Multidisciplinary Senior Design Conference
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PLASTIC ARBORLOO BASES FOR HAITI

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ABSTRACT

Arborloos are moveable pit latrines that are designed to be more affordable than other sanitation options, targeted at consumers lacking basic sanitation. Arborloos have been employed with success previously in several areas of Africa. [1] The purpose of this project was to create two low-cost, plastic, Arborloo bases that would be adoptable products for the Haitian people; the majority of whom lack the most basic of sanitation. [2] Two different base designs were developed; the first design, the Vacloo, used vacuum formed high-density polyethylene (HDPE) with steel rebar supports. The second design, the Deckloo, used plastic lumber boards made from 100% recycled HDPE. The designs were load tested and supported over 570lbs without failure; a value several times higher than the typical loading scenario of 120lbs they will experience in use. [3] The designs are also lightweight, making them easily portable for transportation and installation, both weighing less than 18lbs. The designs have proven to be cost effective, with the Vacloo and Deckloo costing approximately 20 USD and 41 USD respectively. The designs that have been proposed, analyzed, and tested have been designed to meet the needs of the Haitian population, making them easily adoptable, cost effective, portable, and safe.

BACKGROUND

Inadequate sanitation is a major cause of preventable illnesses in children around the world. According to UNICEF, diarrhea alone causes over 1.5 million deaths in children under 5. [4] These illnesses can easily be prevented by improving sanitation. However, cost is a major barrier limiting the adoption of sanitation in Haiti. [5] One tool to improve sanitation is the Arborloo. The Arborloo is a simple latrine built over a small pit, which when filled is then moved to a new pit location. The old, filled pit then has vegetation planted on top of it, such as a fruit tree. [1] The problem with the current state of the Arborloo is that it is difficult to adopt in rural areas due to lack of skills and knowledge for do-it-yourself construction, and transportation difficulties. [6] The desired state for the system would be a low cost, portable, easy to assemble, and aesthetically pleasing Arborloo base that can be financed in parts. The main project goals are to analyze the current Arborloo base design to find opportunities to incorporate plastic and create a product, with the end goal of improving sanitation in Haiti.

PROJECT SUMMARY

The goals for this project were to use Multidisciplinary Senior Design I (MSDI) to design two different Arborloo bases that used plastic following a strict design process, and to then build and test prototypes for each in Multidisciplinary Senior Design II (MSDII). The major constraints for this project were the system should incorporate plastic, be compliant with the skills and tools available to the intended population, and be financeable in parts. The budget for this project was $2900. The two designs that were selected and built during MSDI and MSDII are called the Vacloo and the Deckloo.

The Vacloo is primarily constructed from vacuum formed HDPE and steel rebar. The main structural support for the design comes from the rebar, which forms a grid similar to two pound signs (#) that rest on top of each other. The rebar extends beyond the edges of the plastic and digs into the ground after the design is installed on location, which helps to provide stability and prevent movement while in use. Additionally, during assembly the device is inset slightly into the ground so that the outer perimeter flange of the plastic and the rebar are covered by a thin layer of dirt. The HDPE sheet is vacuum formed to create recesses for the rebar to nest inside of, and to create ribbing to increase the load distribution. A second, flat, piece of HDPE rests on top of the vacuum formed section to provide a surface to stand on, aid with load distribution, and increase the strength of the device. There is also another smaller section of HDPE which serves to cover the opening of the squat hole in the device when not in use. The entire device weighs 14.5lbs when assembled and is designed to support 270lbs.

The Deckloo is constructed from plastic lumber boards made from 100% recycled HDPE. The design has thinner sections of HDPE which lay next to each other to form the top surface to stand on. This is supported by several thicker cross-member sections of HDPE under the top surface that run perpendicular to the top boards. The inspiration for the design was based on the standard design layout for most common household decks and patios. The design is slightly inset into the ground to provide stability and prevent movement while in use. Also, there is an additional piece of HDPE to cover the opening to the hole below while the device is not in use. The entire device weighs 17.4lbs when assembled and is designed to support 270lbs.

