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Utilizing Bricks Made from Recycled Plastics to Construct a Gravity Drip Irrigation System for Cocoa Farms in Ghana

An Interactive Qualifying Project

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By:

Adam Dincher Architectural Engineering	Karris Krueger Architectural Engineering	Casey Snow Computer Science

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Approved by:

Professor Robert Krueger, PhD, Social Science, Worcester Polytechnic Institute

Professor Mustapha S. Fofana, PhD, Mechanical Engineering, Worcester Polytechnic Institute

Professor Hermine Vedogbeton, PhD, Social Science, Worcester Polytechnic Institute

ABSTRACT

The overall goal of our project is aimed at improving the food security and rural employment of Ghanaians, while also promoting the benefits of recycling and repurposing material waste. Ghana's seasonal patterns have experienced changes as a result of global climate change. These changes affect the growth and fruiting productivity of crops and directly endanger the subsistence of rural communities. Recently, the chief of Akyem Dwenase facilitated the planting of 16 acres of cocoa trees to support the village's economy. The chief wishes to implement an irrigation system to continue supplying water to the cocoa trees during the increasingly inclement dry seasons. A gravity drip irrigation system can target the cocoa plants directly and minimize water loss caused by evaporation and unwanted vegetation. One main basin with multiple lines branching out to different sections of the field allows for future expansion. A sustainable irrigation system brings the concept of generative justice into play as the local economy benefits from the production of these systems as well as the ability to easily restore and reproduce the system without relying on expatriate resources. With a drip irrigation system, cocoa plants are given the large and consistent levels of water they need when starting, thus providing a larger yield when they eventually start producing fruit. In return, farmers don't have to spend as much time manually watering and maintaining their crops, or bear the consequences of an unpredictable climate. Our irrigation system design is reliant on access to materials from local suppliers. With the help of partners like Nelson Boateng and his company NelPlast Eco Ltd. in Accra, building bricks can be fashioned out of recycled plastic that would otherwise end up in overflowing landfills. Using local suppliers and repurposing waste allows for the ability to replicate the system in other small-holder farms.

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INTRODUCTION

Global climate change is a phenomenon that affects different regions of the world in various ways. In the West African country of Ghana, these effects are identified in the form of higher temperatures, increased climate variability, and drought. Historical data from 1960-2000 shows a progressive rise in temperature in the region. In these 40 years, the average temperature has increased by 1-degree Celsius (Klutse 2021). This temperature change leads to increased evaporation rates, drying up water resources and surrounding soils.

Climate change is also reflected through a decrease in mean annual rainfall in all six agro-ecological zones in the country. The rainy season, between May and August, accounts for 75% of the total annual rainfall for the country. The major dry season falls between mid-November to April, with a short dry spell in July and August. Rainfall peaks tend to disappear northward. In the northern part of the country, the rainfall distribution is unimodal (Lacombe 2012). These seasons are restrictive to the growth of vegetation and agriculture in general. Many activities in the region revolve around the annual rainfall, one of which is farming. The dry and semi-arid climate in the Northern region leaves many farms at risk as the climate crisis evolves, but challenges exist in the southern, more humid regions, too (Namara 2010). With rainfed agriculture being a dominant economic activity during the rainy seasons, it is highly vulnerable to global climate change and climate variability. These impacts provide specific challenges to communities in Ghana, where agriculture accounts for 60% of the total economic activity and any insufficiencies can put a village's food security at risk (Aquastat 2005). This proves to be a large issue. According to a United Nations report, the West African region is set to become a climate-change hotspot (Shepard 2019).

Making this problem even more challenging is the fact that farms in Ghana are often not accompanied by irrigation systems. Many farmers in Ghana have livestock that often live in proximity to their crops. Having irrigation systems is difficult with the presence of livestock as they threaten the sustainability of the systems infrastructure (Nhemachena 2010). Other threats to irrigation infrastructure include flooding and the build-up of silt and algae in reservoirs. Having solutions to potential sustainability issues with irrigation infrastructure is crucial for maintaining these precious cash crops that so many communities depend on.

With this in mind, we set out to develop a solution to alleviate the exacerbated problems brought on by global climate change. Our project site was located in the Eastern region of Ghana, in the village Akyem Dwenase, whose primary industries are artisanal mining and agriculture. To generate new income for the village, the chief Osabarima Owusu Baafi Aboagye III, developed a 16-acre field (figures 1 & 2) to grow predominantly cocoa, a cash crop for export. Currently, this field relies solely on rainwater during the wet season, leaving crops to fend for themselves during the dry months. This in turn reduces the cocoa yield because not all the plants can survive this drought. Making this even more challenging is the variability of when the rainy season begins and ends. A ten-day difference can mean the death or survival of food-bearing crops.

Figure 1. Akyem Dwenase's cocoa field landscape

Ideally, the field must have access to a reliable water source to last throughout the dry season. One way to mitigate this issue is through the process of irrigation to allow for year-round agricultural production. To set the standards for the irrigation systems infrastructure, we identified key components with our partners in Ghana that would facilitate a successful irrigation system. Working with our partners in Ghana allowed us to open the door for generative justice, a core concept of our project that allowed us to innovate around monetary needs and implement solutions that communities can benefit from most. It was essential in our design process to allow our co-designers in Ghana to partake in decisions and steps. This collaboration gave us the ability to develop a project with adequate feasibility for future implementation. The initial goal involved developing a method for the creation of a water reservoir that could store and disperse the natural rainwater in a streamlined way. Other preliminary components involved researching and analyzing what form of irrigation would best suit the growth of the crops. Lastly, our partners were able to help us in identifying local sources of material and labor to make sure the likeness of the design process could be replicated in the future by other farms in the region. These preliminary steps helped set up the structural framework for both our social and engineering-related objectives.

Eastern Ghana and surrounding regions offer a multitude of supply accessibility options to sensibly tackle these foreseen needs. Bricks made from recycled plastic waste are domestically manufactured and are proposed to be used to build a catchment tank. There is also a local supply shop that can provide PVC and other piping materials that can be used to disperse rainwater to the plants. The project intends to inspire and encourage communities to create their systems for drip irrigation methods, even when the rain cycle varies by a week or two.

This process would not have had the success it had without key partners in Ghana. One of which included Nelson Boateng and his company Nelplast Eco Ghana Ltd. Mr. Boateng's inventiveness played a vital role in our design inspiration. For over 8 years he has been utilizing recycled plastic waste to produce materials for construction. Moreover, Nelplast has been creating structural bricks for roads and residential homes all over Ghana. Using a 70:30 ratio of plastic to sand creates an extremely durable brick that can withstand the arid climate. With the current earth-building practices that Nelplast offers, we were able to utilize new ways of composing his material into an agricultural application.

Another resource we had was the help of engineering students from Academic City College (ACUC) in Accra, Ghana helped us in discussing and developing the project. Kelvin Atograph, Joseph Atedoghu, Fiifi Addae, and Ayomide Akerejola are first-year engineering students at ACUC. We met as teams throughout our project development to discuss the project and extended details collaboratively. With their expertise and indigenous knowledge of surrounding communities, they provided solutions that were both practical and effective. With access to the Nelplast Ghana Ltd Bricks, our partners at ACUC were able to co-design with us. Obtaining and testing the bricks to see if they could be implemented as an adequate material to construct for a catchment tank. With the enlightening information provided by our partners, we went in-depth to understand the cocoa economy and why the implementation of agricultural systems is crucial to the future of agriculture in Ghana and Sub-Saharan Africa at large.

