innovation Center and back. Any comments about carrying the base are also noted along with the number of people involved.

Time to Assemble / Hand Tools Needed to Assemble Test: This test involves having all the materials laid out and the stopwatch is started once the "mixers" have begun. The mixers weigh/measure out the quantities provided for the mix. After the mix is ready, the mold is then laid up with the fresh concrete. The stopwatch is stopped once the mold is determined to be the correct thickness. Upon mixing, any tools used are documented.

Life Cycle Assessment: The life cycle assessment (LCA) was conducted using SimaPro Life Cycle Assessment Software and information from the EcoInvent database to quantify the environmental impact associated with manufacturing, distributing and disposing of our two arborloo designs compared to Peter Morgan's original design. One of the main assumptions made for this analysis is that the bases will be made in Le Borgne, Haiti. Additionally, Portland cement and the ¼" rebar for the handles will come from Santo Domingo, Dominican Republic, be trucked to Cap Haitien, Haiti, and then be trucked to Le Borgne, Haiti (255.2 miles). The sand and water being used will be coming from Le Borgne, Haiti. The polystyrene being used in the bases will be coming from recycled Styrofoam clamshell containers, which are also very abundant in Haiti in the form of trash. The coconuts in our design will be gathered and crushed manually. The material amounts used for the LCA are consistent with those stated in Table 4.

RESULTS AND DISCUSSION

Based on the Pugh selection process as supplemented by the ANSYS analysis, we decided to pursue a dome shape and a Peter Morgan-style circular slab. The dome was selected primarily for its load-bearing abilities. Among the simple, flat geometries, the circle shape was chosen since it covers the pit hole with the least amount of extraneous material. The modular shapes were discounted due to safety and installation challenges along with the fact that joining separate concrete pieces requires a high level of shape precision. Figure 4 shows the geometry and dimensions of our circle slab design, with an outer diameter of 30 inches, an inner diameter (squat hole diameter) of 10 inches, and a thickness of 1.5 inches. We were able to reduce the thickness from 2 in. to 1.5 in. through testing. The mold design is shown in Figure 4 uses spring steel that was rolled to diameter with flanges welded to attach each half. Spring steel was chosen for the circular slab mold because of its ability to be welded, concrete release capability, and structural rigidity. To cover the waste hole, a concrete lid was molded from the bottom of a 5 gallon bucket and has small rebar handle on the top for easy handling. Since the original squatting hole in the base is created by the bottom of a 5 gallon bucket, the two mate perfectly.

Figure 3: Circle Slab Design

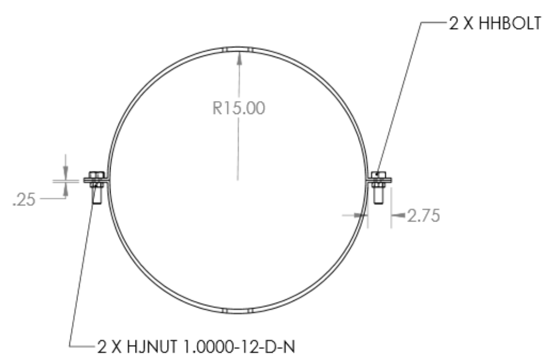

Figure 4: Circle Slab Mold

The dome geometry and dimensions are shown in Figure 5 along with the mold in Figure 6. Similarly, this design has an outer diameter of 30 inches, an inner diameter of 10 inches, a thickness of one inch, and a change in depth (bottom surface to top surface) of approximately four inches. Originally, we tested a plastic saucer sled for the dome arborloo; however, the dimensions were not desirable which led us to explore Styrofoam for its ease of manufacturing. This gave us the ability to choose our exact dimensions. The mold is constructed from Styrofoam housing insulation. Four one-inch thick squares were glued together and the dome slope was sanded in and smoothed out. We then used plastic sheets to protect the Styrofoam for re-use and to provide an effective release interface.

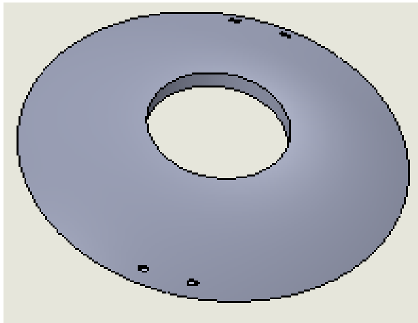

Figure 5: Dome Design

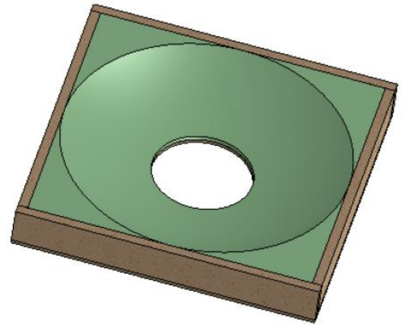

Figure 6: Dome Mold

Our goal was to find a mix that was lighter than a standard concrete mix, strong enough to support our loads at the cheapest cost to the end consumer. Considering the tradeoffs that each ingredient presents, we were able to develop the mix shown in Table 4 below. The composition of Peter Morgan's base is also shown for comparison.