rqmt #	Source	Engr. Requirement (metric)	Unit of Measure	Marginal Value	Ideal Value	Pass Fail for Deckloo /Vacloo
S1	CR6, CR4, & CR1	Cost in lots of 1000	$	100	50	P/P
S2	CR2	Force supported by base	N	>1200	>2000	P/P
S3	CR2	Arborloo hole is covered by base	m	0.45	0.54	P/P
S4	CR2	Maximum squat hole diameter	m	<=0.25	<=0.25	F/P
S5	CR2	Static coefficient of friction		>0.5	>0.6	P/P
S6	CR2	Maximum change in level (tripping hazard)	mm	6mm	0mm	F/F
S7	CR7	Time to assemble on site	hrs	4	1	P/P
S8	CR5 & CR1	Complexity of tools needed at use location	Scale of 1-3 tool complexity	3	1	P/P
S9	CR5 & CR3	Weight of largest assembled component	N	4320	2160	P/P
S10	CR3 & CR5	Weight of largest unassembled component	N	392.6	196.2	P/P
S11	CR10	Ease of cleaning		cleans with soap, water, and abrasive sponge	cleans with water and cloth	P/P
S12	CR12	Maximum gap size (pest entry)	mm	2	1	P/P
S13	CR11	Life duration	Yrs	>3	>5	P/P
S14	CR6	Life Cycle Cost/year of service	Kwh			P/P

Table 1 - Engineering Requirements

PROCESS

The Customer Requirements (CR) were developed by performing customer interviews and studying research literature regarding the factors limiting Haiti's access to sanitation. The customer requirements were ranked in terms of importance with the most important requirements being that the Arborloo is a product, is safe to use, is portable, is financeable in parts, is easy to assemble, and is economically feasible. The Engineering Requirements (ER) were derived from the CR; shown in *Table 1 - Engineering Requirements*. The House of Quality (HOQ) tool was then used to weight the priorities of the ER. Cost was found to be the most important requirement and drove many of the design decisions. Using the HOQ, a Pareto Chart, shown in *Figure 1 – Pareto Chart*, was constructed, which visualized that the most important ER were S1, S2, S8, S9, and S10.

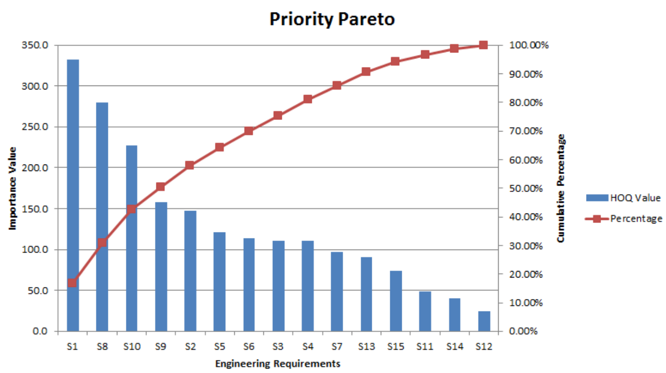


Figure 1 – Pareto Chart

Benchmarking was the first tool employed during the concept selection phase. Plastic structural products such as plastic lumber and plastic tables were researched and studied. The team also benchmarked manufacturing techniques. Blow molding, vacuum forming, rotational molding, and injection molding were researched and judged based on their feasibility and cost. After benchmarking existing products and processes the team brainstormed 14 possible concepts. A Pugh selection matrix was then used to compare the concepts. The team finally voted to continue development on four of the designs.

Vacuum forming as a process was selected primarily on the basis of feasibility and cost effectiveness. For the scope and scale of this project, injection molding, blow molding, and other molding processes required expensive molds with costs ranging on the order of tens of thousands of dollars. [7] The ability to vacuum form on campus at RIT greatly decreased the amount of cost associated with producing a functional mold as well as functional prototypes, which was a main factor in the process selection in MSDI. However, after struggling in MSDII to vacuum form any thicknesses of HDPE on campus, the team turned to a local company to produce prototypes. The simplistic nature of vacuum forming as a process opens up the opportunity for someone in Haiti to have and operate a machine and produce the bases there. The machine could either be built from commonly available parts or purchased and donated. [8]

Mock-ups of the four concepts were constructed to determine fit and function. It was determined at this time that two of the four concepts, the conical and pyramidal ones, were impractical for use and were dropped from further development. It was also determined that the initial squat hole sizing for what would eventually become the Deckloo was too small for practical use. The brittle properties of Acrylonitrile butadiene styrene (ABS) plastic were observed after vacuum forming trials. This prompted a discussion which brought about the shift from the initial material of ABS to HDPE for the Vacloo design.