2. LITERATURE REVIEW

2.1 Cocoa Economy

Cocoa is Ghana's largest agricultural export commodity, supplying 17% of the world's inventory. Producing this large amount of cocoa means that farmers constantly need to keep their farms and their crops sustained. A lack of cocoa tree yield is largely due to deficiencies caused by climate variability, including low soil moisture and excessive sunlight exposure. Oftentimes, Ghana's cocoa farmers have limited access to finances that would allow for the purchase of specific supplies and planting materials to address deficiencies. Furthermore, challenges arise as cocoa farms age, taking around 5 years to start bearing fruit, and sustain a peak growing period of around 10 years. While cocoa plants can continue to grow and produce fruit for decades, the decline in soil fertility, pests, and diseases impact productivity and eventually wither the cocoa trees. Regular maintenance activities, which include weeding and pruning, alleviate the adverse effects of availability reduction.

Established in 1938 the Cocoa Research Institute of Ghana (CRIG) is a branch of Ghana's Department of Agriculture striving to develop sustainable, demand-driven, commercially oriented, cost-effective, and socially and environmentally acceptable technologies which will enable stakeholders to understand the overall vision of the cocoa industry. Between the 1930s and 1970s Ghana imposed a mandate to cut out trees due to swollen shoot disease which was greatly delayed by the Anglo-Ashanti war and continued to devastate cocoa crops in the country. Since then, the cutting out campaign led to over 162 million trees that had been identified and removed because of the swollen shoot disease. In the 1960s a new threat to cocoa farming was coming from pests that devastated farms, HCH was an effective pesticide until Ghana's economic difficulties in the 1970s led to a shortage of sprayers and pesticides. Ghana's history with cocoa production runs deep, and the socioeconomic position it holds in the country is responsible for employing 65% of the workforce (International Cocoa Organization 2021). Therefore combating potential risks for these crops is so crucial for the future prosperity of Ghana and its people. To combat foreseen agricultural hardships, farmers are encouraged by organizations like the CRIG to use irrigation systems.

In all of Ghana's cocoa farming regions, it is estimated that up to 40% of the crop is lost to pests and disease. To prevent pests and maintain soil viability, education on best maintenance and agroforestry techniques can benefit productive, healthy, and sustainable farms for cocoa-growing communities (Tackie 2022). With around 95% of the world's cocoa grown by small farmers, the working and living conditions of cocoa farmers and their families are difficult. Additionally, less than 2 percent of the total cultivated area in Ghana is irrigated; it is clear that more encouragement to progress irrigation development is needed. (Danish 2015, 10) With over 70% of Africa's extremely poor populations relying on agricultural production for their livelihoods, a change in development strategy could be the answer to improving food security and community benefit.

2.2 Irrigation Systems

Rain-fed systems are a primary source of crop production, which in turn limits most of the crop to a 3–6-month rainy season. With a water retention method, farmers would be able to cultivate year-round, mature crops faster, and grow higher-value crops that require a more reliable water source. Implementing reliable water sources such as an irrigation system can mitigate the impacts of climate stress associated with expected drought and extreme heat (A. Burney 2013).

Irrigation systems are established all over the world and utilize unique characteristics based on their needs and geographical circumstances. The methods native to Africa's western sub-Saharan climate are chosen based on numerous factors. These include elements like the amount of available rainfall in a season, crop type, soil type, environmental conditions, and topography. The most common systems are based around manual irrigation, the traditional distribution of water through manual labor and watering cans to supplement any lack of rainfall. A system like surface irrigation uses the existing structure of the land and gravity to distribute water with no mechanical pump involved. When looking to invest in long-term crop growth, some farmers choose to implement sprinkler irrigation with pumps that allow water to be quickly distributed overhead from a high-pressure sprinkler.

Drip irrigation is a localized form of irrigation in which water is dripped at or near the root of the crops. This method is very satisfactory for farms located on mountainous or sloped topography as gravity can be used to induce water pressure. Another desirable factor for drip irrigation is the consistent and direct feed of water going to plants allows them to grow more efficiently. This form of watering is preferable for arid climates, where much of the surrounding vegetation is competing for root space and moisture in the soil (Büyükcangaz 2017).

However, issues with drip irrigation can make themselves present through the clogging of pipes and irrigation lines. The lines being exposed to the soil can cause potential blockage in the pipes, stopping the water's flow as well. Another issue with drip irrigation is that it does not adhere to each specific plant's watering needs. If two plants are next to each other, they are going to get the same amount of water, even if one needs more than the other. It was important to analyze all the factors specific to the farm in question when deciding on the right irrigation system. Considering both the pros and cons of a drip irrigation system as well as the desired outcome and the environmental factors at play, we saw a drip irrigation system best fit for this site.

2.2.1 Tubing Sizes

Different tubing sizes also need to be considered in a drip irrigation system. With drip irrigation, there will be a significant pressure drop in the pipes. These different sizes help water flow and build pressure at different points. The tubes directly attached to the tank needed to be larger to support the volume of water needed for the section of the field its branches were supporting. A study (cite properly (Table 1 & 2)) showed that the mainline that was 80mm in diameter and was 40 meters long had a pressure loss that was 8% higher than an 80mm diameter, 80-meter pipe. Additionally, a field that had an 80mm diameter mainline, no sub-main lines, and a lateral line that was 12mm in diameter showed a pressure loss of 25%, while a field with an 80mm in diameter, 56m long mainline, a sub-main line that was 57mm in diameter, and 71 meters long with lateral lines that are 16mm in diameter and 71 meters in length showed a 40% pressure loss. Overall, this report showed that the smaller amount of tubing included, the less pressure drop is experienced.

Table.1 Pressure and discharge measurements in the experimental fields

Sl. No.	Field No.	Discharge (lph)				Pressure (kg/cm^2)		
		Location 1 (Inlet)	Location 2 (Middle)	Location 3 (End plug)	Discharge drop (%)	At Inlet	End plug	Pressure drop (%)
1.	F_1	4.0	3.8	3.8	5.0	1.0	0.75	25
2.	F_2	3.0	2.9	2.9	3.3	1.2	0.9	20
3.	F_3	3.0	3.0	3.0	0.0	1.25	1.1	12
4.	F_4	3.8	3.8	3.6	5.3	1.1	0.8	27
5.	F_5	4.0	3.9	3.8	5.0	1.2	0.9	25
6.	F_6	3.8	3.7	3.5	7.9	1.0	0.6	40
7.	F_7	3.8	3.7	3.7	2.6	1.1	0.7	36
8.	F_8	3.7	3.5	3.5	5.4	0.9	0.5	44
9.	F_9	3.8	3.8	3.7	2.6	1.0	0.7	30
10.	F_{10}	4.2	4.0	4.0	4.8	1.2	0.8	33

Table.2 Diameter and lengths of laterals, sub-mains and mains of the drip irrigation systems

