Garden Irrigation

Junior Secondary School Akyem Dwenase

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Abstract

Our team worked with the community in Akyem Dwenase, a village located in the eastern region of Ghana to create an irrigation system that collects rainwater and stores it for distribution during the dry season. To accompany this system our team developed a set of lesson plans for the junior secondary school to help with their hands-on learning initiative.

Executive Summary

Introduction

Our team starts off by giving information about the west African country Ghana. The team provides history and culture that lays out the place that we stayed and the climate and additional information that we dealt with while going through the process of our project. We also included what we did during our time in Ghana. The key points in this section are introducing the project and the things that we studied before arriving at the project site.

Background

In this section, our team goes into more depth of what research was useful for our project. This included the weather cycles, crop information, and more specific information about Akyem Dwenase, the village where the garden is located. The team lays out what we dealt with and all the information needed to go about the project and why we are doing this project. The key points of this section is to understand why we did this project and the background information that was needed to accomplish our goals.

Design and Development process

Our team laid out the entire preliminary design process for the full farm. We include our calculations, what we planned on doing for the system, and all the background work that needed to be done before implementing the final design. The key points of this section is what the goal was for our project, all the work we did to get to the final design and why we made certain choices.

Lesson Development

Our team talks about the structure of and how the junior secondary school runs. We looked into teaching styles, topics of interest, and how the students learned best. Through working with the headmistress and other teachers in the school system we were able to develop lesson plans to help students better understand the topics they were already learning. The key point of this section is how the students at the junior secondary school would benefit from hands-on learning.

Execution

Our team lays out the design we took into making the system. With the project not being fully built, we talked about what we were able to complete and the processes that we would have executed if we had more money and time. This is where the team lays out the construction of the final design and how the system was going to be completed.

Conclusion

Our team talks about what we learned from working with the community and the school. We talk about the production of our project as well as recap the purpose of the project and how it will continue to be produced in future years. The key points of this section is to demonstrate what we took away from our time here and how it will be beneficial to us, the next group, and more importantly the community.

Recommendations and Further Work

The group came up with further work that could be done not only in the junior secondary school garden but around the community as a whole. With respect to the garden, we highlight the importance of gathering money so that the next group can produce a more beneficial system for the farm as well as obtain the materials that would be the most effective. The team also included work that can be done for the garden but also around the community as a whole and we also mentioned work that we just see as a need to be done in the community. The key points of this topic is implementing the full scale design and how to get the money to implement it with extra work to be done.

Overview

Acknowledgments

This project was successful with the help of many different individuals. We would like to acknowledge their contributions that helped make this possible.

To Osabarima, the chief of Akyem Dwenase and the sponsor for our project, we are grateful for the opportunity to engage with the community, leadership, teachers, and students. We appreciate you preparing us to go abroad, supporting us in our project, and connecting us with any necessary resources. Thank you for sharing your community with us.

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To WPI graduate students Samuel Yusuf and Enis Boateng, who supported and guided our project plan development. To Enis, for connecting us with Nelplast and helping us tour the facility, and for remaining a valuable contact even though he was not physically on site with us.

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1. Introduction

Ghana, formerly known as the Gold Coast, was the first sub-Saharan African nation to achieve independence, having negotiated freedom from Britain in 1957[1]. Though there were periods of instability in the past, Ghana is considered to be a stable country since its transition to a multi-party democratic system in 1992[1]. Gold and cocoa are the main economic exports of Ghana and are linked to the livelihoods of millions people across the country[1].

Ghana is located in Western Africa and is bordered by Burkina Faso to the north, Togo to the east, Côte d'Ivoire to the west and the Atlantic Ocean to the south[2]. The country of Ghana covers 238,535 square kilometers and is bisected by the Prime Meridian, which intersects Ghana in the city of Tema, located approximately 25 km east of the capital, Accra[2]. Furthermore, the peninsula known as Cape Three Points is the closest land fall to the intersection of the equator and the Prime Meridian[2]. The coastline is populated by sandy beaches and lagoons, which devolve into a narrow grassy plain stretching inland[3]. This plain widens into the east while the south and west are covered with dense rainforests. As one travels north, one will pass through forested hills to reach the dry savannahs and open woodlands.

Due to its proximity to the equator and the low elevations (the entirety of the country lies below 1,000m), Ghana has a traditionally tropical climate[3]. Temperatures can range from surpassing 30 ℃ (86℉) during the day to around 20 ℃ (68℉) at night[2]. Throughout the year, humidity is also high, most notably in the more coastal regions of the country.

Ghana has two rainy seasons, from March to July and from September to October with higher rainfall being experienced in the southern regions[2]. Some southern areas can receive an amount surpassing 2,000mm of rain annually while the more dry regions of the north receive approximately 800mm each year[2]. Furthermore, the capital of Ghana, Accra, along with its eastern coastline, lies within the Dahomey Gap. This is a region of savannah that receives lower rainfall than other southern regions of West African countries. As a result, Accra receives significantly less rain than would be expected given its location in comparison to countrywide rainfall trends[3].

Akyem Dwenase, where the team developed our project, is located in southern Ghana, specifically the eastern region, which is north of the capital, Accra. Dwenase is a small agricultural village with a population close to two thousand people. Due to the region's tropical climate there are alternating wet and dry seasons twice yearly. The eastern region has two wet seasons, from April to July and September to November, respectively that are separated by major and minor dry seasons from December to April and the month of August[3]. These prolonged dry spells limit the type of crops that can be grown within the region, leading to decreased crop production due to inconsistent rains. This will ultimately hamper the economy when people have less crops to sell and therefore less income.

Agriculture is the dominant economic sector in Ghana with over 60% of the working population being reliant on farming and crop production for their livelihood[4]. Yet less than 1% of farmland in Ghana is irrigated[4]. The rainfall fluctuations, exacerbated by climate change, makes the region and economy vulnerable.

In the eastern region, climate change is driving an increase in temperatures and a decrease in annual rainfall. Since 1968 there has been an overall trend of rainfall reduction between 2 and 4 mm per year per region. Furthermore, there has been a delay in the start of the rainy season by an average of 0.5 days each year[5]. The inconsistent rains decreased crop production and has had a greater impact on crops since seeds are traditionally planted after the first rainfall and require a large amount of water during the early stages of growth. Thus a delay in the rainy season reduces crop yields impacting the local economy. In the event that a rainy season experiences a significant delay, regardless of any potential reduction in intensity, there is a risk of communities experiencing food insecurity.

At first, the team designed and planned for the implementation of a drip irrigation system for Osabarima's, the chief of Akyem Dwenase, cocoa farm (see Section 4.1: Design and Development Process: Original Design). However, after arriving in Dwenase and consulting with local leadership, we reoriented our project to develop an irrigation system for the junior secondary school's garden. Working in collaboration with the school and its teachers and students was ideal as a number of goals could be accomplished within the same project. Our focus centered on mitigating the effects of climate change, supporting local educational efforts, through science, gardening, and construction education, and to develop a scalable irrigation system for the garden that could be incorporated into local farms in the future.

The initial goal of our project, for the junior secondary school's irrigation system, was to collect and store enough water for the whole garden throughout the dry season. This would allow the plants to thrive year round rather than just during the rainy season, and hopefully prevent the crops from dying. Our initial design included catchment, storage, and delivery sub sections. The collection system would be an inverted umbrella shape and funnel the water into the collection tank where it will be stored until the dry season. The delivery sub section will allow this collected and stored rain water to be delivered to the plants during the dry season. However, due to budget constraints the implemented system only works for a small subsection of the garden. The intention was to collect rainwater utilizing a new system for the community and the scaled down system still utilized the catchment system described above and thus accomplished this goal.

Additionally, Madam Francisca, the headmistress of the junior secondary school, brought it to our attention that the garden required a fence which the goats cannot break through. Previously, the goats were breaking through the fence resulting in allowing many of the local animals–chicken, sheep, goats, etc.–to enter the garden and eat the plants. In addition, the garden has multiple stumps from trees that were cut down. These stumps need to be uprooted and removed so the land can be tilled for more garden beds. While both of these problems are not directly related to our project goal, which is the irrigation system, we worked with the school to advocate for the remedy of these issues.

In support of the junior secondary school and the Dwenase education system, we also wrote and supplied the materials for practicals to cover a range of topics. These practicals were focused on erosion and weathering, the molecular structure of water, simple circuits, and basic engineering principles. The team was able to complete two of these practicals with the different levels of students at the junior secondary school and gather observations to generate suggestions for future groups.

2. Background

Due to the nature of our project and the goal involving factors outside of the group's expertises, the team did a lot of research before starting our project, so that we were as informed as possible. Our research areas included the environment in Ghana, the building materials we intended on using, and the Ghanaian education system. We wanted to create a final project that was useful for the community, and to do so we needed to understand a range of different criteria when we were making decisions. Accompanying this background research, we asked for continuous and ample input from the community and collaborated with them to successfully execute our project.

2.1. *Environment*

Ghana is located near the equator and the country experiences a tropical climate. Additionally, in the gardens different crops are grown that are more suitable to the climate in Dwenase. This required research on the climate, seasons, rainfall, crops, and water requirements before a system design could be generated. Furthermore, in Ghana, there are a number of smaller farms in contrast to the large scale farming system used in the United States, this lends itself more to the practice of crop rotation which is common in these small farms.

2.1.1. *Ghana's Climate Background*

Ghana's climate is generally broken into two seasons, wet and dry, corresponding to the expected rainfall during that time. While northern Ghana has only one wet season from May to September, southern Ghana has two, a primary and a minor, from April to July and September to November, respectively. The village of Akyem Dwenase is located in the south of Ghana, so it experiences two wet seasons.

Additionally, the northern region of Ghana receives less rainfall than the southern region. The northern region receives ~800mm of rain while the southern region receives ~1400mm of rain. This is because the northern region of Ghana experiences higher temperatures. The rainfall across the country is shown in Figure 1.

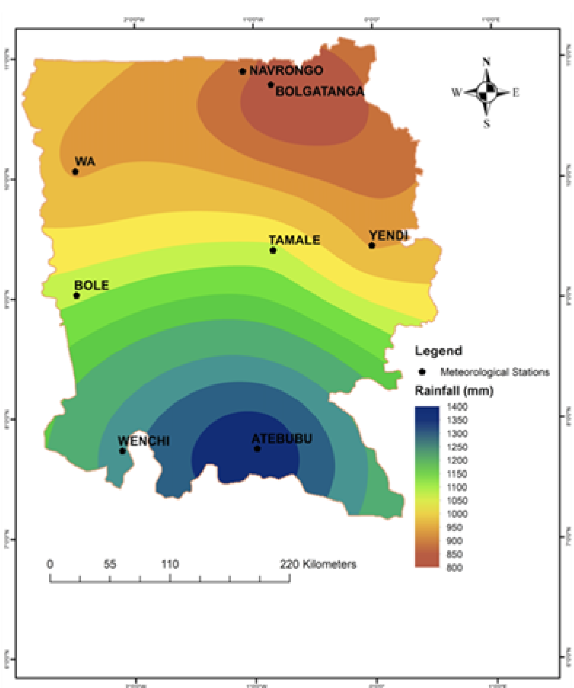

Figure 1: This figure shows the average rainfall in Ghana by region. The red color indicates lower rainfall and as the map progresses to the blue purple color the rainfall increases. The scale for the rainfall can be seen in the lower right corner[5].

The seasonal minimum temperatures get the lowest in the Ashanti region, where Akyem Dwenase is located, between the months of December and February where the average minimum temperature drops to 21.77℃ which is ~71℉. The average minimum temperature in this region is recorded between March and May, recording around 23.26℃ which is ~74℉. The average high low and mean temperatures along with the average precipitation is depicted in Figure 1 broken up by month. As shown in Figure 1 the lowest minimum average is 21℃ which is again ~71℉, and the highest average maximum is 36℃ which is ~97℉. The average temperature is higher during the dry season than it is during the wet season.

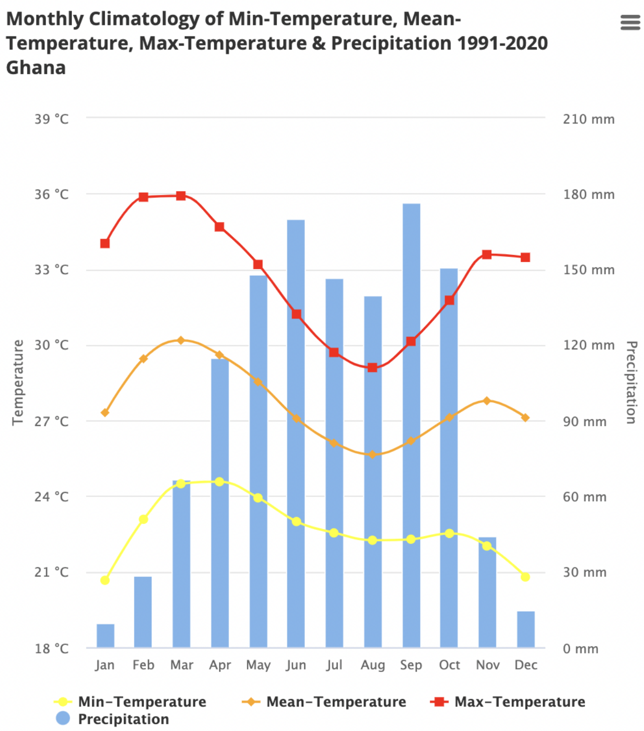

Figure 2: The red line shows the average max temperature. The orange line shows the average mean temperature and the yellow line shows the average minimum temperature. The temperature values are shown on the left y-axis in celsius, and the x-axis is broken up by month on the bottom of the graph. The blue bar graph shows the average precipitation with the values shown on the right of the graph in millimeters[6].

Climate change has caused an increase in the average temperature in Ghana; rising by 1 degree celsius since 1960. The rate of increase has been more rapid in the northern region than in the southern region, where the country already experiences higher temperature[7]. The average number of "hot" days in Ghana has increased by 48 days, and the average number of "hot" nights has increased by 73 nights between 1960 and 2003, and data shows this trend is continuing. The increase in temperatures has impacted the timing and rainfall capacity of the wet and dry seasons. The average rainfall of the wet season is decreasing, and the predictability of the season change is becoming more sporadic. Additionally, the rate of desertification of Ghana is also increasing. All of these changes are impacting agriculture, human health, poverty, and general welfare in the country[8].

2.1.2. Crops Background

The Dwenase junior secondary school's garden grows a variety of crops. Currently the garden is focusing on garden eggs, okra, carrots, and beans. The school's headmistress, Madam Francisca, also intends on having the students plant cabbage and lettuce if they have an irrigation system to accommodate the additional water requirements of those crops. Thus, we looked at the different features of each of these plants to inform our project.

First, garden eggs are a variety of eggplant that grows in Ghana. There were no water requirements specific to garden eggs, but most eggplant varieties require 1-2 inches of water per week[9]. Additionally, there were some specific fertilization recommendations for garden eggs to take under consideration[10].