HDPE was finally selected as a material because it has decent strength properties and is inherently very ductile. [9] HDPE is suitable for outdoor environments and has better UV resistance when compared to other plastics such as ABS. [10] The deep draw characteristics of HDPE make it a suitable material for vacuum forming. [11] HDPE is relatively cheap compared to other plastics such as polycarbonate. Additionally, because of the extreme ductility of the material, it becomes very difficult to have catastrophic failures with HDPE because it simply deforms, as opposed to cracking or breaking. [9]

Feasibility

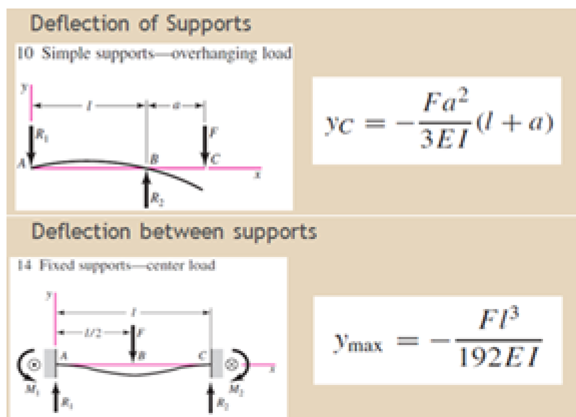


Figure 2 – Deckloo Structural Analysis

Stress and deflection analysis was conducted using two methods. For the Deckloo, the main concern was high deflections because of the highly elastic behavior of HDPE, and was modeled using cantilevered beam style analysis.The deflection analysis of the supports and between the supports can be seen in *Figure 2 – Deckloo Structural Analysis*. For the Vacloo, ANSYS software was used to model two loading scenarios: 270lbs and 120lbs. The 270lb value was selected because it was the marginal value for the ER for loads to support, S2, and the 120lb value was selected because it represented a typical loading scenario for the device in use in Haiti. [2] For this analysis, the rebar and HDPE were analyzed separately. This analysis method was chosen because the rebar was designed to support the entire load, and the plastic only needed to support the load across an unsupported gap between sections of rebar. For the rebar, the load was distributed across a 4in diameter circle, centered about the innermost section of rebar on one side of the design; simulating a person standing on one foot in the location causing the most cantilevering over the hole in the ground. For the plastic, the largest unsupported section was modeled and loaded with the same 4 inch circular load, centered about the center of the plastic segment. The rebar for the Vacloo was also analyzed to find the number of cycles of use that it could support before failure using the peak stress values from the ANSYS analysis and a distortion energy failure theory.

To establish the costs of the two designs the costs of the materials required, shipping and manufacturing were combined. Shipping costs were estimated based on the volume of the materials used and how they would stack into a standard shipping container with a specified base cost of US$3000. [12] It was assumed that the arborloo materials would be shipped from Miami, FL to Port-au-Prince, Haiti by boat. The assumption was that the materials would be sourced from within 30 miles of the port in Miami. It was also assumed that the materials would be shipped in a full 20 foot shipping container. Finally, it was assumed that once the materials arrive in Haiti, a pick-up truck would be used to transport the materials to Borgne. Labor costs were based on labor rates per hour in Haiti, with the rate for a welder/fabricator being US$10.00/day. [6] The times for labor were calculated using Therbligs, an analysis tool for calculating the times for specific actions [13], with assumptions on times based on expert opinions and video of actual processes. [14]