Sl. No.	Plot No.	Area (acre)	Emitter Q (lph)	Pump Q (l/s)	Diameter (mm)			Length (m)		
					Main	Submain	Lateral	Main	Submain	Lateral
1.	F_1	3.0	4.0	8.2	80	57	12	120	50	54
2.	F_2	2.0	3.0	7.6	80	57	12	40	50	40
3.	F_3	1.0	3.0	7.9	68	57	12	20	50	40
4.	F_4	4.0	4.0	8.4	80	57	16	50	40	49
5.	F_5	1.5	4.0	7.9	80	57	12	10	60	50
6.	F_6	3.5	4.0	8.4	80	57	16	80	0	49
7.	F_7	4.0	4.0	8.2	80	57	16	56	71	56
8.	F_8	4.25	4.0	7.8	80	57	16	144	72	60
9.	F_9	4.5	4.0	7.7	80	57	16	80	100	40
10	F_{10}	5.0	4.0	8.3	80	68	16	100	60	60

2.2.2 Irrigation System Materials

When considering what materials to construct with, we identified that materials coming in direct contact with the funneled water need to be water-resistant, sustainable, and readily attainable in Ghana. Polyethylene comes in a variety of forms and densities and is commonly used in many agricultural industry applications. It has a high resistance to corrosion and exceptional toughness that can stand up to harsh conditions. Additionally, materials like mesh screen filters, supporting garden stakes, rain chains, and grommets are all metals that could be subject to corrosion. In our case, we used bronze and stainless-steel materials which are heavily resistant to corrosion and do not rust with moisture. Metals like aluminum that are found in the repurposed garden stakes can be protected by a polyethylene layer.

Furthermore, Mr. Boateng's plastic bricks were readily available, so we wanted to use those. However, in an interview with Mr. Boateng, he shared that he had never used the variety of bricks for other applications, outside of housing structures and pavement substitutes. We further inquired if he thought these bricks could be used in a water tank application, like our proposed catchment and irrigation system. He replied saying that he hadn't and that he believes despite the lego-like structure of the bricks, they are not suitable for impervious applications. Although he did note that the plastic bricks alone were waterproof. This is due to the sand and plastic contents being heated and mixed before being pushed through an extruder into tight molds. As of today, demand is growing for Mr. Boateng and his recycled brick operation. His design allows for these bricks to stay cool in Ghana's warm climate while also being fire resistant. The Lego-like design and implementation of rebar-sized holes resolve the need for any special adhesive or mortar component to ensure structural integrity.

3. METHODOLOGY

At its core, a drip irrigation system has three main components: a catchment system to collect the rainwater, a tank or reservoir to store the collected water, and piping connections to deliver the water. There are also many smaller components to be considered in the design process as well, a mesh screen, a rain chain, spigots, and a water sealant liner.

3.1 Rainwater Collection

For our specific case, there were many different options to consider concerning the rainwater collection method. For this application, a catchment system that funneled into the tank was the best choice. The main aspect of the catchment system proposed was a large surface area for water to be caught. To determine the necessary surface area, we first needed to find how much water would be needed to survive a dry season. Each cocoa plant needs 1-2 inches of water per week, and the typical dry season lasts 16 weeks (Woodson). Thus, we planned for 32 inches of water per plant. This led us to opting for a 1000-gallon tank. To collect the amount of water needed to fill a 1000-gallon tank, the surface area of the catchment would need to be 26.75 square feet. Appendix I shows how we calculated the tank size.

To design an adequate catchment system, we started with identifying types of systems that were being used by everyday people online. This “do it yourself” genera of rainwater catchment systems helped us understand the general shape that our prototype would take. The design idea we deemed most fitting for our prototype was a conical-shaped surface for rain to land on, that funneled into the tank (figure 2).

Figure 2. An example of a pre-existing, small-scale rainwater collection system

The overall design for the catchment system attempts to scale down what a real-life application of the system would resemble at a 1:10 scale. Our catchment design, similar to the DIY design, takes an inverted umbrella-like shape to feed rainwater into the water tank. Using a square cut out of polyethylene drop cloth material, we shaped the rain collection surface. The catchment's polyethylene sheet is supported by a structure designed from garden stakes (Figure 3a). These garden stakes, made from polyethylene-coated hollow aluminum tubing, created a secure hold between the garden stakes and the polyethylene, grommets were installed at the corners of the polyethylene and attached to the stakes. Smaller plastic stakes pieces were also used to create a support ring underneath the outer surface of the polyethylene material (figure 3b). It was easy to create more support as needed by connecting straight sections of any material between the existing supports. To create a center feed, we installed a grommet that allows the catchment layer to hook onto the connection that leads into the tank. Forming the connection between the surface and the tank is a central coupling connection with a primary filter on the top (Figure 4), and a 3-layer secondary filter on the bottom. These filters prevent silt and other debris from entering the irrigation piping and causing clogging.

Figure 3a. - Catchment prototype structure (left). Figure 3b. - tarp layout (right)

Figure 4. - Primary filter

Another small, but necessary component we added was a rain chain. Having a rain chain that guides the rainwater from the mesh filter down to the water surface (figure 5) in the catchment tank prevents the first flush of water from mixing sediment that may have washed in from the catchment saucer.

Figure 5. Rain Chain

3.2 Water Reservoir

The second most crucial component of the irrigation system is the water reservoir in which to store the collected rainwater throughout the dry season. The first step to designing this tank was to figure out how big we would need it to be, based on the amount of water needed to sustain the 3,800 cocoa trees through the 16-week dry season. There are currently 3,800 cocoa plants and at 2 inches of rain per plant, the tank would need to hold 6,333 gallons of rainwater. Appendix III shows how we did the tank math calculations. It was also necessary to account for human error in turning the spigot on or off, any leaks in the tank, and evaporation during the wet season when the lid is off. Other more uncontrollable factors to consider are longer dry seasons, shorter wet seasons, or field expansions. Evaporation during the dry season was a large concern, but research shows that it is negligible in closed containers. Given all of these factors and considerations, it was determined that there should be 7,000 gallons of water collected and stored, whether this is through one large tank or multiple smaller ones.

Figure 6. - Nelplast's LEGO Brick mold

To construct the tank, we wanted to use Mr. Boateng's plastic bricks, which we did not have at our disposal. In solving this problem with our ACUC partners in Ghana, they were able to obtain the bricks and experiment with them. Our ACUC partners tested the bricks using a sealed section filled with water on the seam of two connected bricks. When water was applied, the seam let water through as suspected by Mr. Boateng in our discussion. The ACUC students then used a piece of polyethylene to cover the sidewall and seam of the bricks. After testing the bricks with the polyethylene sheet, our partners noted that no water had escaped through or damaged the material. Mr. Boateng also shared with us that he has plans of developing practical roofing tiles to move away from traditional metal roof panels. If he develops these roofing tiles by the time our tank is built, we would be interested in using those instead of the metal roof.