Next, the crop okra is in the hibiscus/mallows family which contain edible seed pods. Okra requires 1 to 1.5 inches of rain per week. Without testing the nutrients level of the soil the recommended fertilization is 2 pounds for each 100 square feet[11].

In addition, carrots require approximately 1 inch of water per week, and should not be overfertilized. Too much nitrogen decreases root growth in the carrots, so it is important to deliver no more than 2-3 tablespoons per 10 feet of crop row[12].

Furthermore, black eyed peas, locally known as cow peas, are the type of beans grown in the garden. Black eyed peas require 1 inch of water per week and ideally should be irrigated every 7 to 10 days. Beans don't require nitrogen based fertilizer as they are known for reintroducing nitrogen to the soil[13].

Lastly, cabbage requires 1-2 inches of water per week and should be watered infrequently. For fertilizing a half cup of nitrogen based fertilizer should be applied for every 10 feet of row. Nitrogen should not be applied to the plant after the heads form as this can cause loose heads or splitting to occur[14].

Similar to cabbage, lettuce also requires 1 to 2 inches of water per week, but this can vary based on location. It is also important to consider Ghana's hot climate as this will most likely draw more water from the plants[15].

2.1.3. Crop rotation

Crop rotation is the act of changing which crops are planted in a specific area so that no one plant type would be continuously planted in the same bed. This is important for maintaining the health of the soil. Rotating the crops ensures that the same nutrients are not being drawn out of the soil time and time again. Different types of plants utilize certain nutrients while replenishing others in the soil. Those nutrients depend upon the plant family a specific crop comes from.

Plants are in one of eleven families, but there are seven families most agricultural plants fall into: legumes, nightshades, chicories, umbels, chenopods, brassicas, and allium. The legume family commonly includes beans and peas, and this family returns nitrogen to the soil. In contrast, the nightshade family, which commonly includes tomatoes, eggplants, peppers, is known for drawing lots of nitrogen and phosphorus from the soil. Furthermore, the chicories family commonly includes lettuce and endives and the umbels family commonly includes carrots, parsnips, and fennel, and are often used for their edible roots. The chenopod family includes beets, swiss chard, and spinach while the brassicas family commonly includes cabbage, broccoli, and brussel sprouts. Many of the species in this family are capable of releasing toxins into the soil that hinder weed growth, pests, and pathogens[16]. The brassicas family is also good at capturing nitrogen from the soil, so they are beneficial after a harvest. Finally, the allium family includes onions, garlic, and leaks. These crops are rich in organosulfur compounds, so they are known for their antibacterial and antioxidant activities[17].

Each of these plant families have different effects on the soil. For example, nightshades require a lot of nitrogen and phosphorus to grow, but root crops extract more calcium and potassium[18]. A common example of crop rotation is after a corn harvest farmers may plant beans. This is because corn removes a lot of nitrogen from the soil while beans will return large amounts of nitrogen to the soil, ensuring that corn will be able to grow in those fields again. This helps to ensure the health of all the plants grown and continue strong yields for years to come. Additionally, crop rotation helps with biodiversity and interrupts pest and disease cycles[19].

2.2. Materials

We wanted our project to be sustainable and work with materials that the community would be able to cheaply replace with wear and tear. We also wanted the community to be able to replicate our design in the future, so using materials that were accessible to them was paramount. We learned about an ecobrick company in Ghana, called Nelplast, where the bricks are partly made from recycled plastic. This is something we chose to research for our project as it is a local, sustainable and affordable material. Furthermore, we were told bamboo was readily accessible in the area. This is a building material in many parts of the world, but because we were not personally familiar with building with bamboo we chose to learn more about the material before making a final decision regarding our project.

2.2.1. Brick Background

Nelplast is a company that makes ecobricks out of recycled plastics. They create three main styles of bricks–lego bricks, corner/pillar bricks, and tiles. The lego bricks are 14 inches long, 5 inches wide, and 6 inches tall. The corner/pillar bricks are 15 inches long, 8 inches wide, and 6 inches tall–see Appendix 10.8. Each brick weighs approximately 25 pounds. The corner/pillar bricks are hollow in the middle so they can be filled with cement and rebar during the building process while the lego bricks are designed to interlock. These bricks need to be hammered together to get a tight fit and do not require cements due to their interlocking nature. Additionally, structures with these bricks only have rebar going through the column pieces as the bricks themselves are already reinforced with rebar. The column bricks must be cut using a grinding wheel rather than split as stone bricks are, due to the nature of the material. Images of the bricks can be found in Appendix 10.1.

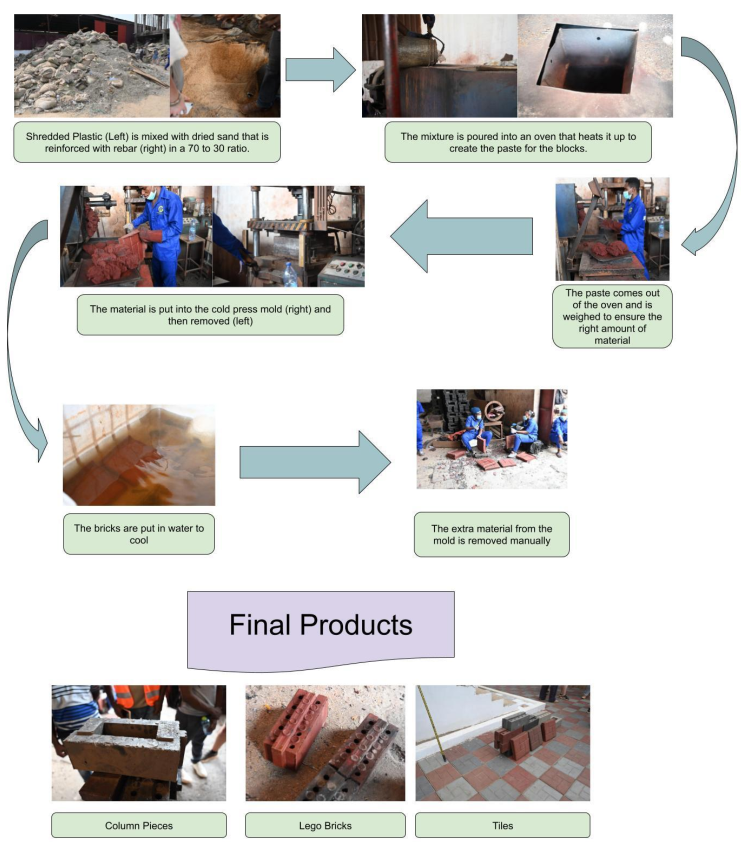

Figure 3: This figure shows the step by step process for the construction of the Nelplast bricks.

The Nelplast bricks are made by combining 70 percent recycled plastic with 30 percent sand which is reinforced with rebar particles. This is then melted down and weighed. The proper amount of material is then placed into the form and put on a cold press. The material is pressed into the desired shape and subsequently allowed to cool. Any excess material from the form is removed and the bricks are ready for construction. This process is diagrammed in Figure 3 with photographs taken from the factory.

In Ghana, bricks are graded A, B, and C. A-level bricks are those used for commercial buildings while B-level bricks are those used for very nice, expensive dwellings or lower scale commercial buildings. C-level bricks are mainly used for the construction of average houses. On this scale, Nelplast's ecobricks test at the high A-level meaning they are actually stronger than the average bricks being used in the commercial building market.

The bricks currently cost 8 GHC a brick, but there is discussion at Nelplast of raising this price. There is also discussion of decreasing the amount of material per brick to reduce production costs and brick weight. Nelplast is working on acquiring more space, so the company can make another factory as they currently only produce about 200 bricks a day. This means they produce the materials to make 15 to 18 houses per year.

In communicating with Nelplast about delivery prices and potentially buying or renting the machinery required to cut the column bricks to make the corners, they informed us that we would need to find our own car to transport the bricks. This would account for an additional transportation cost. We were also told we would be able to rent the grinding wheel capable of cutting the bricks from a hardware store. However, if Nelplast's grinding machine is not in use at a future use for these bricks it may be able to be borrowed. The email communication on this topic is included in Appendix 10.2.

2.2.2. Bamboo Material Analysis

Bamboo is commonly used as a construction material, most notably in places such as Asia and Indonesia. It is sometimes referred to as poor man's timber because it is inexpensive and grows quickly. Bamboo is a strong, fibrous building material that is more flexible than wood which allows it to meet unique architectural needs. Bamboo is partly hollow as it is made of augmented hollow joints. The composition of this material is 50% parenchyma, 40% fiber and 10% conducting tissue. The compressive strength of bamboo is twice that of concrete, its tensile strength is close to that of steel, and its fibers can withstand higher shear stress than wood. As a construction material bamboo is susceptible to termite and fungal attacks, so typically it is dried and preserved before use in architecture[20].

Drying bamboo takes longer than the drying process for wood of similar density. This is a result of bamboo's increased ability to absorb moisture as a result of the hygroscopic materials in the bamboo. As a piece of bamboo dries it will both contract and shrink. During the drying process bamboo poles can reduce in diameter by 10-16 percent and reduce ion wall thickness by 15-17 percent. Because green/wet bamboo is subject to shrinkage and more of a target for insects it should not be used for construction until it has been dried[21].

Typically, bamboo poles are air dried. In this process it is important to reduce its contact with soil to prevent insects and fungi from infecting the poles. Quickly changing the bamboo's environment from moist to dry can cause splitting of the stalks, so it is recommended that bamboo not be dried in direct sunlight, however this does not pertain to anyone working with split bamboo poles.. Bamboo should be dried in a location with good air circulation, and it can be stacked horizontally or vertically while the drying process is taking place. Typically the bamboo drying process takes 6-12 weeks depending on the moisture in the bamboo when it is cut and the moisture in the environment in which the bamboo is drying[21].

2.3. Education

Our project was done in conjunction with the junior secondary school. To accompany the irrigation system we constructed, we were also tasked with producing lesson plans focusing on practicals for the students. Since we were assigned this task we chose to research different learning styles, teaching styles, and lesson plan design processes to best inform our own lesson plan development. We also found it valuable to learn more about Ghana's educational background so we could be well informed on their classroom environment. This research was combined with our own hands-on experience, observations of a classroom setting and our partnership with the teachers at the junior secondary school.

2.3.1. Learning Styles

Each student experiences the world in a different way and therefore learns in a different way. A student’s learning style is the way in which that particular student understands, interacts with and responds to a given learning environment[22]. As such there are four widely recognized learning styles: visual, auditory, kinesthetic, and reading and writing. Some students absorb new information best when visual aids such as graphs or infographics are utilized in combination with lecture based learning while auditory learners thrive best off of lectures and group discussions. Furthermore, students who have a kinesthetic learning style succeed most often when they are able to use their hands and experience concepts through a physical and practical approach. Lastly, reading and writing learners absorb information through the written word and prefer utilizing books, articles and expressing their thoughts through writing essays and reports[23].

In education, it is necessary that there be a constant balance between the way in which a teacher presents information and how students absorb information. Part of a student's job in learning is learning how they learn and how best to adapt to different teaching styles. In an ideal world, each student would experience instruction that is tailored to their specific way of learning but as class sizes increase it becomes challenging for teachers to accommodate the many ways in which students will perceive a lesson for optimal comprehension and retention[22].

2.3.2. Teaching styles

Just as each student has a preferred learning style, each teacher will have a preferred way of teaching. This teaching style is developed from a teacher's personal experiences as a student and the subject that they teach. It is essential for the learning styles of the students in a class and the teaching style of the teacher to blend as much as possible to decrease student frustration and boredom and ensure they remain engaged with the material.

In general, there are two broad categories of teaching styles: teacher-centered and student-centered. In a teacher-centered style, the teacher takes on the role of expert or authority on a given topic while the students are viewed as novices or having no knowledge of the subject matter. The students are there to receive and absorb the information presented by the teacher and may experience more lecture-based instruction. However, in a student-centered style the teacher and the students are on more equal grounds. The teacher is still viewed as the authority on a given subject but more class participation is encouraged. Under this teaching style, students may experience more group assignments and a teacher that takes on more of the role of a coach than a lecturer[24].

Furthermore, there are two substyles of teaching within each of the two broader categories. Within the teacher-centered category, a teacher could adopt a formal authority style or a demonstrator model of teaching. The formal authority style is a rigid style of teaching and focuses solely on the teacher providing content and the student receiving it. Limited student participation is usually accompanied by this teaching style and if not done properly, this style has a tendency to promote passive learning. However, the demonstrator model allows for a teacher to act as more of a role model by demonstrating certain tasks and then guiding the students to apply the demonstrated skills. This model allows for much more student participation and skill development and also teaches them to ask for help when needed[24].

Within the student-centered category, a teacher can adopt the role of a facilitator or a delegator. As a facilitator, teachers can focus on hands-on activities and place the importance on the students for taking responsibility for their own learning. Group projects are also a helpful tool to encourage interpersonal skills, problem solving and creative applications of the subject matter. However, a teacher that adopts a delegator approach passes much more of the learning into the hands of their students. The students create and manage their own projects, assignments and learning through this style and receive feedback from the teacher as necessary. This allows for the students to be responsible for their own motivation and engagement.

No one teaching style will work best for all students in a class and as class size increases it becomes more challenging to teach to the needs of all students. Thus, a diversified approach utilizing skills and ideas from each of the above teaching styles has been shown to be the most successful. This allows students to find what works best for them and gives them the necessary tools to be responsible for their own learning[24].

2.3.3. Ghana's Educational Background

In the Ghana education system students spend 6 years in primary school, 3 years in junior secondary school, 3 years in senior secondary school, and 4 years getting a university degree. During the first three years students may learn in their local language, but after this they are taught in English, the official language of Ghana. Through 9th grade students continue to learn Ghanaian languages along with French, as Ghana borders many francophone countries. Other than language classes, textbooks and other materials are in English[25].

In Ghana acceptance into senior secondary school and university is competitive and not guaranteed. In senior secondary school students take English, science, math, and social studies as their core classes. Students are then able to elect to take additional classes–electives–for which they can choose from arts (social sciences and humanities), vocational (visual arts and home economics), technical, business, or agriculture[25].

In 2014 Ghana started redoing their teacher education program through an initiative called T-Tel. The initiative thrives and has greatly improved the education program. T-Tel worked to change teaching degrees, so the new teachers were learning more practical and less theoretical. The goal of this was to increase critical thinking and education specific to the age group, and in turn this would decrease dropout rates of students. The curriculum goal was to shift from the typical chalk and talk methods towards practical hands-on experiences in the classroom. One of the main successes of this initiative is that it was able to build a consensus of support for the new teaching style. The strength of the education has improved remarkably and with this the teachers confidence has also grown[26].

2.3.4. Making a Lesson Plan

Before a teacher can begin to impart knowledge to their students they must first generate a lesson plan[27]. A lesson plan provides an outline of the teaching goals and the plan to accomplish them for a teacher prior to presenting information to a classroom of students. When making a lesson plan, there are three key factors an instructor has to consider: the learning objectives, the learning activities and an assessment to check for understanding. Furthermore, these all must be contained within a given time frame.