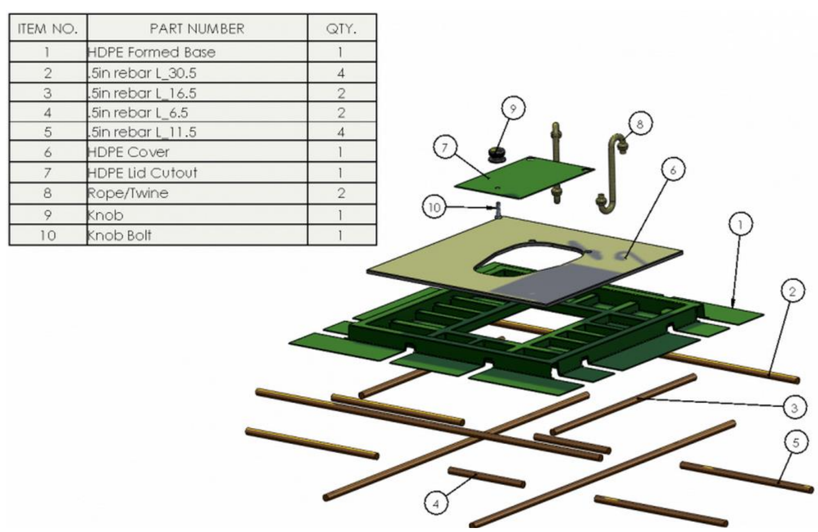
As the environmental impact of each product is a concern, it was necessary to perform a life cycle assessment (LCA) for each design. The assessments were then compared to the LCA of Peter Morgan's arborloo to create a baseline. The LCAs required the input of raw material extraction, manufacturing process, energy required for assembly, and the transportation distance and methods to represent the complete life of the bases from creation to disposal. Several assumptions were made to accommodate the gaps between the known and unknown aspects of the products life cycle. These assumptions were made across all of the designs to ensure a fair comparison. Regarding the transportation of the designs and the materials associated, it was assumed that all material would be resourced within 30 miles of Miami, FL. It was also assumed that the materials would be shipped from Miami, FL. It was assumed that all products would be assembled in the Port-au-Prince region because of the availability of electricity sources.

For each ER, a test was developed that could be applied to any design prototype; there were 14 tests created in total. Each test was performed under the same conditions and compared to the respective engineering metrics. The test for ER S1 was a cost analysis based on the assumptions described previously. The test for ER S2 used a custom set of loading fixtures to simulate a person standing on the bases and followed ASTM E455. For each base there was a fixture to simulate the ground during the test, and there was a second fixture that held standardized gym free-weights which had two posts underneath to simulate the feet of a person standing on the base. The tests for ER S3 and S4were conducted using a tape measure. Material properties of the materials, as specified by the suppliers, were used to ensure that ER S5 was satisfied. The tests for ER S6 and S12 were conducted using dial calipers. The tests for ER S7 and S8 were conducted base on observation and a stop-watch during the installation process. The tests for ER S9 and S10 were conducted using a scale. The test for ER S11 was conducted using organic compost matter to soil the prototypes and a wet rag cleaning. An ideal durability test for ER S13 could not be conducted due to time constraints. Instead, analysis was conducted based on the aforementioned mechanical analysis of the designs for cycles to failure and weather degradation. The test for ER S14 was conducted using SimaPro software for the LCA.

RESULTS AND DISCUSSION

VACLOO

The Vacloo, shown in *Figure 3 - Vacloo*, was designed with three primary components: a base, support frame, and cover. Additionally, there are four secondary components: a lid, knob, bolt, and section of rubber. The functions of the base are to provide a barrier between the user and the pit and to house the rebar support frame. The base was vacuum formed using a 2-ft square sheet of sixteenth inch thick HDPE. The physical, dimensional size of the base ensures the base meets ER S3 for size of hole covered by base. To maximize squat hole functionality, ease of use, and meet ER S4, a six inch by nine inch rectangular section of material was removed from the base to create a passage for waste entering the pit. This section of removed material was used at the lid for the device.