However, we needed something to construct for the prototype. To recreate these bricks initially, we watched a video of Mr. Boateng's past work. After analyzing the LEGO Brick and Pilar Brick's uses in building interior and exterior walls of houses from a video of Nelson's work, the design/layout decided on was to stagger each brick so that each row was offset by half a brick in the horizontal direction. From the video, we gathered initial designs (figure 6) and drew them out. Appendix IV shows how we drew them out. Using the CAD software *Solidworks,* we took our best guess at the dimensions and overall design of the tank (figure 7). The LEGO bricks were estimated through digital photo measuring to be 6 inches wide, 6 inches tall, and 12 inches long. The corner brick dimensions were 6 inches wide, 8 inches tall, and 4 inches long. From this CAD model, we were able to 3D print them in our school's maker space.

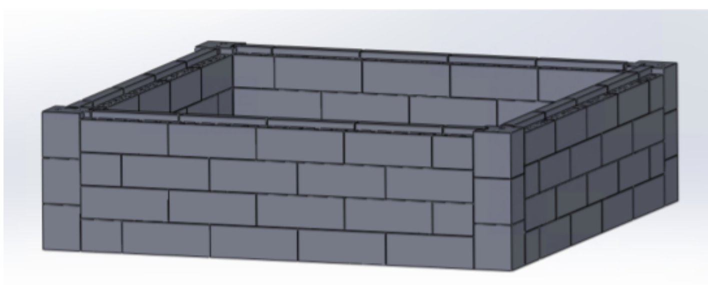

Figure 7. - Initial Solidworks design

From the first iteration printed, we concluded that we needed to adjust for the margin of error between the bricks. We made the extrusions the same size as the protrusions. With that in mind, we developed new LEGO and column bricks. The new ones had the same dimensions, however, the extrusions were .1 inches wider and the protrusions were .1 inches narrower. These were then printed and tested. The fit was still not as seamless as we had hoped (Figure 8).

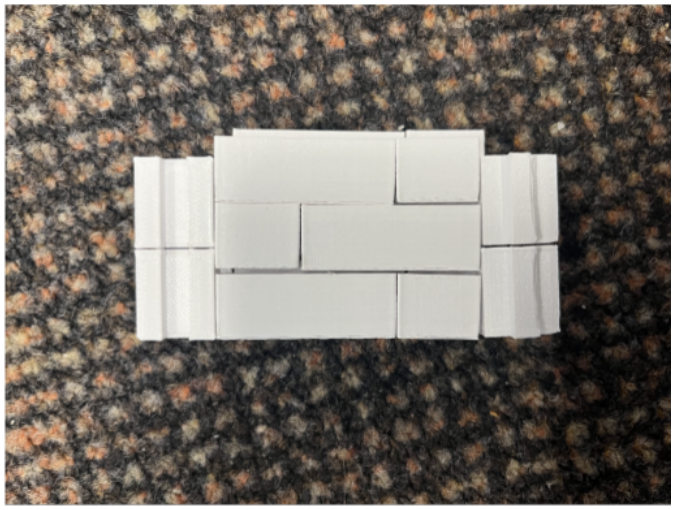

Figure 8. Second brick iteration prototype

To precisely replicate these bricks, we needed actual dimensions. So, we contacted Mr. Bennet who obtained bricks from Mr. Boateng. The dimensions were measured and sent by Mr. Bennet. Appendix V shows those dimensions. After replicating the exact dimensions in Solidworks, we printed out the redesigned bricks again (figure 9). These fit a bit better, but still needed their margin of error increased due to the variability of the 3D printer. We increased the extrusions to be .2 inches wider, and the protrusions to be .2 inches narrower, making for a total of .4 inches between the bricks. Once these were printed out, we were finally able to get the bricks to fit together (figure 10) to give us an idea of how they would work on a much larger scale.

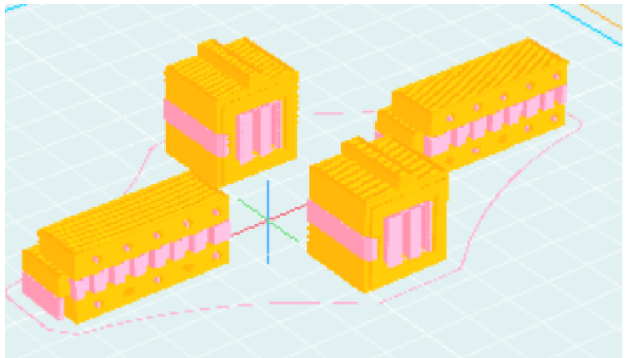

Figure 9. Bricks on 3D printer software

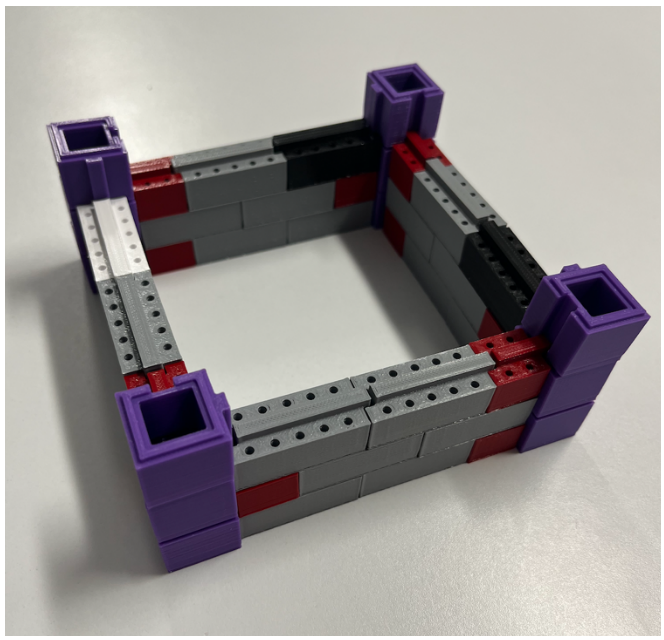

Figure 10. Final 3D printed bricks assembly

In our prototype for testing the tubing, however, we did not use the 3D printed bricks but rather used a recycled milk jug as we were focusing more on testing the piping and water delivery (figure 11). We used a drill bit and Exacto knife to carve our feed hole into the milk jug to fit a ball valve in. To secure the ball valve we hot glued the seams and then added a layer of hardening epoxy to prevent any small leaks from getting through the hot glue barrier.

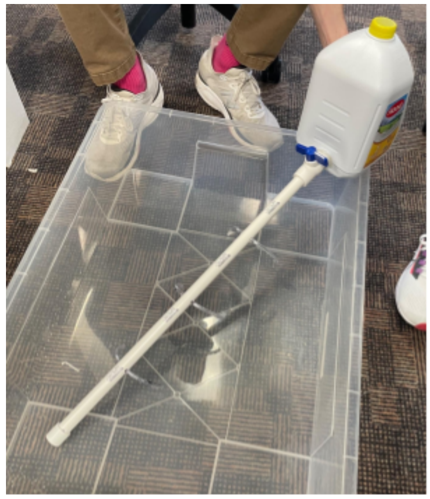

Figure 11. - Initial tubing prototype

3.3 Pipes and Tubing

The third main component of an irrigation system is tubing. From the study mentioned above and other preliminary research, we knew different tubing sizes were necessary for our design. The larger tube directly attached to the tank we used was ½ inch PVC piping. Originally, we thought it would be best to lay the PVC pipe perpendicular to the edge of the tank and run down the field (figure 12a). Then, after tests, we decided to run the pipe parallel to the front edge of the tank (figure 12b). The parallel design allows for more variability, as well as the capability to water a larger quantity of plants.