To prepare a lesson plan, the first step is to identify the learning objectives or the overall learning goals an instructor has for their students. The second step is to design and plan the specific activities that will be used to help students understand and reach the set learning objectives. There are five different commonly used activity categories: interaction with content, interaction with digital content, interaction with others, problem solving and critical thinking and reflection. Each category has a series of possible activities that can be used to engage students with the material and help them achieve the predetermined learning goals.

When allowing students to interact with the content, it has been shown that the students are more likely to retain the presented information. Some possible activities that fall in this category include drill and practice, lectures with visual aids, quizzes and student presentations. In addition, as technology is becoming an essential part of classrooms around the world, allowing students to interact with content on a digital scale through games and simulations can create a whole new perspective and understanding of the subject matter. Digital interaction allows for visualization of effects and consequences of a given experiment in a virtual environment and can help improve students' decision making and problem solving skills.

The third category of learning activities is interactions with others, a method that has been used for many decades to help facilitate learning and the ability to see issues from a different perspective. Some examples of these activities are debates, discussions, performance feedback for other students and for the teacher, and potentially the inclusion of a guest speaker. In contrast, in order to foster problem solving and critical thinking skills, activities such as case studies, concept mapping or projects with real-world applications may be the way to allow students to use the knowledge they already have to think about situations in different ways. The final category is the reflection category, which includes activities such as having students keep a reflection journal or write a reflection essay on what they learned and/or what they gained from a particular lesson or project. Regardless of which learning activity is chosen, it must be useful, engage the students and align to the lesson's objectives.

The final component of the lesson plan is the assessment of student understanding. This can take many forms such as tests, papers, problems sets, presentations and performances and provides an opportunity for students to demonstrate and practice what they have learned. Assessments also allow for targeted feedback for the instructor to guide further learning and lesson plans[27].

Overall a lesson plan must be organized in an engaging and deliberate manner to optimize student focus and understanding. It must have a realistic timeline for the given time constraints and a plan for lesson closure must be generated to help summarize the major points and give students a sense of accomplishment at the end of the lesson.

3. Collaborative Approach

When we started our work in Ghana our emphasis was on co-creatorship. Our team focused on working with the community to develop a system that met their needs. We approached with a questions first mindset in order to properly establish the parameters of the project and ensure that we were solving the desired problem rather than solving our preconceived idea of the issue. We started by visiting the garden so we could visualize the space. We gathered feedback on the potential designs we had generated and discussed modifications that the headmistress and her coworkers saw fit for their needs. This included pivoting to the hose delivery system over the small scale drip irrigation because the community found this most desirable. After having these conversations, we developed a design to meet the community's needs. We then completed a cost analysis for this new design and compared it with the available community budget through conversations with Osabarima, the chief of Akyem Dwenase. From here we scaled down the design to come to a design that was more feasible for the community. After finalizing the reduced scale design we obtained the necessary materials and began construction all while maintaining an open dialogue with the local community. While construction was ongoing, we gathered pictures of our work, so they would be available for future groups to iterate on.

When developing lesson plans, we worked with Francisca to observe her classes and received feedback on the topics and preliminary designs. This was done so that the lesson plans we created would be relevant to the school's work and curriculum. Through this process it became clear that our focus should be on developing practicals and experiments that the students could execute to help reinforce concepts that they have learned.

The collaborative process is essential because the community members of Akyem Dwenase should be directly involved in the project as they have local knowledge and insight that we did not have. In addition, any system or lesson plans and materials generated by us would be used directly by the community. Thus, generating something the community does not want is inadvisable. By immediately initiating the conversation with the locals and maintaining open communication with the community we were able to foster a collaborative environment that allowed us to produce the best possible outcome given the budget and time constraints we had to work with.

3.1. Graphic/Flow chart of communication

While working on this project we communicated with many different members of the community. We created a graphic to track our communication over the term shown in figure 4. We broke this graphic up into a few main sections: town leadership, school, Nelplast, and local masons. An additional category would be our WPI support system. While these individuals did not make the graphic because we wanted it to be community focused they worked with us in our design development and helped us overcome obstacles we encountered along the way.

Additionally we collected all relevant contact information any future group might need in a spreadsheet which is shown in Appendix 10.3.

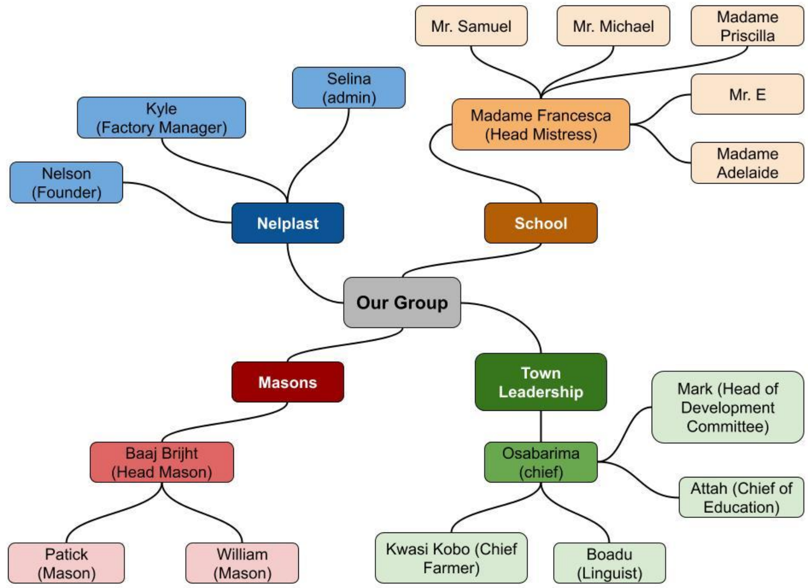

Figure 4: Visual shows our team's contacts and communication within the community throughout our project's progression.

3.1.1. *Town Leadership*

There were many key members of the town leadership that our team worked with to complete this project. Kwasi Kobo is the chief farmer for the town and manages the cocoa farm, but we continued to work with him even after our project pivoted as he is a prominent member of the community. He was able to help us obtain materials for the project. He also helped us manage construction of the foundation, and served as a liaison between us and those who were helping us to complete the work.

Next is Boadu, Osabarima's linguist. It is customary that the linguist accompany the group to other towns. This is a tradition kept from when it was more common for different areas not to have universal language, so they needed a translator. It is also customary to speak to the chief through his translator, and this tradition comes from some of the same origins. Boadu helped us throughout the project and our time in Dwenase, by helping us communicate with Osabarima and ensuring we had everything we needed to be successful.

It is important to note that the town leadership is majority male. This is common in Ghana as it is an older part of the culture that still remains. This is especially prominent in aspects of smaller village communities. Dwenase happens to be more proactive than some other villages in the area in which women are not allowed to speak during important meetings. However, in Dwenase, women are allowed to speak to the men and be a part of society, though women are often addressed second and a man is more likely to be seen as the leader of a team. Women however do have a very important and well-respected role in the education system.

3.1.2. School

When working with the junior secondary school, our main contact was the headmistress Madam Francisca. We consulted with her when determining the initial parameters of our project as well as when problems arose to determine the best solution. Madam Francisca is in charge of the garden behind the secondary school and thus we deferred to her judgment when decisions needed to be made as she would be the person who would be responsible for whatever system was built. We also communicated with her when we wished to observe the students' lessons so we could get a better idea of how to structure our own lesson plans.

Also at the school was Mr. Samuel, who teaches both Science and English. As the science classes were most relevant to the topics we wished to teach the students, we observed one of his classes on electrical energy and basic circuits. He provided a brief recap at the beginning of the lesson so that we could get a better idea of how individual lessons flow together and provided a time for us to ask questions at the conclusion of the lesson.

Finally, at the junior secondary school we also were able to speak to and observe the students. We were able to observe how they absorbed the material during their lessons and were able to speak to them later about what they learned from each lesson. We were also able to observe which students participated in which lessons so that we could incorporate methods into our lesson plans which would engage all students.

3.1.3. Nelplast

In determining the design we would ultimately build, we were granted the opportunity to visit the Nelplast Ecobrick factory and speak directly to the engineers there about utilizing the bricks as construction materials. Pictures were also able to be taken to gather an in depth look at the process by which the bricks are made and used to construct housing.

After the visit to the factory, we were able to contact the Nelplast admin, Selina, and ask her questions regarding the brick delivery and its cost, and how we would both cut the bricks and obtain the necessary tools with which to cut the bricks. She was also able to communicate our questions to Nelson Boateng, the owner of Nelplast, and provided us with his answers when applicable.

3.1.4. Masons

Another group that was instrumental in providing us with information about how to construct the desired tank was the masons. We were able to ask questions regarding how they would build a concrete slab for the tank to rest on and how much cement, sand and other materials the slab would require. Specifically Baah, who was the head mason, and his assistant Patrick spoke to us often and provided invaluable insight into the local construction process. This informed how our final design was generated and how it would need to be constructed. Furthermore, we were able to enlist the help of a couple of the masons when constructing the concrete base which helped the process go smoother.

4. Design and Development Process

4.1. Original Design

When initially approaching the project we were planning on designing and implementing a drip irrigation system for the chief - Osabarima's - cocoa farm. Our original design for this system contained catchment, storage, and delivery subsections. Our original research, completed in ID 2050, was in conjunction with this design and included topographical analysis of the area, background information on cocoa trees and the economy in Ghana, as well as information on how to construct a pictographic manual for the project. The original design is presented here and the pivoted modifications are included in later sections.

4.1.1. Topographical Evaluation

We wanted to evaluate the topography of the cocoa farm, so we asked our contact in Ghana to acquire coordinates for the cocoa farm. The coordinates we were given are N 06°05.999` W 000°41.472`. These coordinates were plugged into Google Earth and we blocked off a plot, larger than the space we know the cocoa farm occupies. We then did an elevation profile of the area. Images of the evaluation profile are shown in Appendix 10.4 at different points along the slope.

4.1.2. Catchment

The catchment system uses an inverted umbrella shape to collect rainwater and direct it into the container. We intend on using a tarp to collect the water, and piping, bamboo, or other abundant stiff material to create a sturdy frame for the catch system. The final material choice will be made in combination with our partners in Ghana. We will put a mesh panel or a grate where the water enters the reservoir to prevent any large debris from entering. The previous group recommended adding a rain chain to funnel the water into the collection basin. We currently did not include this as an element in our design, but it is something we are keeping in mind as a potential addition.

We designed three primary catch systems which can be scaled and adjusted on site. All three have one square meter of surface area, and use similar flexible materials for construction. The designs are included in Appendix 10.5. There is a square and a circular design which are very similar and would most likely sit on top of the tank. The third design is tapered to one corner. This design would not be able to sit directly on top of the tank, but it would be easier to clean and access. Additionally available materials, tank design and the preference of our partners will impact our onsight choice.

Our back up plan involves leaving the tanks open during the rainy season and manually closing them at the start of the dry season to prevent the water from evaporating. This is more labor intensive, and not our ideal plan. Additionally, one concern with this method is the potential for injury caused by having an open tank in an open area. We are also concerned about the inability to prevent debris or animals from entering and damaging the tank. However, this collection option would require less material, be easier to assemble, and possibly more accessible for the community, so we maintain this as a reserve option. If this becomes the system preferred by the local community and we put into practice, we are going to pivot to address the safety and damage concerns that come with this collection method.

4.1.3. Constructing the Reservoir

We intend on making the reservoir out of bricks made from recycled plastic designed by a Ghanaian entrepreneur, Nelson Boateng. We chose this material because it is sustainable and accessible for our project. From research completed by prior students, we know that the bricks are not water tight. For this reason we chose to line the sides of the tank and seams of the bricks with polyethylene. Polyethylene was chosen because prior research completed with student counterparts at ACUC in Ghana, informed us that polyethylene was an accessible material.

In addition, prior research informed us that the bricks were approximately six inches wide by six inches tall by twelve inches long. These measurements were obtained through digital photo measuring of the bricks via images sent to the previous team. They were also able to ask the manufacturer for more precise measurement. The bricks measured 36.1cm long, 15.2 cm wide, and 12.5 cm tall with a 2 cm offset for the interlocking section of the brick. We chose to confirm the dimensions when we visited the Nelplast factory once we arrived in Ghana, but these dimensions were used for our original preliminary design.

We intend on making a design for the reservoir that is square, so the dimensions can be easily modified accordingly on site. We want to keep the reservoir as tall as possible to maintain the pressure gained from the water's height in the reservoir as this will help the drip irrigation system run. Our preliminary design has a 1 meter by 1 meter by 1 meter reservoir that would hold roughly 1000 liters of water. This reservoir would be replicable which would make it accessible for expansion of the plantation, or if the community finds that they are actually using more or less water than we originally calculated the plants to require.

Furthermore, we plan on creating multiples of the reservoirs and interconnecting them using piping as this would allow for easier maintenance and decreased water loss. A diagram of this is located in Appendix 10.6. In this scenario, if one of the tanks had a leak, it could simply be removed from the system, drained and fixed with only the loss of approximately 1000 liters of water instead of the entire system running out of water would be the case if there was only one tank.

When making the base of the reservoir we want it to be flat so the water does not pool in the same locations every time and wear down the base. With our current plan the base of the reservoir will most likely be constructed out of concrete. This is ideal because then we can press the bricks into the concrete so they are firmly connected to the ground. We also discussed using concrete with a layer of treated sheet metal on top. This treatment will ensure that the metal does not rust or deteriorate in the wet conditions and the use of the sheet metal could reduce the amount of concrete the base requires. However, there is concern with the sheet metal option that there would be sharp edges that could potentially puncture the lining creating a leak in the tank. The final choice will be made based upon conversations with our co-creators once we arrive in Akyem Dwenase.

The previous group corresponded with students in Accra. When this group was considering how to make the tank water tight they were looking at different materials to line the tank. The counterparts in Accra suggested polyethylene as it is readily available and water tight. Our primary plan is based on using polyethylene to line the tank. We would buy the polyethylene in sheets and place spikes at the top or sides of the tank and puncture the sheets and then let them run down the inside of the tank to waterproof the bricks. In addition, we would use silicone to seal the area around the exit pipe to prevent leakage. If silicon or epoxy was not accessible concrete could be used. We discussed also considering other available resources for lining the tank. While we are open to using many different materials we will not know what we have available until we are on site.

There are two main ways to attach the outlet pipe. One of these would be to cut a hole in the bricks that fits the pipe. This would be done with a saw or a drill. We would then seal around the pipe using silicone, or another available material. The second option is to build the tank with a hole opening where we intend on placing the outlet pipe. This would require less materials for cutting the bricks, but it would leave a larger area to seal. We also need to consider how cutting the bricks could compromise their structural integrity.

4.1.4. Construction of Piping

The main outflow pipe will be made of a large diameter PVC pipe. We have been told we will have access to a 4 inch, 10.16cm PVC pipe. There is a chance we will be able to get access to pipes with a larger diameter than 10cm. The outflow pipe will require a valve, so we are looking into the most affordable valve that is also ideal for working with water. We intend on running hard line piping horizontally across the top of the plot. We then intend on running soft line piping down the sections of the plot to the trees.