ITEM NO.	PART NUMBER	QTY.
1	HDPE Formed Base	1
2	.5in rebar L_30.5	4
3	.5in rebar L_16.5	2
4	.5in rebar L_6.5	2
5	.5in rebar L_11.5	4
6	HDPE Cover	1
7	HDPE Lid Cutout	1
8	Rope/Twine	2
9	Knob	1
10	Knob Bolt	1

Figure 3 - Vacloo

The rebar support frame was designed to fit the vacuum formed base. The function of the support frame is to provide adequate strength and durability to the support an individual's weight over the pit. A secondary function of the rebar is to secure the entire assembly to the ground, with rebar that extends past the vacuum formed plastic of the base and is buried in the surrounding terrain. Half inch steel rebar was selected as the material for the support structure because of its availability and ability to be welded in Haiti. Steel rebar exhibits excellent mechanical properties which ensure ER for force supported by base and life duration, S2 and S13 respectively, are met. The top layer of the support frame is to fit under the outside perimeter rib structure. The top layer is constructed using two 30.5 inch length sections, and two 16.5 inch length sections, which are welded together. The bottom layer of the support frame is to fit under the inside perimeter rib structure located near the squat hole. The bottom layer is constructed using two 30.5 inch length sections, two 10.5 inch sections, and two 6.5 inch sections.

The cover rests on top of the base inside the perimeter of the outer ribs. The major functions of the cover are to hide the exposed ribbing features, to provide a secure platform for the user to stand on, and to distribute the weight of the person across the rebar supports. The removable cover allows for easy cleaning and upkeep of Arborloo; ER S11 and S15. The cover is made using a 16 inch by 16 inch sheet of 0.25 inch HDPE. The ER for maximum gap size, S12, states that the maximum gap size is not to exceed .08 inches. A cover that is 16 inches by 16 inches results in a maximum gap size of .06 inches, meeting the requirement. The 0.25 inch cover thickness was selected to account for the unsupported gaps for ER S2. An elliptically shaped hole is cut into the cover, centrally located, to provide a functional passage for both liquid and solid waste entering into the pit. The shape mimics the squat hole shape used in Peter Morgan's Arborloo and was tailored to meet the size requirements of ER S4. The cover has two 0.25 inch holes drilled above the elliptical shape to provide an attachment mechanism for the lid.

The aforementioned rectangular cut out from the vacuum formed base is used as the primary material for the lid. The lid functions to cover the squat hole when the Arborloo is not in use and to meet ER S12 and S15. Three holes are drilled into the lid. Two 0.25 inch holes are located at the top edge of the lid, located 4.94 inches apart. The center to center hole distance is driven by the two holes drilled around the elliptical hole shape used in the cover. Two 1.5 inch by five inch rubber strands are cut out from rubber tubing and rolled up into a strand. These strands are used to attach the lid to the cover. Rubber tubing was selected for the attachment mechanism between the lid and the cover to: minimize costs, ER S1, to improve life duration, ER S13, and to simplify time and complexity of assembly, ER S7 and S8 respectively. A third 0.25 inch hole is centrally located near the bottom of the lid. The hole is used to attach a knob to the lid. The primary function of the knob and bolt is to provide ease of use for opening and closing the lid when the latrine is in use.

The results from the ANSYS analysis for the 270lb loading scenario are presented in *Figure 4 - Unsupported HDPE ANSYS Analysis* and *Figure 5 - Rebar ANSYS Analysis*. For the 270lb and 120lb loading scenarios, the peak stress in the rebar was found to be 38.1ksi and 16.9ksi respectively; each less than the yield stress of the material of 40ksi. For the plastic, the peak stress in the 270lb case was 3ksi, less than the ultimate stress of the material of 4.1ksi. This analysis showed that the Vacloo was capable of supporting the load, without failure, meeting ER S2. Additionally, the analysis itself was overly conservative in design, because the load would be more distributed across the rebar from the vacuum formed HDPE, and the unsupported sections of HDPE are formed with ribbing to increase their strength. Therefore, it was concluded that it was safe to say that the design could support the loads required during use. The cycles to failure analysis found that the rebar could support a 270lb load for 29600 use cycles, and for 120lbs had infinite life with a factor of safety of 2.02. Assuming seven users using the device three times a day every day, 29600 cycles would equate to 3.86 years of use. Based on these results, it was concluded that the rebar would not fail from loading use for at least 3 years, fulfilling ER S13 for years of use for the device.