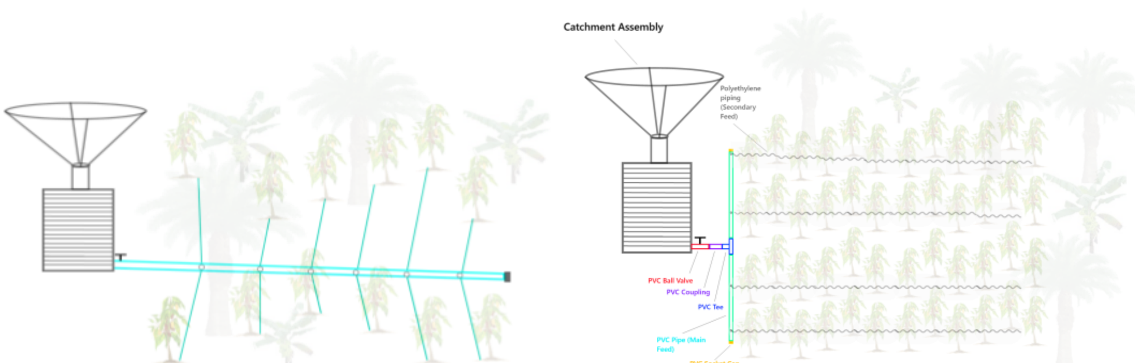

Figure 12a. Initial perpendicular pipe (left). Figure 12b. Parallel pipe (right)

For the smaller pipes, in our first prototype iteration, we used ⅜ inch vinyl piping and drilled holes into it. After the initial tests, we determined that the holes were too big. Then, in our meeting with ACUC students, they suggested using polyethylene piping instead of vinyl. The next iterations consisted of using polyethylene piping with smaller holes. The holes this time were poked with a push pin and worked significantly better.

In the first iteration of the pipe design, we also tested two methods of the pipe going through the PVC. In the first one, we put 6.5-inch sections of the vinyl pipe through the PVC and drilled holes in them to allow the water to get through. These holes were of various sizes to see which one worked best. The second form was gluing the very end of 3-inch sections of the smaller pipe to the opening of the larger pipe. We determined that both methods worked similarly, so on our second pipe design, we used the latter method. This decision was largely because, in this second design, the smaller pipes only go out one side of the larger one.

3.4 Replicating the Farm

The process of replicating the field's conditions was difficult as it was hard to obtain detailed site plans or topographical data due to the project being remote. Some knowns were the size of the farm, 16 acres; the layout, an 8' by 8' grid; and what types of vegetation resided alongside the cocoa plants; cassava plants, plantains, and cocoa palms. On the other hand, unknowns had to be assumed via images and drone footage. The unknowns were precise topographical data, and how these 16 acres were distributed across the hillside field. Thus to account for unknown variability of the field, we designed our prototype to be dynamic.

To properly replicate the farm, the soil was necessary to see if the pipes clogged when they were in the dirt. To achieve this, we placed dirt into a large plastic container and set up the prototype in it. Although this plastic bin is nowhere near the size of the farm itself, we needed to scale it down for practicality and feasibility purposes. The pipes did not clog, and we were easily able to direct them to certain locations in the dirt. We purposely used a flexible material for the smaller pipes to account for the fact that the cocoa plants may not be in an exact grid. We also sloped the dirt in a way that angled the pipes downhill. This was to replicate the field's slope and to encourage the gravity-fed aspect of the system.

The final prototype was assembled and able to be tested (figure 13).

Figure 13. Final prototype

3.5 Maintenance Options

If the system were to fail, various maintenance options were discussed. One of those was gate valves along with the PVC (figure 14). If one section was not working properly, a gate valve could close off that section during repairs. These gate valves could also provide a different way for the water to pressurize if one section was not getting enough pressure, or a section was flooding.

Figure 14. Gate valve design

Additionally, in a meeting with our student partners at ACUC, they suggested, if the bricks did not pan out successfully, we should consider using old refrigerators. Many refrigerators can be found in the e-waste dumps, and while they do not work electronically, they still have their sturdy frame and function there that could be repurposed. In terms of sealing water in, a fridge is designed to keep air, and subsequently moisture, within its body. During the rainy season, the fridge would simply be placed on its back and filled with water. When the dry season comes, the refrigerator door could be closed and it would seal out a large amount of outside heat and prevent evaporation. These “broken” refrigerators could easily be found at dumpsites, would be highly affordable, and in theory, would serve well in their repurposed use.

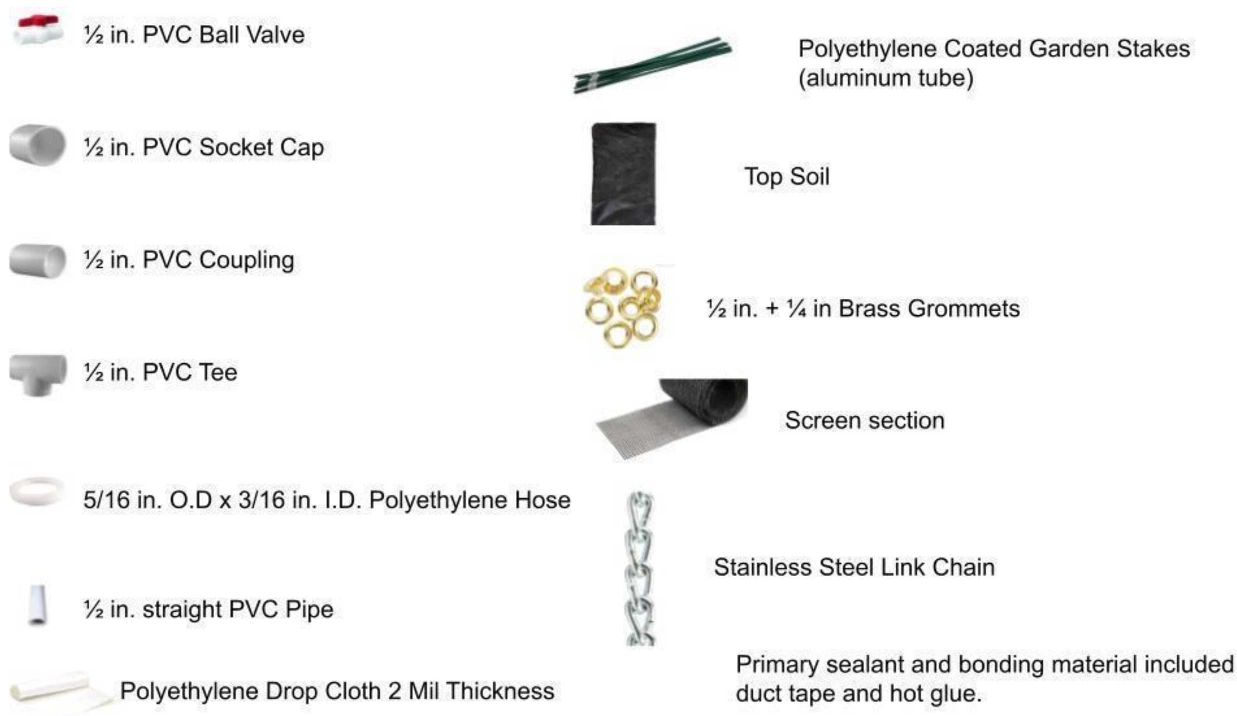

Table 3. Prototype materials.