We designed a few different methods for distributing an even amount of water to each plant while accounting for the pressure inside the system. Sketches of each system can be seen in Appendix 10.7. One of our proposed options involved running a soft line pipe all the way down the section of the farm and popping holes in the pipe using a drill or a nail and hammer. In executing this design we would pop more holes at the top than at the bottom as the top will pressurize last, so it will have water flowing out for the shortest amount of time, but at the largest volume. In contrast, the bottom would pressurize first, thus having the outflow for the longest amount of time, but with the lowest volume. This would attempt to accomplish a more equal distribution to all of the plants.

Our second design involves running pipes down the farm at double the frequency. Every other pipe would be the full length of the farm, and only the lower half would have holes in it. Every other, other pipe would run half the length of the farm and have holes the full length of the pipe. This would fix the issue where the top of the pipe pressurizes notably later than the bottom of the pipe, but it would require much more material, and the design already requires a large volume of piping.

We are going to present the different delivery solutions to the community members. We intend on asking for feedback, and using the delivery method they feel will work best for them as they are going to be the ones using the system, so we would like it to be practical for them.

4.1.5. Constructing the Manual

When constructing our manual we need to account for language barriers. Ghana has many different languages, and if we want more areas in Ghana to be able to access this technology we need to make it accessible. Additionally, while the official language of Ghana is English, literacy rates vary, so we need to focus on photos and diagrams as much as possible. To achieve this goal we intend on taking photos during the active assembly process, so anyone viewing the manual can see the steps we chose first hand. We also intend on using Solidworks to draw up diagrams and other digital visuals to explain the construction process. Some example diagrams can be seen in Appendix 10.9.

4.2. Pivoted Preliminary Design Plan

When our project was revised from working on the cocoa farm to working with the junior secondary school's garden it was necessary to adjust our preliminary plan drafted before our arrival. These revisions occurred in the first couple of weeks and included running new water requirement calculations and adjusting the storage and delivery systems. The additional project goals were also pivoted to be more applicable for the new design.

4.2.1. Space Evaluation

When our project pivoted to the garden, we first went to evaluate the space. We determined the dimensions of the garden using a string of a fixed length and a short measuring tape. Using these dimensions we calculated an estimated area of approximately 1500-1600 m^3. The uncertainty in the estimate is due to the curved edge of one part of the garden, making it difficult to obtain completely accurate measurements. Additionally, the garden is on a gentle slope, a feature that was useful when determining where to build the tank. The highest elevation is near the left upper corner of the drone photo in Figure 5, and the low point is the bottom most point of the drone photo included in Figure 5.

Figure 5: The top image of the is the drone photo of the garden. The bottom image is the drone photo with the stumps marked with circles, different crops marked with rectangles, and a tree marked with a star.

In Figure 5, the marked and unmarked versions of the drone footage of the garden are included. The white circles indicate large stumps in the garden while the yellow star marks the location of a dead tree that we are concerned may fall on the tank. The purple rectangle marks the location of the garden eggs crop and the red box marks the location of the beans. Additionally, the green box marks the location of the palm trees while the blue box marks the location of the okra crop. Lastly, the orange block marks the location of the carrots.

4.2.2. Catchment

We originally designed different potential catchment systems, but with the switch to the school garden we pivoted our design to look at making the roof and the catchment system out of the same material. This would be so the system can be transitioned from catchment during the wet season to roofing during the dry season. The catchment system would be connected directly to the tank using bamboo for the structure. However, after discussing this design with community members, the children's safety was brought up as a significant concern so we modified our plans to include a concrete capped tank with a separate catchment system. We still intended on using bamboo as the structure because it is a free and plentiful material, and would be easily replaced with wear and tear while still being strong and reliable.

We decided on the previous design in which the catchment system is a tarp or tarplike material tapered to one corner. This is important because it would allow access to cap the system if and when that would become necessary while the other designs would make maintenance more difficult. We also decided to add a two-bended PVC pipe inside the tank where water would flow through to enter because this will help prevent water loss due to evaporation. In order to exit the tank, water molecules would have to accumulate enough energy to navigate the bended PVC pipe, a far more challenging feat than vaporizing straight upwards into the air. This being said, the pipe would not prevent all evaporation but would significantly decrease the occurrence.

4.2.3. Storage

Before the focus of our project was redirected from the cocoa farm to the junior secondary school's garden, our intent was to build a storage tank using the bricks made by Nelplast. These bricks are made out of recycled plastic and sand and are designed to interlock, thus creating a solid structure. However, upon initial discussion after the switch to the garden, we considered purchasing a tank of a predetermined size from a hardware store in place of constructing one ourselves. This would decrease the construction time and provide assurance that the structure was safe and wouldn't be a safety hazard to the children as the store bought poly tanks are already in wide use around Dwenase. In order to better inform the decision, we asked the headmistress how long she felt a 2000 liter tank would last. She informed us that she believed it would not last a month when used to water the full garden. Additionally, we researched the crops in the garden and how much water each crop needs, but because it was hard to estimate the number of crops in the garden, and due to crop rotation it was difficult to calculate the exact amount of water necessary to sustain the garden throughout the entirety of the dry season. Ultimately, we used the headmistress' estimate to drive our calculations as the garden belongs to and is maintained by her and her students.

Upon completing the calculations to determine how much water each of the crop types planted in the garden would need, we decided to return to the original plan of utilizing the Nelplast plastic bricks as the tanks we could purchase from the hardware store wouldn't be large enough to store the calculated required 18,000 liters of water. Before moving forward with ordering materials to construct a tank of this size, two members of the group met with Madam Francisca to confirm that she thought the size was appropriate and had no other concerns regarding the placement and construction of the tank. Simultaneously, the other half of the group was able to visit the Nelplast factory and obtain some of the bricks as well as ask questions of the Nelplast engineers.

This storage design involved a tank with approximately 3 meter sides and 2 meter tall walls. Each side would be 8 lego bricks and 2 pillar pieces long and 16 bricks or pillars high. We intended on putting pillars in the corners and halfway through each side to increase the lateral stability of the tank. This is shown in Appendix 10.10. We decided to run rebar through the pillars and then fill them with concrete to give the structure more stability. Additionally, we intended on lining the tank with a layer of concrete to make the tank water tight. The bricks themselves are not water tight, so by lining the tank we increase the strength and keep the water inside. Ultimately, a total of 704 lego bricks and 192 pillar pieces would be required to complete the entire tank.

Furthermore, the tank will be on a thick concrete slab. This will elevate the tank and act as the tank's foundation to help build a strong structure. The local masons suggested making the base 50 percent larger than the structure's base, so this put each side of the base at approximately 4.5 meters. This then translated into 4 pillar bricks and 10 lego bricks per side of the base. The bricks would be inserted right into the cement so they cure with the concrete to increase the strength of the structure. The concrete slab would also be sloped towards the outlet so the water runs out of the tank with the flow of gravity. This slope will ideally be at a 5 percent grade as the required grade for running water is 2 percent, and 5 percent would allow a significant margin for error. After discussing with the masons, and comparing the sloped base to making a shower drain, they informed us that this is something they already know how to do, so we would leave it up to the local experts to construct.

Additionally, we intended on capping the tank as this would prevent the tank from becoming a drowning hazard. This was a concern given the location of the tank in the school yard and how accessible it would be to children. Another consideration was painting the tank white, given that the Nelplast bricks are black, so it would not heat up as quickly. The team thought this would help slow the temperature increase of the water and help combat losses due to evaporation.

4.2.4. Delivery

When we first pivoted to irrigating the garden, we were planning on using a smaller scale of the drip irrigation system intended for the cocoa farm. This would require more valves to control water flow to different sections, and necessitate a way to measure how much water each plant is getting.

After consulting with Madam Francisca, we decided a hose delivery method was more practical than the scaled down drip irrigation system. The headmistress informed us that the students rotate crops to maintain the health of the soil, so a set water distribution would not be beneficial. After looking at videos of the garden in the wet season we decided we did not want to hinder any crop growth by putting lines and piping in the way of the plants. Furthermore, since the students do not plant crops in rows or lines, it would be difficult to run piping for the system. Madam Francisca was also more enthusiastic and interested in the hose option, and seeing as it is not our garden, we would like to do whatever she feels will be most valuable for their purposes and deferred to her judgment.

4.2.5. Cost Analysis

Our pivoted preliminary design included a tank that would hold roughly 18,000 liters of water. We collected the estimated costs of each item as shown in Appendix 10.11. We received these prices from Nelplast, the masons in the town, and the local hardware store. Any price marked with a question mark is an estimate of the price since factors such as delivery fees were subject to change. It is also worth noting that these prices will change as the conversion rate and economic conditions change. We estimated the cost of the full scale irrigation system as being above 2,000 USD. We also completed a cost analysis for a half-sized version of the irrigation system which is shown in Appendix 10.12. This cost analysis came out to ~1,500 USD, as delivery fees are mostly a fixed cost that quantity doesn't alter.

4.2.6. Additional project goals

When we discussed the garden with the headmistress, we found that the animals had been eating the crops. This is a result of the free ranging goats breaking the fence by ramming into it. For this reason, Madam Francisca would like the fence to be replaced with a thick wire mesh fence on metal stakes so that the goats cannot get in. While this was not part of the original scope of our project, in order for our project to be effective a working fence is required. Otherwise it doesn't matter if we are irrigating the crops as they are just going to be trampled or eaten by the goats.

The headmistress also informed us that several large trees were recently cut down but the stumps still needed to be uprooted so the land can be tilled and used for crops. This is not as imperative for the function of our project, but this is also something our group agreed to advocate for while working on other aspects of the garden. Most notably because it would be difficult to complete this task after the fencing is installed.

We intended to work with students and the town masons while constructing the irrigation system so they understand how it was built and can repair and replicate it for the future. This is in place of an instruction manual because our project pivot did not leave us with enough time to complete a quality manual.

4.3. Final Design

After completing our cost analysis for our pivoted design, shown in Appendix 10.11, we had a meeting with Osabarima. It was determined that completing the full scale of the garden was not feasible with the budget we were given. Knowing this, we worked with Osabarima and Madam Francisca, and pivoted the project design to reduce the scale and overall cost.

4.3.1. Space Evaluation

Our final pivot does not change to a new space, so our pivoted preliminary space evaluation still applied. We still worked with the junior secondary school garden which has a gentle slope. Figure 5, which shows the garden and its layout in our pivoted preliminary space evaluation still applied, though because the students use crop rotation the layout of the garden will change in the future.

4.3.2. Catchment

Our team decided on our original upside down umbrella idea for the catchment system (Appendix 10.5). With this design, we would be able to detach the catchment structure from the storage tank. This made the most sense for the type of tank we used, so that the tank can be cleaned and capped when full. We also utilized waterproof flooring material as a tarp to build the umbrella as it allowed the water to run off it and was easily formed into the necessary shape to funnel the rainwater into the tank. The water rolls off the tarp and is funneled into a pipe that then delivers the liquid into the storage tank. The structure of the tarp and catchment system is maintained using bamboo poles. We determined that bamboo was the best material as it would have the strength to maintain the shape of the catchment system and support it while being readily available and cost effective.

4.3.3. Storage

With the budget given to us, our team decided to use a 2000 liter tank that we purchased from the community's hardware store. This saved more construction time and money than using the Nelplast Ecobricks and is safer for the children than an open reservoir that they can potentially fall into. Furthermore, a benefit of this tank is that it came with a cap so it can be easily sealed should the need arise. It also already has an out spout to which we can attach a valve so the water won't exit the tank unless desired. The tank is also portable meaning it can be relocated in the future should it be better used elsewhere or should the school administration decide to replace it with a larger tank. This ensures the tank is not wasted as things may pivot in the future.

4.3.4. Delivery

Our team decided to utilize a hosing method instead of drip irrigation after speaking with Madam Francisca. She expressed that the garden undergoes regular crop rotation and it was determined that drip irrigation would not be a suitable system as each crop needs a different amount of water. With crop rotation, it makes the most sense to have a manual way to water each crop rather than to have a specific amount of water deposited in a given area. Within this design, there is a valve coming from the tank to store the water in the tank until needed. Then there is a secondary valve at the beginning of the hose to control the flow of water exiting the tank. The first valve connects to a pipe that goes straight out from the tank. From that pipe, there is a connector pipe that holds two other pipes going in either direction.

4.3.5. Cost Analysis

Our final design included a tank that would hold 2000 liters of water. We collected the estimated costs of each item as shown in 10.13. These are the prices we have spent on each item and the location in which we have bought them. The final cost of the full system comes out to be 2617 Cedi which is approximately 262 USD.

4.3.6. Additional Project Goals

The final design that was constructed during our time in Dwenase was a significantly scaled down version of what the team initially designed and hoped to build. Despite this, we wanted to give the community the skills to construct more irrigation systems of similar or larger size, with a specific focus on the catchment system. If farmers and others in Dwenase can collect and store rainwater, without the use of a roof this practice has the potential to increase crop yield and subsequent income. In addition, through working with the students at the junior secondary school, we hoped to instill the knowledge in the younger generation and create lesson plans that can be reused to add more value to the current and future students' practical education.

5. Lesson Development

When developing lesson plans for the junior secondary school, our team took several steps to ensure maximum effectiveness. These steps included researching lesson plan development, observing lessons at the school, compiling a list of possible lesson topics, completing research on relevant topics, and developing practicals on chosen lesson topics using materials available locally.

5.1. Lesson Observation

Our group worked with the headmistress, Francisca, to sit in on some lessons at the junior secondary school. The first lesson we observed was a Form 2 science class while the second lesson we sat in on was a Form 3 hand crafts class which is similar to home economics in the United States. In the Form 2 science class, taught by Mr. Samuel, the students were learning about electric power. They learned about how electric power can be generated–wind, solar, dam, etc. The instructor then explained the components of a simple circuit along with the names for each part and the symbol that represents that piece in the circuit. The teacher also discussed how each of these elements work and had students come up to the board to draw a simple circuit as a method of clarifying and correcting any confusion.

In the Form 3 hand crafts class, taught by Madam Francisca, the students were learning about dry cooking methods. As a class they discussed the different dry methods of cooking and the advantages and disadvantages for each of these methods. The team learned that the Form 3 students are preparing for upcoming exams at the end of the school year, so most of their hand crafts class is focused on learning the necessary material to pass that exam.

5.2. Planning

Our team brainstormed a list of possible topics for the lesson plans. We each chose a topic and completed some preliminary research on that topic. Our team researched erosion, light reflection, specific heat, and structural stability. In this process we found that we did not have access to the materials to complete a hands-on lesson for specific heat, so this lesson was pivoted to the molecular properties of water.