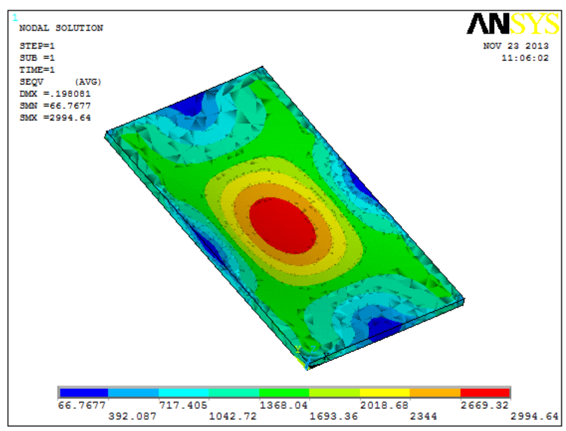


Figure 4 - Unsupported HDPE ANSYS Analysis

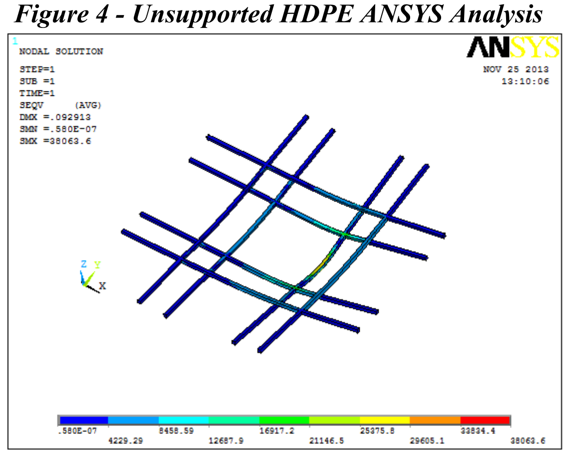


Figure 5 - Rebar ANSYS Analysis

There were three main revisions to the mold design used to vacuum form the HDPE sheets for the Vacloo. The first iteration functioned to test vacuum forming capabilities on campus at RIT. The mold was manufactured from maple wood pieces that were stapled together. This featured a basic ribbing structure, did not include draft angles, and had no release features. The result was the successful vacuum forming of a sixteenth inch ABS prototype on campus. The second revision of the mold was made using cherry wood, and was designed around the final Vacloo design. The mold was made in pieces, which were machined and had three degree draft angles added. Six wood blocks were screwed to the inner perimeter of the mold, which provided flat areas to create the cover support features for the base. Twelve tabs were glued onto the outside of the mold, which were collinear with the rib features. These tabs helped locate the holes and slits that are drilled post forming to allow rebar to slide under the base. The first iteration of the construction of this mold revision utilized glue, modeling clay, and staples to assemble the mold. The first attempt at vacuum forming resulted in the destruction of the mold. The components that were stapled together were torn apart, and putty was melted because of heat from vacuum forming. The second iteration of the mold construction used metal tabs to attach the pieces together. The second attempt at forming resulted in little to no damage to mold. The part that was formed, however, was severely warped after the process was finished due to uneven heating and weak vacuum from the machine, and was unusable.

The third revision of the mold, shown in *Figure 6 – Final Mold Revision*, was created using a 22 inch by 22 inch block of maple laminated wood. The mold was CNC machined at an outside company to form a single component. The mold featured the same rib structure that was used revision two. The base thickness for the rib features were increased to 0.80 inches. The increase in thickness was necessary to create a 0.125 inch clearance for the rebar. The overall height of the outer rib pieces was decreased to 1.0625 inches and the inner rib pieces height was reduced to 0.5625 inches. The reduction in height was to accommodate the switch over from using quarter inch HDPE to sixteenth inch plastic. The reduction in height was to maintain a half inch difference between inner and outer rib features. Two wood blocks were removed from the mold and replaced with eight additional rib features. The rib features were less complicated to machine and vacuum form, and provided improved strength and stability compared to wooden tabs. The four corner wood blocks were retained to provide features to support the cover. The additional rib features had a base thickness of 0.65 inches. Draft angles for outer tabs were increased to fifteen degrees. The increased draft angles allowed for improved removal of the mold from a formed base. All other draft angles were increased to seven degrees to improve mold extraction and to allow for standardized tooling for machining the mold.