4. ANALYSIS OF PROTOTYPE DATA

Our prototype tested two different situations: 1) letting the pipes continue to drip after the spigot was shut off vs moving the cups once the spigot was shut off to only measure what amount of water was distributed during the time the spigot was open and 2) running the test when the pipes were dry vs running the test immediately after another when there was still water standing in the lines. The most realistic conditions to replicate the actual field would be to run the water on dry pipes and let it continue to drip after being shut off. In addition to these situations, we also tested several different variables: 1) small vs large holes in the tubes, 2) uphill vs downhill locations, 3) one hole vs two holes on the line - to simulate few or many plants on a run, and 4) if the line was closer to the tank or farther down the main PVC pipe from the tank. The tables below display and summarize these results. There was a large difference in data as a cup placed alone on a line with a larger than normal hole farthest from the tank had an average of 44.75mL and a high of 61mL while a cup farthest from the tank, downhill, with average sized holes, and two cups on the line had an average of 6 mL and a low of 4.4mL.

	Other Variables Tested (mL/31.85sec)							
	One Hole	Two Holes	Small Hole	Large Hole	Uphill	Downhill	Close to tank	Far from tank
One Hole	32.5		4.00	61			4	61
Two Holes		9.23			5.2	13.25	12.2	6.25
Small Hole	4		8.18		5.2	13.25	12.2	6.25
Large Hole	61			61				61
Uphill		5.2	5.2		5.2		4.4	6
Downhill		13.25	13.25			13.25	20	6.5
Close to tank	4	12.2	12.2		4.4	20	9.47	
Far from tank	61	6.25	6.25	61	6	6.5		24.5

Table 4 shows a matchup of different variables tested (data collected from Trial 1 only in this case) to see what combination created the most ideal results.

We ran four roughly 30 second trials and measured the amount of water collected in each cup after using a syringe and a graduated cylinder. At first, we assumed cup 5 which gave us a measurement of 61mL in our ideal conditions was the best set of variables to choose as the end product. However, when we calculated the flow rate of 1.92mL/s (61mL/31.85sec), we realized that for a goal of watering 1in (16.67mL), we would only have to have the system flowing for roughly nine seconds. This would be too short a time span to build pressure in the pipes enough to water other plants in the line or be able to control the amount in a reliable way.

	Average of All Trials		
	Water Amount (mL)	Time (s)	Flow Rate (mL/s)
Cup 1	6.60	32.75	0.20
Cup 2	9.50	32.75	0.29
Cup 3	6.00	32.75	0.18
Cup 4	13.20	32.75	0.40
Cup 5	44.75	32.75	1.37
Cup 6	6.43	32.75	0.20

Table 5. Average for each cup over all four trials.

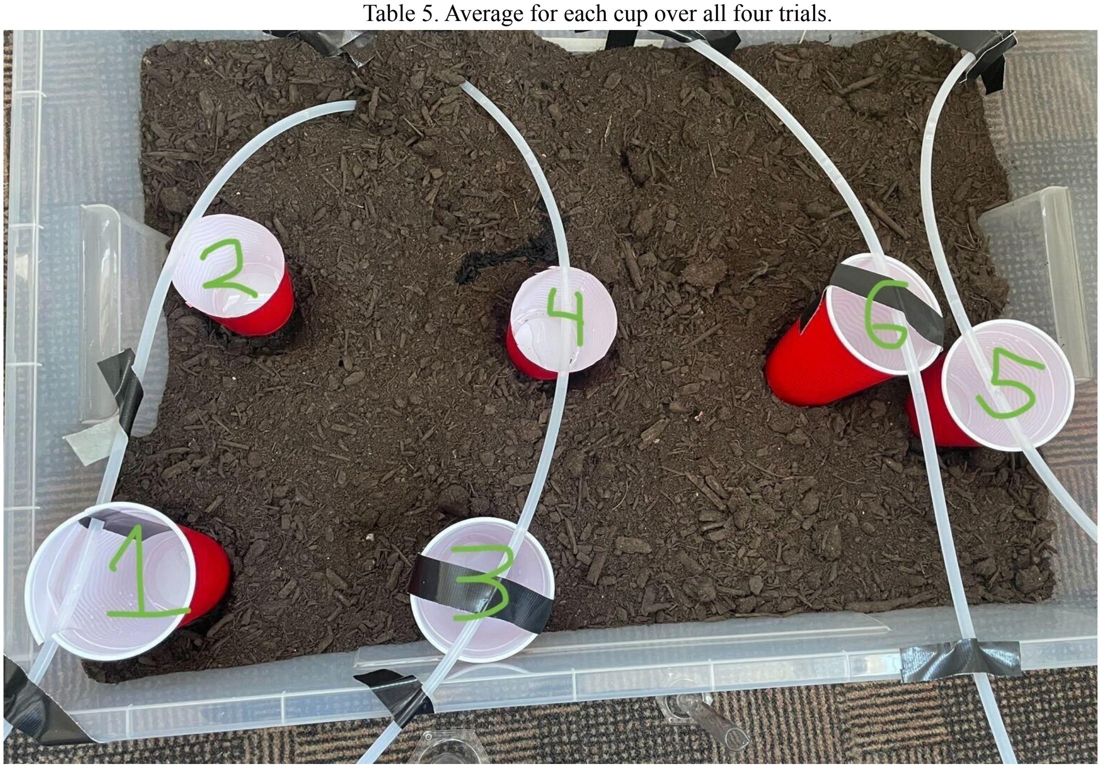

Figure 15. Labeled Cups

Upon further analysis of the data and consideration of the variables/conditions, we concluded that the best option to choose from the prototype test for our actual irrigation system would be first to have many plants on the line, not few, which works in our favor to allow us to use less materials in the end, thus lower costs; and second to make smaller holes in the tubing lines to create a slower drip and slower flow rate. Having a slower flow rate means the water will drip at a more controlled rate so the soil can absorb more moisture more quickly without being flooded and risk water flowing away from the plant and taking valuable soil and nutrients away from it as well. The cups that best show these conditions and setup are cups 1-4 (figure 21). The average of these four test locations from Trial 1 is 9.23mL as shown in Table 9 (Two Holes x Two Holes).

				Trial 1		Trial 2		Trial 3		Trial 4	
				Water Amount (mL)	Time (s)	Water Amount (mL)	Time (s)	Water Amount (mL)	Time (s)	Water Amount (mL)	Time (s)
Top	Far Side	Pipe 1	Cup 1	6	31.85	6.2	31.84	7.8	35.87	6.4	31.43
Bottom	Far Side	Pipe 1	Cup 2	6.5	31.85	16	31.84	8	35.87	7.5	31.43
Top	Close	Pipe 2	Cup 3	4.4	31.85	12	31.84	3.6	35.87	4	31.43
Bottom	Close	Pipe 2	Cup 4	20	31.85	18	31.84	8.7	35.87	6.1	31.43
Larger Hole	Far Side	Pipe 3	Cup 5	61	31.85	40	31.84	42	35.87	36	31.43
	Close	Pipe 4	Cup 6	4	31.85	11.5	31.84	5	35.87	5.2	31.43

Table 6. Raw data from each of our four trials for each cup with a nominal description to the left of the data.