Following this preliminary research, we spoke with Mr. Samuel, the science teacher at the junior secondary school. We discussed our initial ideas and possible practicals with Mr. Samuel and requested feedback. In this meeting he expressed that they would prefer a lesson on simple circuits for the Form 2 class, so we chose to pivot our lesson on light to a lesson on simple circuits. He also emphasized the importance of creating hands-on lessons for the students because that is an area in which the school is currently lacking in access. He emphasized that while some students can master concepts through theory, many students learn better and retain more information with a physical hands-on approach. He explained which topics aligned best with what form was learning. He recommended that the molecular properties of water be done with Form 1 while he requested that the simple circuit be completed with Form 2. He also requested that erosion and weathering be completed with Form 3, as it related closely to the topics in soil conservation the students were already studying.

Furthermore, Mr. Samuel originally suggested the structural stability be completed with Form 3, but then expressed interest in a school wide activity. We wanted to embrace both of these opportunities, so we chose to go ahead and make a general engineering principles lesson plan that could be completed as a school wide activity. In addition, our team chose to complete this activity in partnership with the Makerspace IQP team who were also working with the school. We decided that more direction would be necessary, and it would be better to complete the whole school lesson plan as a joint activity. At this point, we continued to research and then test the practical experiments for each of the finalized topics.

5.3. Topic Research

Once we determined topics for our lesson plan, we did research on the topics we chose, so we were well informed. We looked into hands-on experiments that can be done in the classroom to bring the theoretical knowledge into practical use, by request of Mr. Samuel. Our chosen lesson plans were about erosion and weathering, molecular properties of water, simple circuits, and structural stability.

5.3.1. Engineering Principles

The basis for all engineering projects stems from three areas: problem solving, collaboration, and creative thinking. Without these fundamental skills, engineers cannot succeed in the more technical areas of their field. These skills allow the building and design process to function properly.

Problem solving is a basic life skill that we use everyday without consciously thinking about it. This skill involves the ability to identify and evaluate a problem, develop and consider possible solutions, and determine the most appropriate course of action for the given situation[28]. The ability to evaluate a prior course of action and reflect on the successes and failures of that path is also an essential piece of problem solving. Through problem solving, practical and creative solutions to different obstacles and scenarios can be generated.

The second fundamental skill of all engineers is collaboration. On the surface, collaboration appears identical to teamwork, however they are different concepts. Teamwork is when two or more people work together to achieve a goal by separating out the work and piecing it together to create a final product[29]. In addition, a team hierarchy may form with certain individuals in the group focusing on sections of the project that pertain more to their specific skill set. In contrast, collaboration is when a group of people work together on equal footing. Responsibilities are shared in an open and free-flowing manner. Collaboration requires much stronger interpersonal skills and involves more brainstorming and group discussions than teamwork. Collaboration does not result in a hierarchy and instead means that all group members work collectively to create the best possible solution and it would be challenging to differentiate the contributions of each person from the others[29].

The last skill needed by all engineers is creative thinking. While engineering does sometimes require large amounts of technical knowledge and more analytical thinking, creativity is often still necessary to generate the best solution. Through these three skills - problem solving, collaboration and creative thinking - engineers have a solid foundation to tackle any issue or scenario that is presented to them.

5.3.2. Erosion and Weathering

Weathering is the process of degrading the earth without moving it, while erosion is the process of moving the earth. Weathering can be broken into one of three categories: biological, chemical, and physical.

Biological weathering can be caused by several factors. One of these factors is human disruption of the earth. This could be done through making hiking trails, moving earth to create a road, or clearing land for a better view of a lake. Another factor of biological erosion is animal burrowing. When animals burrow in the ground they create tunnels which change the physical properties of the ground. In many instances this can make the ground weaker by creating open tunnels below the surface which can cause crumbling and collapse. Plant growth is another factor that works similarly to animal burrowing. While plants grow they extend roots through the ground which disrupt the physical properties of the earth. This separation can cause weakening in the earth similar to the animal burrows and then crumbling and collapse can occur.

The second category of weathering is chemical weathering. This is when the physical properties of the earth change along with the chemical properties. Similar to biological weathering there are several examples of chemical weathering. Chemical weathering can be caused by acid rain or rusting on rocks. Examples of chemical weathering would be the rusting of iron, or the breakdown of limestone due to carbonation. Both of these examples physically change the material while also changing the chemical composition of the earth.

Lastly, physical weathering is when the physical properties of the earth change, but the chemical properties remain the same. Physical erosion is typically broken into three subsections: water, wind, and freeze thaw. Water can be rivers creating cliffs or valleys by breaking away the stone. Ocean waves changing the form of a coast or creating caves or archways in rocks would be another example of water erosion. Wind erosion can smooth out rocks or form sand dunes in the desert. Freeze thaw can crack surfaces due to the expansion of ice, and land can be displaced by glaciers and avalanches.

Physical weathering is the topic we chose to use for a hands-on activity, so we directed more of our research here. It is also more common than some of the other types of weathering. Because Ghana does not experience freeze thaw cycles we chose to steer away from this element of physical weathering, so much of our research was directed towards wind and water erosion.

Water erosion is the main type of mechanical erosion on earth. When it rains the water must go somewhere[30]. Over time this leads to the formation of streams and rivers which drain into other larger bodies of water. The process in which this happens has four main stages. The first stage is splash erosion which is caused by raindrops hitting the soft topsoil and changing the conformation of the earth. Over time this develops into sheet erosion which is the erosion of soil when water can no longer be absorbed into the earth, so the excess water moves over the area of soil in a flowing sheet. Sheet erosion then develops into rill erosion. Rills are small streams or trickles. As these rills continue they continue to break down the earth and create a place for water to flow. These rills eventually grow into gullies which are ravines formed by the movement, flow of water. An example of a gully would be the grand canyon which was formed through erosion caused by the colorado river. Another aspect of water erosion is coastal erosion. Coastal erosion is caused by the mechanical impacts of waves. In some cases coastal erosion breaks down the rock creating a cave. This cave often opens up into an arch, and when the arch collapses it leaves a free standing rock column known as sea stacks. Coastal erosion also causes the formation of sand as the mechanical aspects of the waves pound rocks and shells into small smooth pieces which make up sand.

Wind erosion is common on grazing land and is one of the main factors leading to desertification. Light texture soils in areas with limited rainfall are more susceptible to wind erosion as there is nothing preventing the wind from picking up and displacing the earth. Wind erosion can cause earthy materials to become airborne. While these materials blow through the air, they can hit rocks and cliffs smoothing the surface. In some instances this is called a desert varnish. This airborne material also makes the common forms we know as sand dunes which are piled collections of material[31].

Erosion can also lead to different types of disasters such as dust bowls and landslides. Dust bowls are typically caused by a combination of drought, high temperatures, and poor agricultural practices[32]. All of these factors erode the earth, loosening the top layer and leaving it susceptible to being lifted by the wind. The dust can turn into dust storms, and severe dust storms are known as dust bowls, which can be dangerous for people. While dust bowls are caused by wind erosion, landslides are typically caused by water erosion. Landslides are characterized by five main types of movement–Falls, topples, slides, spreads, and flows–and three main types of geologic material–bedrock, debris, earth. Landslides occur when the downward force on a given material is stronger than the material composing the slope. At this point, the material gives out, and begins to make its way down the slope. An example of a landslide would be a mudslide which is a debris flow. In contrast, rocks tend to fall causing aptly named rock falls. All landslides can be dangerous to people, and some landslides are perpetuated by human excavation or other elements of human's interaction with the earth[33].

5.3.3. Molecular Properties of Water

Water is essential to all life on Earth and it makes up 70% of the planet and 65% of the human body[34]. Distinct molecular properties of water, such as its polarity and ability to hydrogen bond, are the reason why this molecule is necessary to sustain life. The underlying force that gives water its properties is the difference in electronegativity, or electron affinity, between the two hydrogen atoms and the oxygen atom that comprise the structure of a water molecule.

The oxygen atom has a higher affinity for the electrons shared along the bonds between oxygen and the hydrogen atoms[35]. Therefore, the electron density will be pulled closer to the oxygen atom. As electrons are negatively charged, this creates a partial negative charge around the oxygen atom and partial positive charges around the hydrogen atoms. These partial charges ultimately cancel each other out so that water remains a neutral molecule. However, it does influence the structure, properties and subsequent abilities of water.

Due to the partial charges, water is a nonlinear molecule[36]. That is, it adopts what is called a "bent" structure where the two hydrogen atoms are bonded to the central oxygen atom at angles. A diagram of this structure is shown in Figure 6.

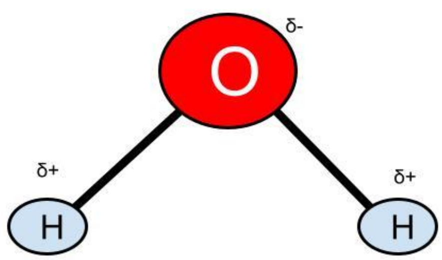

Figure 6: Structure diagram of a water molecule. The oxygen atom is depicted in red with a white O while the two hydrogen atoms are in blue with black Hs. The partial charges on each atom are also shown.

The partial charges are also responsible for the polarity of water, a property that gives rise to most of water's more unique molecular abilities. The definition of polarity is the intermolecular forces between the slightly oppositely charged ends of two molecules, regardless of whether they are the same chemical or not. From this definition, a polar molecule can be defined as any molecule that has a partially positive end and a partially negative end. Therefore, water is considered a polar molecule, with a slightly negative oxygen and slightly positive hydrogen atoms. Due to its polarity, water is considered the "universal solvent"[35]. Water can dissolve ionic compounds by dissociating the bonded atoms of the chemical being dissolved and can interact with other polar molecules. Therefore, other polar molecules are known as hydrophilic or water-loving. However, the classification of water as a universal solvent is not correct as water, a polar molecule, cannot interact with nonpolar molecules such as vegetables or any other type of oil. Therefore, nonpolar molecules are termed hydrophobic, or water-fearing.

From the polarity and chemical structure of water, arises the ability to perform hydrogen bonding, an intermolecular force not related to the standard two types of molecular chemical bonding. This type of bonding occurs between the partially positive hydrogen of one water molecule and the partially negative oxygen of another. The ability to hydrogen bond gives water molecules the ability to stick to each other and other atoms with high electron affinities, such as nitrogen and fluorine, and yields the properties of cohesion and adhesion.

Cohesion is defined as the attraction between molecules of the same type. In the case of water, this means that cohesion is the attraction between different water molecules and allows for water to stick together and form droplets. The property of cohesion also gives rise to the surface tension of water, or the ability of the surface of liquid water molecules to resist external forces by behaving like an elastic film. A common example of the surface tension of water is the ability of insects, such as mosquitos, to move across the surface of a water molecule without sinking.

In addition to cohesion, hydrogen bonding allows for the property of adhesion, or the attraction between molecules of different types. This means that water molecules are attracted to other polar molecules and can stick to those molecules as well as to itself. When cohesion and adhesion work together, they allow water to perform capillary action. Capillary action means that water can flow through a narrow channel without the help of or against gravity[37]. This is why when the tip of a paper towel is placed in water, the water will flow up the paper towel, rather than just saturate the portion directly touching the source. Capillary action is also important to plant life, as this phenomenon brings water from the soil up into the roots of a plant. Without the properties of capillary action, cohesion and adhesion, plants could not exist as a form of life on Earth.

In addition to assisting the attractive forces of water, hydrogen bonding also gives rise to several other important physical and chemical characteristics of water[38]. Due to the hydrogen bonds between water molecules, water has the highest specific heat capacity of any known liquid. The specific heat capacity of a substance is defined as the amount of heat that must be absorbed or lost to raise or lower the temperature of one gram of that substance by one degree Celsius. It takes a significant amount of energy to break the attractive forces between water molecules and as such the specific heat capacity of water is 4.186 J/g ℃, approximately five times more than that of sand. This is why land cools and heats up faster than the sea.

Building off of specific heat capacity, water also has a higher boiling point or heat of vaporization than that of other liquids, also due to the hydrogen bonds. The heat of vaporization is the amount of energy required to change one gram of a substance from a liquid to a gas. As water is heated, it becomes difficult to break the hydrogen bonds and separate the liquid water molecules to become individual gas molecules. Only when water has reached its boiling point of

100℃ is the heat sufficient to break the hydrogen bonds and the water molecules can exit the liquid as a gas. However, when water is still below 100 ℃, individual surface molecules can acquire appropriate energy from other water molecules to vaporize. This process is known as evaporation.

Water is directly tied to the formation and continued existence of life. Without water, not only could plants not survive, neither could humans or any other life forms on Earth. If the distinct molecular properties that make water unique had not evolved, life as it is presently defined would not exist.

5.3.4. Simple Circuit

We chose this topic because the Form 2 students had been learning about Ohm's law so implementing a simple circuit practical for them to see how the process works would be very beneficial. Simple circuits are important because they are what power your home and appliances. From the lights to your microwave, circuits control the flow of electricity. A simple circuit is a circuit that consists of a current source, conductor, and load[39]. For the lesson we developed with the school, the current source will be a battery, the conductor will be wire, and the load will be a light bulb. Our lesson plan also includes a switch to control the flow of power and demonstrate how a circuit would work in a home and can be implemented in everyday life. With the materials being used, the teachers could also implement the use of resistors and transistors to aid in further learning.

5.4. Practical Testing

To ensure our practicals work our group tested them beforehand as a team. This helped us work out any kinks in execution before providing the students with the practicals. We chose to do it this way because we wanted to make sure we were limiting any confusion on the topic for the students as the practicals were made to try and enhance their understanding.

5.4.1. Engineering Principles

The plan for the engineering principles was to complete one activity with all three forms. The activity involved encouraging the children to build towers out of a given set of materials.

The materials included thin and thick pieces of bamboo, sheets of paper, string, tape, and crushed water bottles. During the testing process these materials were gathered, tested, and sorted.

There were also meetings in which we elected individuals in charge of each of the forms, and gave each of these individuals an assistant. A lesson plan with step by step instructions was developed, so all three forms stayed on roughly the same page and timeline. Extra individuals were put in place to float between forms, so everyone stayed on the same page, there were extra hands when needed, and ideas could be passed from room to room.

5.4.2. Erosion and Weathering

The plan for the erosion and weather practical was to complete two activities with the students. The first was to show how different materials with different compositions result in different run off while the second was to show how water erodes into streams over time. Prior to going through our lesson plans with the students our team tested our practicals on our own. Images of the practical testing completed by the team for each of these two experiments is shown in Appendix 10.14.

The runoff experiment involved collecting empty water bottles. Some of the water bottles we cut in half the long way while others had the tops and bottoms cut off horizontally. The vertically cut water bottles were filled with materials of different compositions. Our team tested the experiment with dirt, sand, and gravel. Water was poured into the vertically cut water bottle filled with the material. The horizontally cut water bottle was held under the water bottles opening for the lid to collect the run off. The different types of runoff were then able to be compared based on the different types of materials.

The stream experiment involved purchasing bins from the local store. These bins were then filled with soil which was positioned like a hill–higher on one side of the bin lower on the other side of the bin. Water was poured from a water bottle on the high side of the hill and a “river” was formed leading down to the low side of the hill. The more water was poured the more the river eroded. Our team also tested a variation of this in which individuals try to direct the “river” by placing rocks and other materials in the dirt to try and manipulate the water's path.