Design	Material	Amount	Unit	Cost
Circular Slab Base	Portland Cement	24.2	lb	$1.62
	Sand	27.4	lb	$0.43
	Coconuts (Shell and Husks)	14.80	lb	$2.96
	Reused Polystyrene	0.250	lb	$0.00
	Water from River	9.5	lb	$0.00
	Steel Wire (1/4")	14	In.	$0.66
	Glenium	37.5	mL	$0.11
Dome Base	Portland Cement	16.91	lb	$1.13
	Sand	19.11	lb	$0.29
	Coconuts (Shell and Husks)	14.49	lb	$2.72
	Reused Polystyrene	0.245	lb	$0.00
	Water from River	8.5	lb	$0.00
	Glenium	28.0	mL	$0.08
Peter Morgan's Base	Portland Cement	59.12	lb	$3.95
	Sand	177.36	lb	$2.73
	Steel Wire (1/4")	2.004	lb	
	Water from River	29.55	lb	$0.00

Table 4: Final Mix Compositions

Figure 5 below shows the environmental impact of each base option measured in ecopoints. The larger the ecopoint score, the greater the negative environmental impact. The results show that our designs generate about 3.5 times less negative environmental impacts than Peter Morgan's.

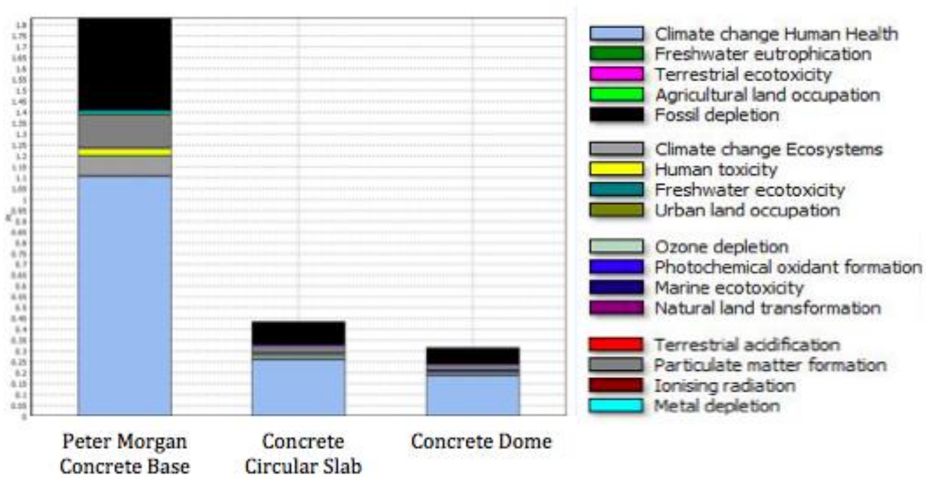

Figure 5: Environmental Impacts of Concrete Arborloo Base Designs

The majority of the negative environmental impact is because of the amount of fossil depletion needed for lorry transportation of materials as stated previously. The sand and water coming from Le Borgne, Haiti have very minimal environmental impact because of their local abundance. The use of recycled polystyrene and coconuts is the major reason for the small ecopoint values of our designs. A small number 'single unit truck miles' were accounted for the transportation of the coconuts around Le Borgne. Both concrete arborloo bases had the same materials and used the same processes, just in differing amounts. Peter Morgan's base only used Portland cement, sand, rebar, and water. One recommendation to get the ecopoints values even lower for our designs would be to use even less Portland cement and to try use recycled rebar from Le Borgne.

The following are the test results as related to the engineering requirements [Table 5].

Importance	Engr. Requirement (Metric)	Unit of Measure	Customer Req	Marginal Value	Ideal Value	Slab 1	Slab 2	Slab 3	Slab 4	Dome 1	Dome 2	Dome 3
High	Purchase Cost	$	1	50	25	8.97	3.83	N/A	3.83	3.78	3.78	3.78
High	Load it can support	lbs	3	270	450	502	375	N/A	490	403	225	285
High	Hole diameter it covers	in	2	18	20	22	22	22	22	22	22	22
Med	Squat hole widest point	in	3	9	10	10.50	10.25	N/A	10.35	10.42	10.42	10.33
Low	Static coefficient of friction against ground	-	3	0.5	0.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Med	Tripping hazards	in	3	6	N/A	2.03	1.46	N/A	1.53	3.9	4.04	4.02
High	Time to assemble	hours	5	2	1	1.25	0.75	0.76	1	1	0.93	0.60
High	Hand tools needed to assemble	qty	1,5	3	0	1	1	1	1	1	1	1
High	Weight of heaviest assembled piece	lbs	4,5	100	80	63.00	43.50	40.0	59.50	31.02	30.91	36.5
High	People needed to move heaviest piece	qty	5	2	1	2	1	N/A	2	1	1	1
Low	90% of Users find easy to clean	%	4,5	90	100	To be tested in Haiti						
Med	Lifecycle	kg CO_2	1,8	27	27	6.5	6.5	6.5	6.5	4.5	4.5	4.5
Low	90% of Users find comfortable	%	6	90	100	To be tested in Haiti						
Low	90% of Users find visually appealing	%	7	90	100	To be tested in Haiti						
Med	Pieces for available upgrade	qty	9	2	3	3	3	N/A	3	2	2	2