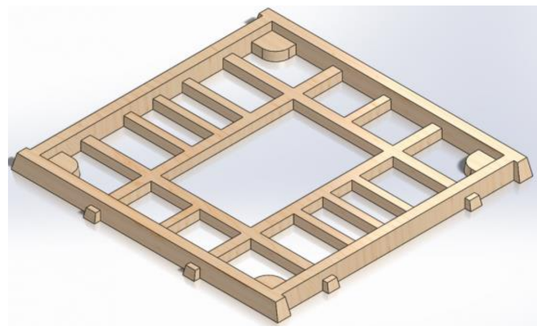


Figure 6 – Final Mold Revision

DECKLOO

The Deckloo was made from 100% recycled HDPE plastic lumber. This material is often used as an alternative to pressure treated lumber and is excellent in outdoor applications. HDPE's resistance to environmental stress cracking makes it ideal for outdoor structural use, satisfying ER S13. Because the Deckloo is made from 100% recycled material, it's impact on the environment is greatly reduced, meeting ER S14. The structural support comes from seven rows of 1.5 inch by 1.5 inch runners that span the width of the Deckloo. Supports are spaced at 5.75 inches apart to ensure that the stress is distributed properly and that the deflection between the supports is not too high. The total deflection under the loading condition of 270lbs in a single location was found to be approximately 0.44 inches. This was validated during load testing when the maximum deflection was found to be 0.45 inches under a load of 572 lbs, distributed across two locations; fulfilling ER S2. The runners are attached to the top platform with standard deck screws. The top platform is made of 0.25 inch thick by 10.25 inch wide sheets cut in 36 inch lengths. The sheets are cut so that an 8 inch by 10.25 inch rectangular gap can be used as the squat hole. Leftover 0.25 inch sheet strips are used to cover the side gaps left by the runners, and a lid is fashioned from extra 0.25 inch sheet. The completed design weighs 17.4lbs, meeting ER S9 and ER S10 and can be seen in *Figure 7 - Deckloo*.

ITEM NO.	PART NUMBER	QTY.
1	board	1
2	board2	2
3	stringer	6
4	stringer2	2
5	endboard	1
6	endcap	2
7	lid	1
8	Rope	2
9	Knob	1

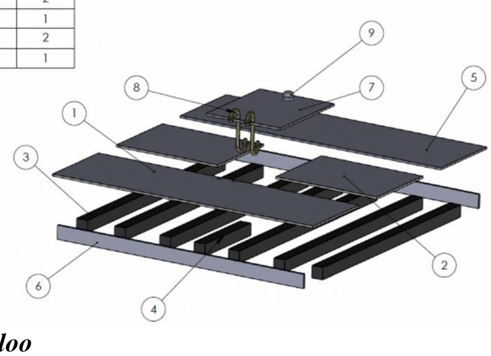


Figure 7 - Deckloo

TESTING

In order to improve processing times, assembly fixtures were created. The rebar support frames for the Vacloo required two fixtures, which required welding; therefore, they were made of steel. A 3/16 inch steel plate and 1/8 inch by 1.5 inch by 1.5 inch angle iron was used for the base and stops for each of the Vacloo assemblies. The stops were welded to the base plate. Process times are improved by clamping rebar to the stops and tack welding to avoid having to measure and square for each assembly produced. The fixture for assembling the Deckloo is made from a particle wood base and sections of 2 by 4's to space the floor stringers at the correct location without having to measure. There are also perimeter stops to line the ends of the stringers and the deck pieces.

Based on the aforementioned assumptions, a cost analysis was conducted and the results are presented in *Table 2 - Cost Analysis*. The total cost for building and assembling the Vacloo was US$22.05 for a single build and US$19.61 for lots of 100 or greater, meeting ER S1. For the Deckloo the total cost was the same regardless of lot size: US$40.90, meeting ER S1.

Design	Vacloo		Deckloo
Quantity	1	100+	1+
Material Cost ($)	20.25	17.81	38.54
Shipping Cost($)	0.42	0.42	1.74
Labor Cost($)	1.38	1.38	0.63
Total Cost ($)	22.05	19.61	40.91

Table 2 - Cost Analysis

The results of the environmental life cycle analysis, pictured in *Figure 8 – LCA Analysis*, showed that compared to Peter Morgan's arborloo, both plastic bases have a smaller environmental impact, meeting ER S14. Furthermore, the Deckloo proved to be the most environmentally friendly. These results are in line with the initial expectation of the environmental impacts as the energy and transportation of Peter Morgan's arborloo, comprised primarily of concrete, requires a significant amount of energy and transportation upon creation. Additionally, the extraction of resources that are used to create the concrete mixture requires a significant amount of energy as well. It is important to note that all of the LCAs were performed using the same assumptions to ensure the validity of the comparisons.