The materials chosen for these lesson plans were selected because they are readily available to the community. Plastic water bottles are common in the community as the local water is not safe for drinking. Soil is available anywhere in the community, and especially available in the garden in which we are working. Gravel and sand are available at any construction project as both are used in the community for the process of mixing concrete which is the main building material in the area. Additionally, there is a lot of ongoing construction in the community and left over gravel and sand from old projects, so resources should be obtainable. The bins were purchased from the local store. The same bins can be used in following years and if a bin were to break they are easily replaceable.

5.5. Lesson plans

Our team developed a lesson plan template based on research completed on lesson plan development. We each filled out these templates as they aligned with the practical of our choice. This allowed us to create uniform lesson plans for the Junior secondary school. The template developed can be seen in Appendix 10.15 and was used to develop Tables 1-4 below.

5.5.1. Engineering Principles

The lesson plan for the full school engineering principles practical is included in Table 1. The plan contains the learning objectives and outlines discussion questions to get the students engaged prior to allowing them to complete the activity. The table also contains instructions for the specific materials students were given as well as an outline for how long the students would have to construct their towers. A materials list and references are also included.

<table>
<tr><td>Level: JHS</td><td>Form: 1-3</td><td>Subject: Science</td><td>Topic: Engineering Process</td></tr>
<tr><td colspan="4">Learning Objectives: By the end of this lesson, students will be able to…..

➢ Discuss the engineering process
○ Creative thinking
○ Problem solving
○ Collaboration
➢ Understand what strong shapes are that will help a structure stand</td></tr>
<tr><td colspan="2">Materials:
1. Bamboo
2. Tape
3. Rope
4. Crushed Water bottles
5. Paper</td><td colspan="2">References:
➢ https://www.sciencebuddies.org/teacher-resources/lesson-plans/tallest-paper-tower-engineering-challenge-3-5
➢ https://tryengineering.org/teacher/tall-tower-challenge/#vocabulary
➢ https://www.k12.wa.us/sites/default/files/public/earlylearning/pubdocs/unit2buildingstructuresandexploringshapes.pdf</td></tr>
</table>

Lesson Outline		
Stage	**Content/Procedure**	**Additional Notes**
Introduction	● Engineering → What is engineering? What are some general engineering principles? ○ Mistakes are part of the process. Regardless of how today goes, we are proud of you for making an attempt. Mistakes are often where we as engineers learn the most. ● Collaboration → the action of working with someone (or a group of people) to produce something ● Problem Solving à the process of finding solutions to difficult or complex issues ○ Define the problem. ○ Generate alternative solutions. ○ Evaluate and select an alternative. ○ Implement and follow up on the solution. ● Creative Thinking the ability to come up with unique, original solutions	- guide questions to get the general idea, the goal being to explain the focus as collaboration, creative thinking and problem solving. - Encourage no wrong answers
Practical	Each group, of between 4-5 students, receives a set of the same materials with the challenge to build the tallest tower that can support the test weight. Each group will receive - 14 sticks of bamboo - 1 roll of tape - 12 ft rope - 5 crushed water bottles - 5 sheets of paper The groups will have 5 minutes to plan without the materials, to encourage collaboration and communication , and will then have around 30 min to build their tower. They will then be tested to see which is the tallest that can hold the target weight.	- offer a level of explaintin fitting each forum, more details with form 3, more help with form 1 - Let the children lead but be prepared to offer ideas and suggestions - Focus on getting each group to have a working tower
Discussion	After the towers have been built, there will be a full group discussion going over what went well and what didn't. Also reiterating the focus on collaboration, problem solving, and creative thinking.	- try and get the engineering process across. - Specifically the idea that if there is a problem they don't always need to talk to an expert to solve it
Extra Opportunities for Practice with Concepts: ★ Building Bridges		

★ Tension and compression discussion ★ Egg drop test ★ Aluminum foil / wood boat

Table 1: This is the outline for the full junior secondary school general engineering principles lesson.

5.5.2. Erosion and Weathering

The lesson plan for the erosion practical activities is included in Table 2. The lesson plan identifies the main learning objectives of the activity. It is accompanied by a materials list and a list of references used to make the activity, which are also included in the bibliography. It has instructions and photos on how to run each practicum along with additional notes for how to get students more involved and thinking more dynamically about the lesson plan. It also has some discussion questions to help the students think about the activity and its relevance as well as some activities the students can do outside of the classroom to continue to grow their knowledge on this topic.

<table>
<tr><td>School: JHS</td><td>Form: 3</td><td>Subject: Science</td><td>Topic: Erosion and Weathering</td></tr>
<tr><td colspan="4">Learning Objectives: By the end of this lesson, students will be able to.....
➢ Define weathering and erosion.
➢ Explain how rivers form in nature.
➢ Discuss different types of run off.</td></tr>
<tr><td colspan="2">Materials:
1. Bin
2. Water bottles
3. Soil
4. Sand
5. Gravel</td><td colspan="2">References:
➢ https://education.nationalgeographic.org/resource/erosion
➢ https://www.usgs.gov/faqs/what-landslide-and-what-causes-one
➢ https://studylib.net/doc/7903785/erosion-match-up---bethesdafifthgrade
➢ https://web.archive.org/web/20170209075924/http://209.7.198.36/geologyonline/lessons/6.3/lesson.pdf
➢ https://geopard.tech/blog/how-to-deal-with-water-erosion/
➢ https://www.qld.gov.au/__data/assets/pdf_file/0021/65217/wind-erosion.pdf</td></tr>
</table>

Lesson Outline		
Stage	**Content/Procedure**	**Additional Notes**
Introduction	Introducing the materials that the students will be using and the overarching concepts they will be focusing on.	Encourage them to ask questions as they work through the practicals, both of you and each other
Practical 1: Runoff	-Find materials of different composition (ex. Soil, sand, gravel, etc.) -Cut a plastic water bottle vertically for each material -Pour the collected material into the vertically cut water bottle. -Obtain a collection cup for each material. -Uncap the water bottles containing the collected material -Pour water into the back of these water bottles and collect the run off from the opening in the cup -Compare and contrast the run off for each material	-The students can find their own materials, or the materials can be provided to them -each student can do one material and compare their run off to their classmates, or they can be split into groups and do the experiment on multiple materials. 
Practical 2: Water Erosion	-Obtain a wide plastic bin and fill it with soil -Instruct the students to make a hill in their bin, so the soil is higher on one side than the other. -Have the students pour water on the high point to view how water erodes earth over time -Tell the students to try and direct the flow of the water by using other materials.	-Allow the students to manipulate the soil, add rocks and stuctures to see how this changes their river. -Allow the students to try the experiment multiple times and see how they get different outcomes. -Have the students pour the water from different heights and at different speeds.

		
Discussion	Practical one: -What is the same about the runoff? -What is different about the runoff? -How do you think this applies to the real world situations? -Is all runoff bad? Practical two: -How did the water "choose" its path? -What factors/materials affected the water's path? -Were you able to direct the water? How easy was this? -Did the height or flow rate of the water impact your stream? -If you did this more than once, what did you notice was the same each time? What was different?	-Encourage the students to think, ask questions, challenge each others thoughts. -Let the students work through the problem and thought process. Guide the students without giving them the answers.
Extra Opportunities for Practice with Concepts: ★ Go outside and find examples of erosions in the world		

Table 2: This shows the outline of the lesson plan for the erosion practicals.

5.5.3. Molecular Properties of Water

The lesson plan corresponding to the molecular properties of water practicals is included in Table 3. This plan includes the learning objectives for the students, a materials list and a list of references used to develop the lesson. These references are cited and included in the bibliography as well. Furthermore, the plan includes instructions for each experiment as well as an outline for a short introduction for the subsequent activity. This is to help the students understand concepts before the experiments allow them to visualize what they just learned.

School: JHS	**Form:** 1	**Subject:** Science	**Topic:** Molecular Properties of Water

Learning Objectives: *By the end of this lesson, students will be able to…..*

- ➢ Define polarity, surface tension and capillary action
- ➢ Understand how polarity gives water molecules their other unique properties
- ➢ Discuss how polarity, surface tension and capillary action are relevant to nature

Materials:

1. Plates
2. Water
3. Oil
4. Beef Seasoning
5. Toothpicks
6. Dish soap
7. Paper towels

References:

- ➢ https://chemistrytalk.org/properties-water-physical-chemical/
- ➢ https://chemistrytalk.org/water-polarity-why-polar/
- ➢ https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Book%3A_General_Biology_(Boundless)/02%3A_The_Chemical_Foundation_of_Life/2.11%3A_Water_-_Waters_Polarity
- ➢ https://www.usgs.gov/special-topics/water-science-school/science/capillary-action-and-water
- ➢ https://bio.libretexts.org/Bookshelves/Introductory_and_General_Biology/Map%3A_Raven_Biology_12th_Edition/02%3A_The_Nature_of_Molecules_and_the_Properties_of_Water/2.05%3A_Properties_of_Water

Lesson Outline

Stage	**Content/Procedure**	**Additional Notes**
Set Up	Students should be put into groups of 4. Introduce water and the bent structure while materials are being passed out	Each group should receive: - 2 plates - 1 bottle of water - 1 half bottle of oil - A small amount of beef seasoning - 1 toothpick coated in dish soap - 2 paper towels
Practical 1: Polarity	<u>Introduction:</u> Explain electron affinity differences between hydrogen and oxygen and how that creates the partial charges. Explain how this is called polarity and that water is a polar molecule. Explain hydrophobic vs. hydrophilic <u>Experiment:</u> - Students should pour the oil onto one half of one of the plates. - Students should pour some of the water (not all!) onto the other half of the plate. - Students should make observations about the differences in behavior between the water and the oil.	

	- Students should carefully swirl the plate to mix the water and oil. - Discuss what happens and why.	
Practical 2: Surface Tension	<u>Introduction:</u> Discuss and define cohesion and how that applies to the water forming a unified drop in the previous experiment. Introduce and discuss hydrogen bonding and how these bonds help create the property of cohesion. Define surface tension and how it relates to cohesion. <u>Experiment:</u> - Students should pour water onto the plate, making sure the surface is completely covered. - Students should then add the beef seasoning to the water and swirl the plate slightly to mix. - Have the students observe how the pepper is floating on top of the water. - Students should take the toothpick coated in dish soap to poke the water at the center of the plate. - Discuss what happens and how this demonstrates surface tension.	- Extra bottles of water may be necessary depending upon the size of the first bottle given to the students. - The toothpicks can be coated with dish soap and passed out at the necessary time of the experiment to avoid a mess and any accidents.
Practical 3: Capillary Action	<u>Introduction:</u> Define adhesion and how it partners with cohesion. Define capillary action and how that applies to plants and their ability to survive. <u>Experiment:</u> - Have students pour the remaining water in the bottle into a small half water bottle container - Each group should have two paper towels, they should dip the tips of the paper towels into the water. - Students should observe how the water runs up the paper towel instead of with gravity.	
Extra Opportunities for Practice with Concepts: ★ Experiment to demonstrate cohesion: - Take a coin and place a drop of water on top - Keep adding drops until the drop breaks - Discuss how many drops it took and why the water molecules were able to pool and conjoin on top of the coin.		

Table 3: This is the outline of the lesson plan for the polarity, surface tension and capillary action properties of water practicals.

5.5.4. Simple Circuit

The lesson plan corresponding to the Simple Circuit practical is shown in Table 4. This plan includes the learning objectives for the students as well as a materials and references list utilized when designing the practical. The outline also includes instructions for the experiment and an additional experiment to help students further their learning.

School: JHS	**Form: 2**	**Subject:** Science	**Topic:** Ohm's Law
Learning Objectives: *By the end of this lesson, students will be able to.....* ➢ To be able to make a simple Circuit ➢ To understand how this Circuit relates to ohm law ➢ To Understand how to implement it into everyday Life			
Materials: 1. Copper Wire 2. Light Switch 3. Battery 4. Light bulb 5.		**References:** ➢ https://youtu.be/QbK5K1d8VkQ	
Lesson Outline			
Stage	**Content/Procedure**	**Timing**	**Additional Notes**
Introduction	To start off the lesson ask students if they know how to make a light circuit.	5 min	Encourage students to ask questions and make sure they fully understand what the lesson is covering
Presentation	1. Draw out the circuit we are creating. 2. Layout all the materials for the students. 3. Start with the battery and explain which end is positive and which side is negative. 4. Connect the wires to the positive and negative ends. 5. From here we connect the negative end directly into the light. 6. After that we will connect the positive end into the switch and from the other end of the switch into the light. 7. From here you should be	10 min	Make sure to be clear and easy to follow so they understand what's going on. Also while teaching them make connections to the introduction about how the process relates to what they are learning about Ohm's law.

	able to turn the light on and off.		
Practice	Pass out materials and have the student then build the system for themselves to see how it works.	30	Walk around and make sure students are doing the process correctly and understand what they're doing while implementing the simple circuit.
Discussion	Talk about all the importances that was shown in the practical and can be used in everyday life	15 min	Recap what they have learned encourages students to ask more questions and make sure everyone understands what they have learned in this lesson plan.
Extra Opportunities for Practice with Concepts: ★ Later the students can make other circuits and also learn about resistors and transistors.			

Table 4: This shows the outline of the lesson plan for the simple circuit practical.

6. Execution

6.1. Materials List

With the project budget being 500 USD we had to find a multitude of ways that our team could save money and purchase materials that will last longer and be most cost effective. After talking to the local masons and looking into prices we came up with our final budget sheet (Appendix 10.13). Our team was able to get some materials donated such as the bricks, cement, and fill used to construct the concrete base. After getting those donations we were able to use a naturally occurring resource, bamboo, to take the place of plastic or metal rods for the catchment system. After examining all of our options and where we could save money this is what our final materials list looks like for the full project.

- 60 feet of hosing
- 65 bricks
- 1000 Liter tank
- 2 bags of concrete
- Sand
- Fill
- Gravel
- 3 feet of Waterproof flooring
- 1 elbow joints

- Piping
- 3 bamboo plants
- Valves

6.2. Prototyping

Our team was able to obtain a material to use as a tarp in our catchment system. It is the same material as the flooring used in the rooms in the Dwenase Guest House. We performed a series of experiments to determine the water resistance of this material and to be certain that no water would leak through. The flooring allowed for water to run off it and down to a low point which indicated it would be a decent material to use in our catchment system. Rainwater would be gathered by the tarp and funneled down to a single point into the storage tank but it would not soak through or stick to the material. We also determined that there were no small holes in the flooring that would allow for leaks and would jeopardize the rainwater collection. After these experiments, the team was confident that the waterproof flooring will be an ideal material to use as a component of our catchment system.

6.3. Building Collection System

6.3.1. Bamboo collection and drying

We chose to make the structural aspects of the collection system out of bamboo. This decision was made because bamboo is a free and readily available material. We collected the bamboo from the river and cut down bamboo stalks using a machete. We then separated the stalks from the forest in which it was intertwined and brought the poles back to the compound where we cut off the leafy tops. We then laid out the bamboo stalks in the compound so they could dry in the sun. They needed to dry prior to use for the collection system because bamboo's size changes as it dries.