	Average of Trials (drip after)		
	Water Amount (mL)	Time (s)	Flow Rate (mL/s)
Cup 1	6.10	31.845	0.19
Cup 2	11.25	31.845	0.35
Cup 3	8.20	31.845	0.26
Cup 4	19.00	31.845	0.60
Cup 5	50.50	31.845	1.59
Cup 6	7.75	31.845	0.24

	Average of Trials (moved cups)		
	Water Amount (mL)	Time (s)	Flow Rate (mL/s)
Cup 1	7.10	33.65	0.21
Cup 2	7.75	33.65	0.23
Cup 3	3.80	33.65	0.11
Cup 4	7.40	33.65	0.22
Cup 5	39.00	33.65	1.16
Cup 6	5.10	33.65	0.15

Tables 7 & 8. Prototype Trial Data

The tables above depict the differences in data between letting the system drip into the cups after being shut off and moving the cups away from the holes to end cap the amount of water measured during the time span and no more..

	Average of Trials (empty line)		
	Water Amount (mL)	Time (s)	Flow Rate (mL/s)
Cup 1	6.0	31.85	0.19
Cup 2	6.5	31.85	0.20
Cup 3	4.4	31.85	0.14
Cup 4	20.0	31.85	0.63
Cup 5	61.0	31.85	1.92
Cup 6	4.0	31.85	0.13

	Average of Trials (full line)		
	Water Amount (mL)	Time (s)	Flow Rate (mL/s)
Cup 1	6.80	33.05	0.21
Cup 2	10.50	33.05	0.32
Cup 3	6.53	33.05	0.20
Cup 4	10.93	33.05	0.33
Cup 5	39.33	33.05	1.19
Cup 6	7.23	33.05	0.22

Tables 9 & 10. Prototype Trial Data

Tables 9 and 10 depict the difference in data between running the system and measuring the amount of water in the cups on an empty, dry line and measuring the amount of water after running the system with tubes already filled with water.

4.1 Successes and Failures of Prototype

Multiple tanks could also be used if the system was unable to support such a large scale. For example, if the gravity-fed aspect was not able to be supported with the tank at the very top of the hill, and it would be easier to find local tops of the hill for different sections, different tanks could be placed on those tops.

Lastly, the harvested rainwater from a catchment system and tank should be used for non-potable applications such as landscape irrigation and washing farm tools and appliances. Collected rainwater should generally not be used for drinking purposes unless filtered and disinfected for contaminants.

5 DISCUSSION

5.1 Smart villages

The typical connotation of the term smart as it applies to cities and villages is a place that uses network-based technology and gadgets to collect data to better that place. For a rural area, these network-based systems are not always an option due to the lack of data and materials within a village. The principles apply between a smart city, loaded with technology, and a smart village do not have to be the same for a village to still be smart. A smart village uses " innovative solutions to improve their resilience, building on local strengths and opportunities" (Vilcu 2019). Some rural areas do not have the same network access as cities, so innovation comes in a wide variety of forms.

Some examples of smart villages are those in Malaysia. These villages consist of affordable homes, high scale educational facilities, and integrated farming systems. To go deeper into this example, the farming system is for fish. Tanks are in a series to help the fish survive and also be farmed. More specifically, "Aquafarmed at the top of the water ladder are fish species sensitive to water quality, next tilapia, then guppies and finally algae, the latter two used to feed the larger fish. Filtered fish tank wastewater then irrigates trees, grain fields, and high-value plants" (Collins 2014, 3). Due to these measures, citizens' monthly income has tripled. This Malaysian system benefits the villages in all kinds of ways, from economic growth to minimizing waste to allowing crops to grow on different types of land.

The village of Akyem Dwense can now be considered smart, not because it uses high-tech items for the betterment of the village, but because it uses an innovative solution. This creative solution uses gravity as its driving force. It improves the village, while also building on what is already somewhat successful. The cocoa farming methods now are working but could be improved, and we hope that our system will greatly improve it.

Furthermore, the drip irrigation system will benefit the village of Akyem Dwense in a variety of ways. As previously stated, cocoa is Ghana's number one export crop, so it is in high demand. That means Osabarima, village chief, can sell the cocoa product from his farm and use the profit to the benefit of the village and his people. He plans to improve the schools and value of education with the money these crops bring in. Without this system, there is less of a chance the cocoa plants survive, which in turn results in less yield. Less crop yield continues the chain reaction, ultimately not leading to the desired success with the system.

Additionally, the drip irrigation system will allow the farmers to spend less time watering their plants. With this extra time, farmers can focus on maintaining the field in other ways or even expanding. Expanding would allow more cocoa to be grown, which will result in more money for the village. This extra produce can help sustain the demands of the crop.

Not only can the irrigation system help the crops, but Nelson's bricks can also contribute to promoting behavioral changes concerning recycling. People can see that his plastic bricks can be used to store water and help their fields. They get something in return for recycling. This positive reward system will hopefully encourage recycling.

Lastly, with this proof-of-concept design, if other villages do not have the same materials, they can substitute with other things that are more readily available to them.

5.2 Co-Design

Co-design also plays a role concerning smart villages. If the people in the village do not know how this system was designed, then it cannot be fixed. Also, if they did not want this system, it would not be used. In the co-design process, partners from ACUC suggested using polyethylene material to line the tank and for the catchment. They knew this material was readily available and great for this use. With that advice, polyethylene was incorporated into the project. Additionally, co-designing with Mr. Boateng allowed us to know that the bricks would not be watertight. Not knowing this ahead of time would have been detrimental to the project. With this knowledge from Mr. Boeteng and help from Boeteng and our partners, we added a polyethylene lining inside the tank. Our partners tested the bricks with and without the polyethylene lining, and the lining was successful in its quest.

On the other hand, co-design presented some challenges. In discussions with co-designers/partners from ACUC, they shared that the use of old fridges could be recycled and used as a makeshift tank if laid horizontally on its back. Sealing the doors with a padlock and other sealants could allow for a more practical solution if recycled bricks are not an option. The fridge would not need a liner and could be easily opened and closed to let in rainfall depending on the season. Furthermore, the same methods in design for catchment to irrigation piping could be used and the water pressure from the fridge as a catchment would be satisfactory in delivering gravity-induced water pressure to the irrigation piping.

5.3 Generative Justice

Implementing a model of generative justice allows us to innovate around monetary needs and implement solutions that communities can benefit from most. It is essential to our design process to allow our partners in Ghana to partake in essential steps and decisions to create adequate feasibility for future implementation. Inadequate local expertise in planning, designing, and construction of irrigation projects were all able to be supplemented with the help of village leaders and Academic City University scholars in Ghana. A large factor preventing irrigation development in Ghana comes from these insufficiencies. Much of the high cost associated with irrigation development comes from the involvement of costly expatriate expertise at nearly every stage of the project cycle. A lack of co-design would also set back the project's feasibility study which could lead to exorbitant design changes during the construction of the system. By implementing a design process focused on generative justice, we are avoiding the procurement of non-standard equipment that may require special maintenance and service arrangements. By designing with our partners in Ghana, we hope that they will not be tied to any external funds, methods, or resources that are not in the vicinity of Ghana.