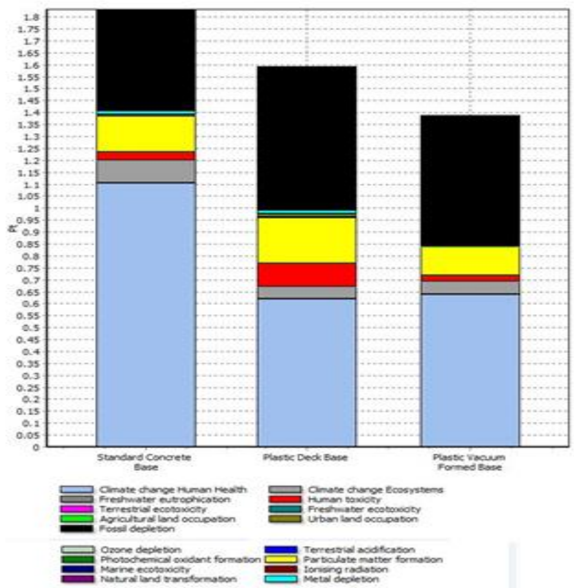


Figure 8 – LCA Analysis

The Deckloo passed all except for two tests and the Vacloo passed all but one test. ER S6 that required a maximum change in level of 6mm was not met for either design. The reason that this ER was failed was because of the need to have a knob to use for the lid. It was concluded with the customer that the handle did not present a significant tripping hazard because it was something the user will actively focus on when using the device. This is because they must physically grasp it to lift the lid to use the device. The customer accepted this failure because they felt the hygiene and usability the handle added were more important than the tripping hazard concern. For the Deckloo, ER S4, regarding the maximum squat hole diameter was also not met. This ER required a maximum squat hole diameter of 0.25m. It was concluded after a discussion with the customer that this was an acceptable outcome, because a hole compliant with the ER would result in a product that would be difficult to use or increased manufacturing difficulty and costs, a much more critical ER. The ER itself was based on a recommendation from the World Health Organization for the size of pit latrine holes intended to keep toddlers from falling into deep pits. This risk was less concerning to the customer because Arborloos have much shallower pits than traditional latrines.

CONCLUSIONS AND RECOMMENDATIONS

In the end, successful prototypes were created for both of the two designs, which passed the majority of the tests for the ERs. The most critical ERs, as selected from the Pareto Chart, were all met for both designs. The Deckloo failed two ER tests, and the Vacloo failed only one test, all of which were for much more minor ER. These failures were all discussed with the customer, and were accepted by them because of the benefits gained by the features that caused the failure of the tests. Assembly fixtures were also built for each design, to aid with the future construction of more of each design.

Based on the knowledge gained from this project, the team is recommending two follow-up projects. The first project would be to create an all plastic base using vacuum forming, without any rebar. With the assistance of the local vacuum forming company that has aided in this project, it would be possible to design an all plastic Arborloo base. The team could also consider making the base larger, to cover a greater range of pit hole sizes. The second project would be the construction of a vacuum forming machine by an MSD team. The prevalence or “at home” vacuum forming machine construction, along with the relative simplicity of their design would make them a realistic project for an MSD team to complete. [8] The team would, however, need to focus on making sure that their machine had sufficient heating capabilities to evenly heat the plastic in the device in order to form larger sheets of plastic. Additionally, they would need to ensure that they had a strong enough vacuum to hold suction on the material, an element that will be critical for forming certain types of materials, such as HDPE. The team felt that if this project could have been repeated, the most important thing to have done differently would have been to have much more critical evaluation of each other’s work. The majority of work done by team members never was subjected to really intensive evaluation by other team members at the time it was done. This caused problems to be identified much later on than they would have if the work was evaluated sooner. The team also felt that a much more serious pursuit in the use of modified existing object, such as milk crates, would have been a worthwhile endeavor.

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