6.4. Building Storage System

6.4.1. Foundation

The process of making the foundation for the catchment system started with marking out the desired area for the pad with the masons. This was done using a rock to draw lines in the dirt. The pad is a square, and the sides are roughly 7 feet. There is also a line going through the middle of the pad to add extra support for the tank. The first day of mason labor they dug out this area to roughly a foot deep. They then filled this area with cement. This is shown in the upper left image of Figure 7.

The following day the masons began the brick work. This process started with mixing concrete, which they make by mixing three wheelbarrows of sand with one bag of cement. After mixing the dry materials, water was added. This was then used as the mortar between the bricks. The brick work is designed to be three bricks high and four bricks long on all sides. The masons also placed a brick layer through the middle and to help support the weight of the tank. The brick work is shown in the upper right and lower left images of Figure 7. Additionally, in the lower left image of figure 7 the masons can be seen using string to align and level the bricks.

The third day the masons completed the foundation. This involved adding a concrete cap and finishing the sides so they are smoothed over. This was then given time to cure, so the concrete had more strength before the additional weight of the tank was added. The final product of the foundation with the concrete cap is shown in the lower right image of Figure 7.

Figure 7: This is a diagram of the building process for the foundation. These are images of the foundation in different stages of assembly.

6.4.2. Tank

Our team designed and built the foundation in accordance with a base needed to support a 2000 liter tank. This was the reduced scale version of the system, so our group knew this would not be large enough to water all of the garden. When the team went to buy the tank Kwasi and Osabarima decided a 1000 liter tank would be more appropriate and purchased this instead. This left the foundation larger than needed, but this also allows the school to substitute with a larger tank in the future if they choose.

After purchasing the tank our onsite team cut a hole in the lid, so we could run a pipe into the tank from the collection system. A pipe was then cut to go into the tank and this was attached to a PVC elbow joint. This elbow was then connected to a second shorter pipe which linked to the tarp. This was all completed with two inch pipe and PVC.

6.5. Education Process

Through working with the students at the junior secondary school to execute the practicals, there were several lessons the team was able to learn from this experience. First, during the engineering practical, the students approached the given problem from a different perspective than the team would have. As the education system in Ghana is more lecture-based the students have more limited opportunities to work in teams in an academic setting so they had to learn how to work together before they began to build their structure. It was also interesting to observe how the students of different forms approached the problem in a different way. For example, though the Form 1 students had difficulty understanding the idea of a tower and made bridges instead, they decided to use the dirt from outside in their structures. These students expanded the crushed water bottles and filled them with dirt to act as anchors for the bamboo sticks that they secured in the soil. As this was not prevented by the instructions, it was a creative way that the team had not anticipated to create a bridge.

In addition, as the students have a different culture, they don't understand scientific concepts the same way as the team did. Something that seemed simple to the team, such as "build a tower" was confusing for the Form 1 students who had never seen a tower or city before. However, upon the switch to constructing bridges, the students demonstrated all three of the discussed principles so their learning was not hindered.

When working on the erosion practicals with the Form 3 class, the students displayed clear interest in the subject matter. Furthermore, though some explanation was required, once they understood the students were able to try out new ideas. The most prominent example of this was when the class was studying rivers using the prepared bins of soil. After the first attempt of running water down the hill, the class required some further explanation and discussion about what had happened and how the water had moved and carved away at the soil in certain spots. However, once the students understood they were able to move the soil and rocks around to attempt to direct the water a certain way. Some students utilized the rocks to make a path, while others used the already carved out channel and some new dirt to direct the river. Once the students understood the concepts they were ready and able to apply their new knowledge along with their own creative thinking to take their own learning further.

Though time did not permit the team to execute the molecular properties of water and simple circuit lessons, all materials and instructions were given to the junior secondary school with the hope that they could execute the practicals on their own. Despite the fact that the team won't be present for these lessons, we have no doubt that the students will be able to understand the concepts and build upon them with their own knowledge and creativity.

7. Conclusions

After gathering all the information our team collected and developed during the eight weeks we were in Akyem Dwenase and worked with the junior secondary school, the team was able to generate a manual that outlines how to implement the full scale irrigation system. We laid out what we believe is the best way to irrigate the farm throughout the dry season, though with the current insufficient funds for this project, the team decided it was best to pivot to a smaller system. Through creating the manual, the team hopes that a future group of students can secure the necessary funds and implement the full scale system. While working with the teachers at the junior secondary school, our group has learned a lot about what their garden needs and how it would be beneficial for the students and larger Dwenase community to have this irrigation system. Not only would this bring more food for the community and a source of increased income for the school, the biggest takeaway is the learning opportunities for the students that come from building this system. Through both learning about and constructing the base for the tank, the students at the junior secondary school have an opportunity to strengthen their structural skills. In addition, the catchment system shows them how to collect rainwater and teaches them different ways to utilize this resource. Furthermore, through construction the whole system, it teaches collaboration, teamwork and the engineering design process.

The students also will be able to extend their learning about gardening like they do in the rainy season throughout the dry season as well as how they can develop an income small business by selling the crops to the community. Outside of the system itself, when working with the school we found out how important the practical part of learning is for the students. Without having the resources and materials to execute the practical parts of a lesson, students don't have the opportunity to further their understanding through hands-on learning. To help with this, we developed four lesson plans that can be used to demonstrate some of the topics that the students have been learning and supplement the junior secondary school's curriculum. This is important as a lot of the students know the basic parts and understand what they are learning but when told to utilize these concepts in the real world it becomes confusing when they don't have the opportunity to see the actual process of how a particular process works. After completing two of our designed lesson plans during our time here our team saw the benefits to doing hands-on activities. It was inspiring to see the students be able to creatively think on the fly to learn and adapt to the task given to them at all levels of the school and the fun they had while working on the projects. It is the team's hope that the future implementation of the full scale irrigation project will only strengthen the students' learning and help the school with having a garden year round rather than just the rainy months of the year.

8. Recommendations and Further Work

While working on our project our team had to pivot our ideas many times. Additionally, living in the Dwenase community gave us a strong idea of what the community members need and want. These needs could potentially be addressed with future projects and we wanted to keep track of all of the potential future work on our project specifically and at the Ghana project site as a whole.

8.1. Future Project Ideas

While working through and developing our project our group came up with ideas for future expansion of our project. These included adding a composting system, developing additional sets of lesson plans, revising the design for other gardens, and expanding the garden. Additionally, our group came up with potential project ideas within the community beyond the scope of our project. Other potential project ideas include working on the school's infrastructure, working on the roads, creating a community database, and working with the health center to develop a filing system. Our team chose to include these future project ideas for further work.

8.1.1. Composting

Our group thought about incorporating a composting system into our irrigation system so the system would both fertilize and water the garden. However, we decided it would be best to not incorporate the system directly with the irrigation system. This decision was made to protect the irrigation system, and because our team faced many budget and time constraints. The school already practices crop rotation in the garden, so adding a composting system would continue to enhance the health of the plants but was not necessary to the crops survival at this time. Additionally, the community has many animals and burns their waste, so this would be a great way to add more sustainable systems into the community.

8.1.2. Additional Lesson Plans

The rural communities do not have as much access to hands-on practicals as students living in the more largely populated cities. While some students understand the theory, it is more beneficial for the learning of all students at the junior secondary school if they can experience a visual or physical aid as well. The community appreciates any additional lesson plans for hands-on work, so this could be an area of future work for this project.

8.1.3. Other Gardens

Creating a universal system that could be replicated for any garden would be ideal, but since all the gardens have different layouts and different crops they have different water requirements. This means a universal irrigation system design is a good starting place, but it must be modified to meet the particular garden needs. A future group could work to modify this system such that it can be applied to different gardens or small farms around Dwenase.

8.1.4. Expanding Garden

Not only is there more space to expand the existing garden, but there are other places in town where gardens can be added. The more gardens the community has and the larger they are the more food there is for the community and potentially more profit. In the case of the junior secondary school they are selling the garden yield and putting the money towards the school and materials that would enrich the students' education. Garden expansion throughout Dwenase could use additional irrigation, and this could be used to provide additional income and food supplies for the community.

8.1.5. School Infrastructure

The school classrooms are bare and on some occasions students are sharing desks because there aren’t enough to go around. Furthermore, the classrooms are open to each other, so sound travels between them, making it harder for students in one room to hear their instructor. Updating some of these aspects could significantly improve the educational experience for the students. Additionally, having spaces in the classrooms where materials and belongings could be stored would also be beneficial. All of these infrastructure projects could be completed by future teams.

8.1.6. Database

Boadu, one of our community contacts, showed interest in creating a database in which everyone receives a pin. When the individual's pin is entered it will pull up their information such as date of birth, birth location, sex, etc. This would allow the community to keep track of their members. He then expressed interest in expanding this database such that town leadership can track actions such as community donations per member. This privileged information would be a resource for the town leadership. This would be an extensive project, but this is something that could potentially be accomplished by a project team.

8.1.7. Filing System

Onsite members of our team visited the local health center which currently does not have an organized system for paperwork. A future project team could work with the health center to create a filing system. The community is starting to acquire more computers, so there is potential that this system could be hybridized between digital and paper records. If digital, barriers would need to be considered such as the unreliable power and internet access. This could potentially be a future IQP or MQP project.

8.2. Sponsors

The major problem our team ran into was funding. With the given budget, we were not able to attempt the original full scale model of our system. For future work, our team would recommend finding sponsors during the preparation process, so any additional group does not run into the same budget issues as we did. Material costs are included in the appendix based on the cost of materials in Dwenase and the surrounding towns in early 2023. While these prices may vary, our team faced a lot of challenges during the preparation process acquiring accurate prices stateside for available materials and our hope is this cost breakdown will help a future team create a strong pitch to a sponsor to develop the full scale version of our system. Based on the water needs of the crops in the garden we designed the full scale system to build an 18,000 liter tank, so the cost analysis is for this full scale system. We also included unit prices so that if and when adjustments are needed the cost analysis can be adjusted as well. After evaluation the team came up with around a $2,500 budget to build a full scale irrigation system for the garden that would be able to provide water for the duration of the dry season.

Our team has several points we feel are important to bring up in conversation when trying to find a sponsor. The community cannot spend up to 3000 USD on a project like this. This project is important, but it is not a high priority for the community as they have more pressing areas that require their attention and funds at this time. Our team would also recommend including what this would mean for the community. The full scale irrigation system would allow the community to grow crops throughout the dry season. This has both educational and financial benefits for the junior secondary school as the garden is used as a tool for hands-on learning, and the crops are sold to raise money for the school. A full size irrigation system would mean more growing time which would result in larger profits and more hands on learning experience for the students. After speaking with the school administration at the junior secondary school, our team learned the lack of hands-on learning makes it challenging to have the students fully understand concepts that they are being taught. In turn, this affects their performance on their examinations at the end of Form 3 for entrance into senior secondary school. The final point our team would recommend raising is that this donation doesn't just end at the school garden; the community reuses resources, making use of the materials they have, so it would be helpful even if its benefits in the garden come to an end.

8.3. Proposed Full Scale Design Construction Process

Since we did not have the budget to irrigate the whole garden the team decided to make a manual to outline how our team would tackle the full scale system. First, a future group would have to raise the funds for the full scale system that our team laid out in Section 4.2: Pivoted Preliminary Design. Upon obtaining the funding and arriving in Akyem Dwenase, the students would need to consult with Madam Francisca and Osabarima to confirm that the design is still relevant and beneficial.

Next, the students would have to construct the base for the tank, likely by working with the local masons. The size of the base will depend on the amount of water that is agreed upon to be stored through working with Madam Francisca and Osabarima. Our team predicted that 18,000 liters of water would be necessary to water the whole garden. This number was determined based on predictions that the stored water should last through an 18 week dry season. Given the size of the garden is 1636 square meters and roughly 70 percent are used for crops, in combination with the average amount of water per week that the various plants being grown would need, the team arrived at 18,000 liters as the required amount of water to be stored.

Once the amount of water was finalized, the team decided that the tank to be built would be a 2 meter high square with dimensions 3 meters by 3 meters and that it would be constructed out of Nelplast bricks. As highlighted in Section 4.2: Pivoted Preliminary Design, the Nelplast bricks seemed to be most cost effective and structurally sound for the size of the tank the team needed to build. Furthermore, after speaking with the local masons it was determined that the base should be larger than the tank which yielded ideal dimensions of 4.5 meters by 4.5 meters for the foundation.

After the base is constructed, the catchment system should be attached. This would consist of a tarp that would have three high sides and one short side that leads into the tank, allowing for rainwater capture and guidance of the water into storage. Once the water was in the tank, there should be a valve that would stop the water from exiting at the base of the tank. This valve should also be attached to a pipe that would reach across the farm. This allows for the tank to be attached to the delivery system which would consist of a central pipe with valves and hoses stretching out over the length of the farm. With the hoses the students can control the rate at which the water exits the tank and waters the crops. Furthermore, to aid in the construction of this system the team has included a manual outlining this process in Appendix 10.21.

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10. Appendices

10.1. Nelplast Images

(More images available)

10.2. Nelplast Email Communication

[EXT] Re: Cutting bricks

SA

Selina Ama Segbefia <selina@mindnetgh.com>
To: McGinty, Taylor

Friday, January 27, 2023 at 4:04 AM

This message is flagged for follow up.

Hi Taylor,
Unfortunately the machine for cutting bricks is currently being used by our team. However, you don't need to buy one as it is usually rented in hardware stores. You can find out if there are any hardware stores in the town or the next town.
Secondly, I tried to find out from Nelson and a couple of people about the cost of transportation to Dwenase but they are unsure. I suggest you talk to your drivers and find out if they know anyone that might be willing to bring the blocks from Accra to Dwenase or perhaps talk to drivers of public transport that commute to Dwenase from Accra?
Good luck.

Regards,
Selina.