Many journals and research publications are not able to stray away from big technology conglomerates that strive to make money from the next-generation smart city and village development. We must be wary of implementing specific products based on technological enterprises that are looking to contribute to these efforts. Implementation of technology that is not being sought to incorporate local production or preservation is only to the benefit of expatriate business and profits. In earlier chapters, we argued that external interventions may offer short-term results, but as time goes on and repairs are needed, or new, similar projects initiated, communities are left in the same cycle of dependency as they were before the initial project. For this project, we worked with the community to identify locally available materials and expertise that will support the construction, maintenance, and creation of new systems. Not only does this added part of the design process meet the needs of the community, but it also helps to transform the cycle of dependence into one of self-determination, self-sufficiency, and sustainability.

6. CONCLUSION

Overall, this project was ultimately a success. We designed a working irrigation system, using Nelplast bricks, gravity, and various pipes. We were successfully able to test it and see it working effectively.

Furthermore, relations between partners in Ghana were strengthened. Every time we had a conversation with our partners, bonds were secured. This in turn allows our advisors to keep the connections we made and use them in the future. Specifically, if contact with ACUC students is going to be established for future projects, they can use the experience they had through this project to prepare for other projects. Also, we can continue to promote the use of Mr. Boateng's plastic bricks and hopefully encourage recycling within the community.

6.1 Future Work

An idea for future irrigation systems is using an old fridge to store the water. This would also promote recycling in another way. The fridge would already be water-tight, so it would not need the extra polyethylene lining. It would also be easily able to seal, as discussed previously. If plastic bricks were not an option, an old refrigerator would be a suitable alternative.

In the future, we're hoping this irrigation system lasts and increases the yield of the crops. If this is the case, we hope that this methodology can be used to build and implement irrigation systems in other regions, not just Akyem Dwense. We are hoping the students from ACUC can rebuild this on their own due to the fact that we co-designed it with them. We're hoping Mr. Boateng can propose creating his tanks with his bricks, or with a new variety of mold.

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APPENDIX

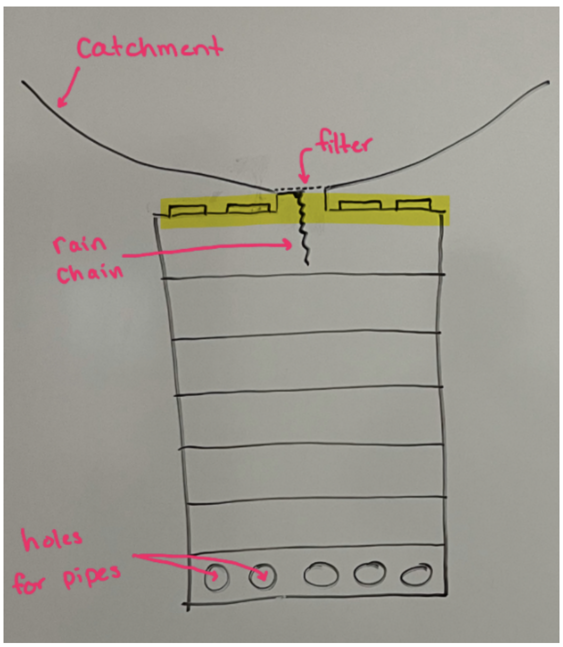
Appendix I

Tank size calculation

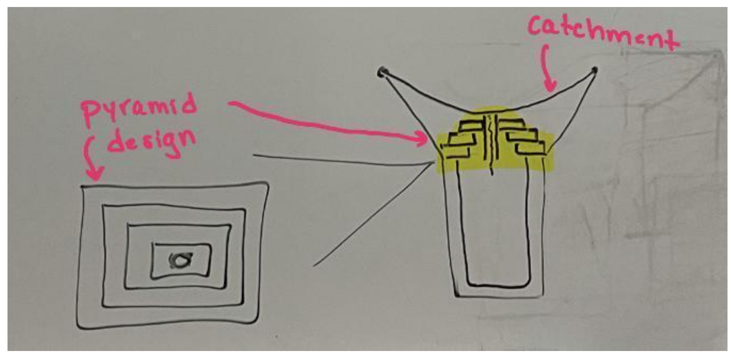
$$\frac{1{,}000\ \text{gallon tank}}{1} \times \frac{1\ \text{in per ft}^2}{.623\ \text{gallons}} \times \frac{1\ \text{year}}{60\ \text{in rainfall}} = 26.75\ \text{ft}^2$$

Appendix II

Initial catchment design with flat roof.



Initial catchment design with pyramid roof



Appendix III

Tank size calculations

.623 gallons of water = 1 inch in a square foot of water

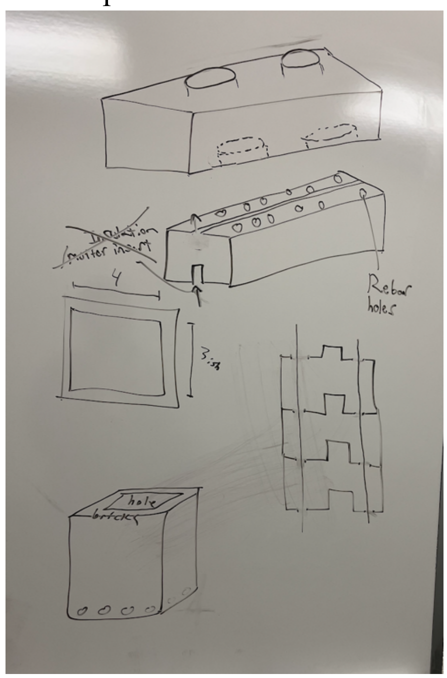
16 week dry season & 2" water per week = 32" rain water

32" rain water = .14 gallons per plant

$$\frac{3800 \text{ plants}}{1} \times \frac{.14 \text{ gallons}}{1 \text{ plant}} = 532 \text{ gallons}$$

Appendix IV

Initial brick design drawings and rebar placement



Appendix V

Precise brick dimensions provided by Mr.Bennet

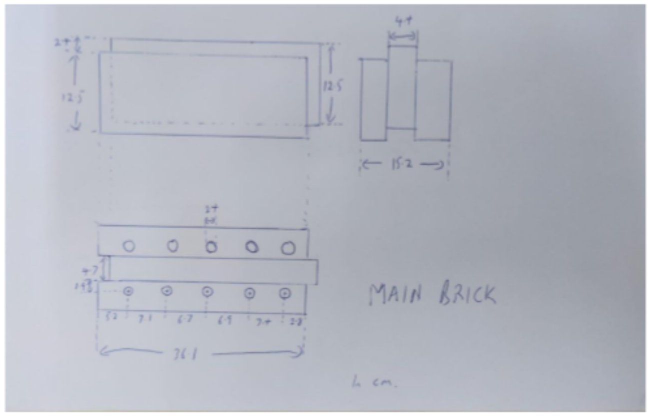


Figure 12