Table 5: Prototype Test Results

Slab 1 was our first mix, which contained too much coconut and had a thickness of about 2". Slab 2 was our improved mix with less coconut for improved workability. Slab 2 also contained a thin layer of sand, water, and cement to help with our surface finish. We also thinned out the slab to a thickness of about 1.5" to reduce some of the weight. Slab 3 used the same mix as in Slab 2 along with the same thickness and thin layer of concrete on top for an improved surface finish. Slab 4 was the same mix and thickness, but also included handles. For Slab 4, we used more than 0.25" of the thin layer of concrete to help hold the handles and this is where the extra weight came from.

None of the domes included a thin layer of a regular concrete mix. The surface finish of the domes was smooth due to the mold itself. Dome 1 was made using our improved mix (the same mix used from Slab 2 and on), using less coconut for improved workability. Dome 2 was the same mix as Dome 1. Dome 3 used the same mix, but to help increase the thickness along the edges, we added some of the regular concrete mix to fill in some spots and this added to our weight.

Overall, we were able to design a product that can be produced, and more importantly installed, in an efficient manner. The greatest amount of labor required to prepare the raw materials--grinding the clamshell containers into pieces and crushing the coconuts--can provide jobs to the community. The mixing and measuring will be performed by a trained mason. The arborloo base safely covers a 22" diameter hole and doesn't introduce any new tripping hazards. As far as being transportable, the best weight recorded for the dome was 31.02 lbs compared to the circular slab of 43.5 lbs, both under the marginal weight of 80 lbs. The bases can be lifted by one person and comfortably carried by two. Most importantly, in regards to strength, the bases are able to support the weight of the people using them. The best results for the dome and slab were 403 lbs and 375 lbs, respectively.

CONCLUSIONS AND RECOMMENDATIONS

For the next stage of the project we have some recommendations that might have suited our multidisciplinary team during our time together. In order to have a better understanding of the static properties of concrete, placing a civil engineer on the concrete arborloo team is a strong recommendation. His or her knowledge and accelerated background in strength testing, aggregate selection, and overall mixing skills would save a lot of time and potentially make for a better final product. In addition, during future phases of this concrete arborloo we would suggest perfecting the molds used to cast the concrete. Specifically, making the geometry of the mold more precise, thus avoiding point loading which induced stress concentrations and ultimately made the prototypes weaker. Another recommendation for future work would be to focus on reducing the weight of the mixture further.

Overall, this project was successful for us on many levels. Not many MSD teams get to work on a long-term project that has the potential to affect so many lives for the better. Being involved in a sustainability project has allowed our group to not only focus heavily on the highly constrained requirements of the customer, but also cultivate our code of ethics that has been instilled since the beginning of our careers at RIT. More specifically, we were able to learn about materials (i.e. coconut, aggregates, etc.) that we had little to no exposure with before. With the majority of our efforts going to our design and concrete mixture, we were able to investigate the properties and performance differences between many common concrete ingredients; as well as, benchmark several "grassroots" materials. For example, we went through several iterations meeting with the experts at the local concrete mixing company, Manitou Concrete. Experts there introduced us and provided us with several key ingredients such as glenium and many different tensile reinforcement materials. As a team, we were successful in reaching out to many different concrete and composite experts and using their guidance effectively in developing a successful design.

Another crucial part about our team's success; perhaps less technically, was our team's ability to maintain positive meeting environments and effective communication. There was little to no arguing during our most important meeting phases, usually ones before major design reviews. Our effective communication became evident right from the beginning as we have several team members with very different schedules. As a group, we were able to delegate roles appropriately with the right individual taking responsibility for something that they were most suited for. There was a division of workload, and everyone was always encouraged to share opinions.

Concluding with a failure for any task is very disappointing, instead of failures, we would consider them missed opportunities. The area we fell most short was probably our investigation into other, more common lightweight aggregates. Although expensive, there was little investigation by any of our team members for any similar materials that had similar strength and weight properties. The amount of time spent during the mixture testing might have been the largest culprits for this "failure." Similarly, we spent a lot of our money (relatively) on cylindrical testing molds, and although this was a very basic way for us to learn about the properties of concrete (compressive strength), the results from these tests did not really tell us much about how the prototypes would handle arborloo forces.

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