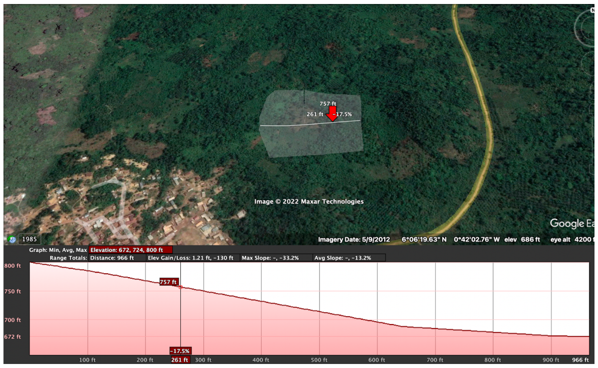
On Tue, Jan 24, 2023 at 10:35 AM McGinty, Taylor <tjmcginty@wpi.edu> wrote:

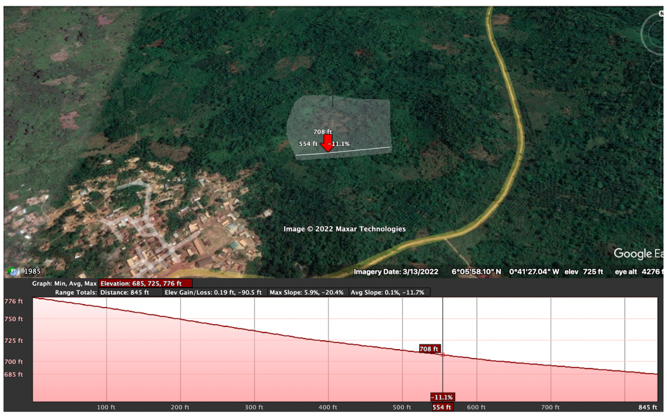
> Hi Selina,
>
> We would really like to use the Nelplast bricks for our project, but we are concerned because we do not have the machinery to cut the bricks. Is there any chance we could borrow this machinery from Nelplast? We are working on a tight budget which will only cover the bricks. Additionally, if we ordered bricks how much would it cost to have them delivered to Akyem Dwenase.
>
> Thank you,
>
> Taylor
>
> **Taylor Jane McGinty**
>
> WPI 2024

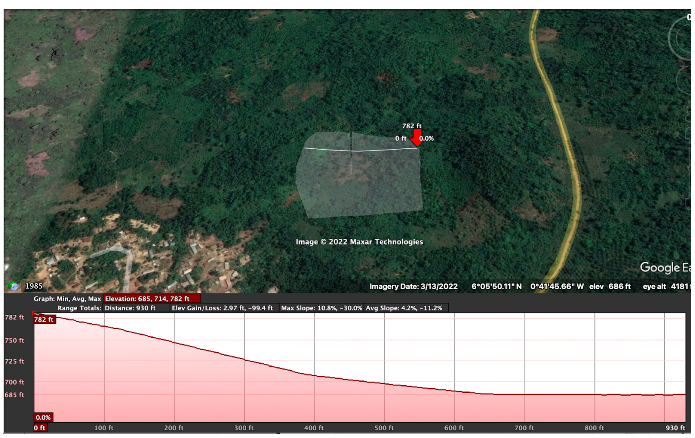
10.3. Contact Sheet

	Name	Email	Whats App	US Contact	Notes
Nelplast	Selina Ama Segbefia	selina@mindnetgh.com		N/A	Responds best to email
Town Leadership	Osabirma / Kwabena	kkyeiaboagye@wpi.edu			Responsive to email and timely for set meetings
	Kwase		248616291		Responds best to phone call or in person
	Boadu		208229833		Responds best to phone call or in person
WPI Contacts	Robert Krueger	kreuger@wpi.edu			Responds best to email
	Lamine Sagna	msagna@wpi.edu			
	Sam Yusuf	soyusuf@wpi.edu			
	Enis Agyeman Boateng	eagyemanboateng@wpi.edu		(774) 519 - 9270	Responds best to imessage/text
2023 Team	Charlotte Adams	cadams3@wpi.edu	(203) 427 - 1193		
	Luis Aldarondo	laaldarondo@wpi.edu	(978) 877 - 6910		
	Sam Dickens	sadickens@wpi.edu	(917) 794 - 9394		
	Taylor McGinty	tjmcignty@wpi.edu	(978) 460 - 5112		

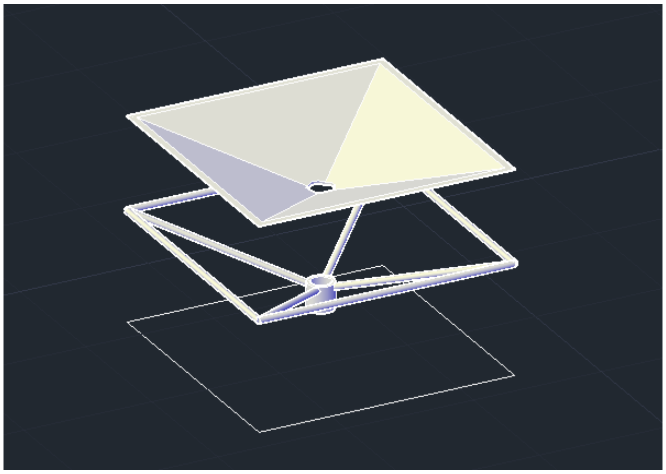
10.4. Topographical Analysis of Cocoa Farm

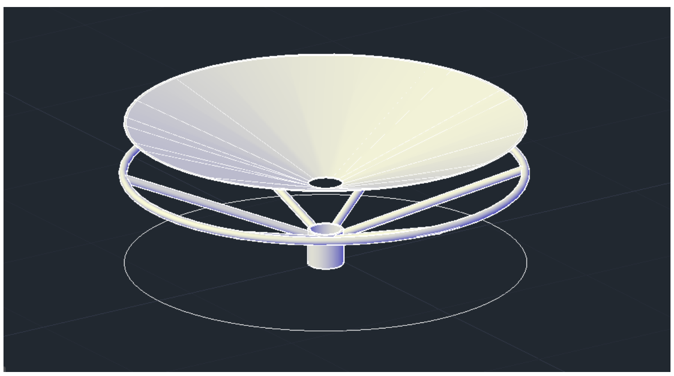


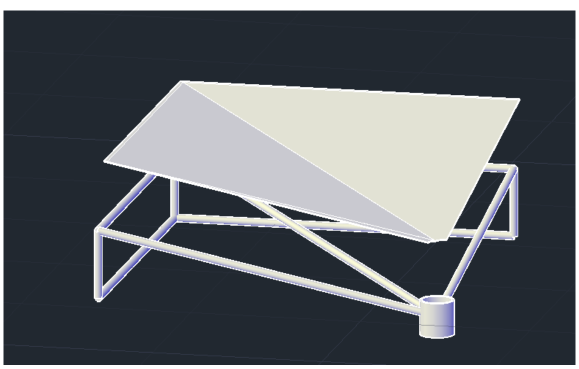




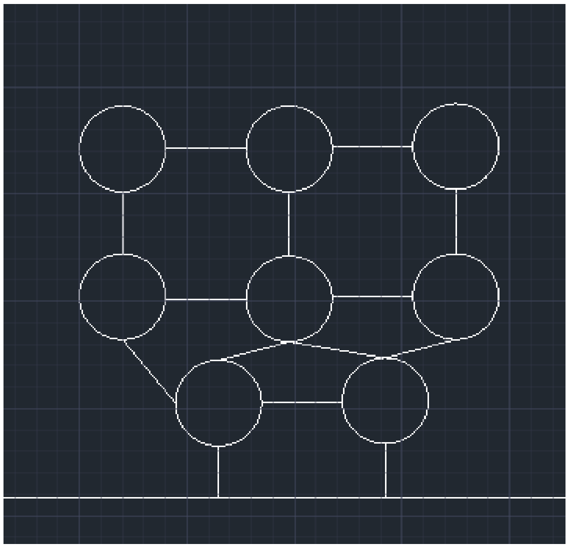
10.5. Catchment System Design





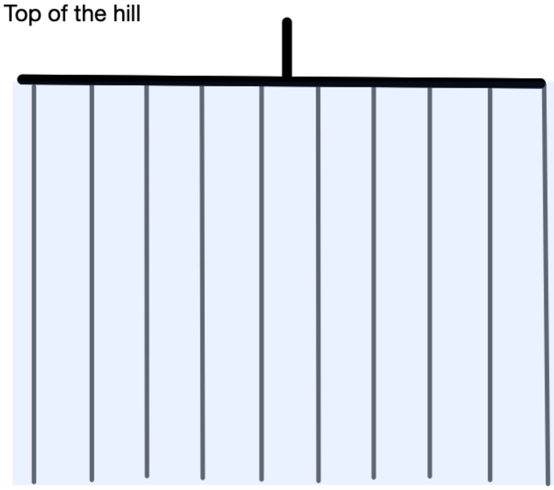


10.6. Interconnected Tank Design



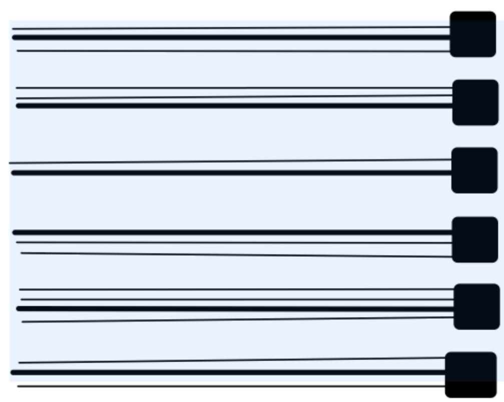
10.7. Cocoa Farm Delivery System

Top of the hill



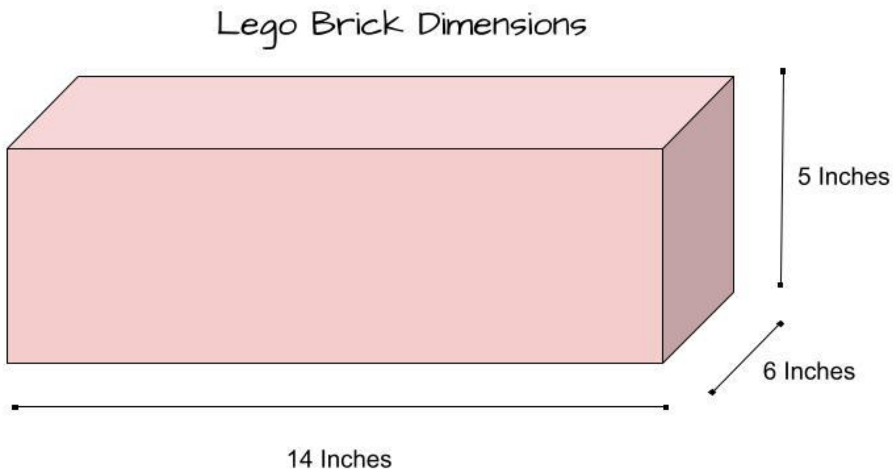
Bottom of the hill

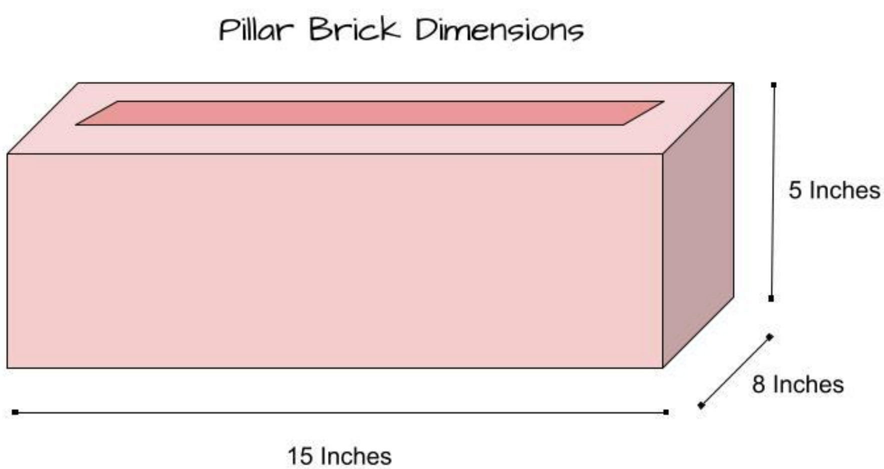
Top of the hill



Bottom of the hill

10.8. Eco-brick Dimensions

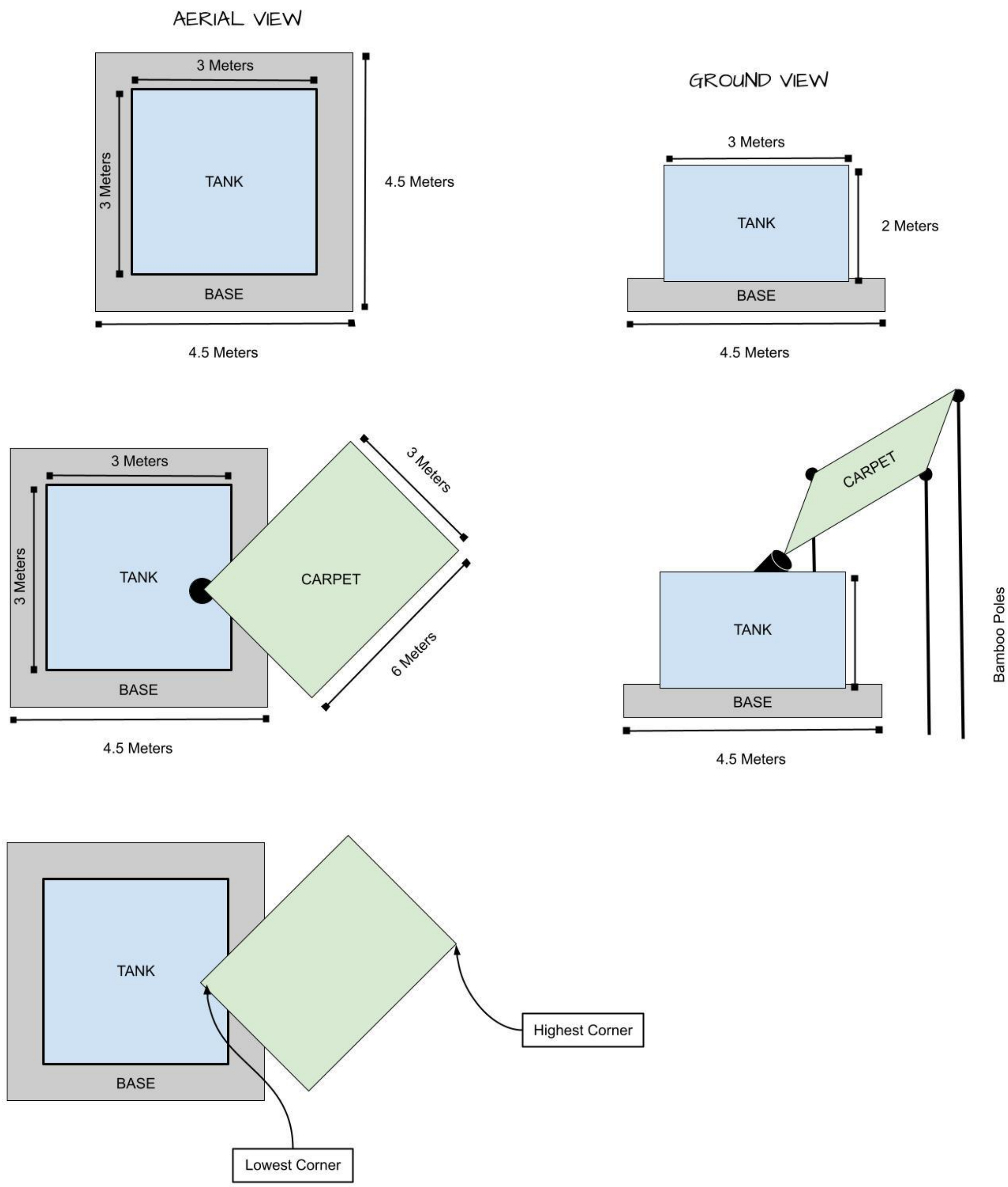


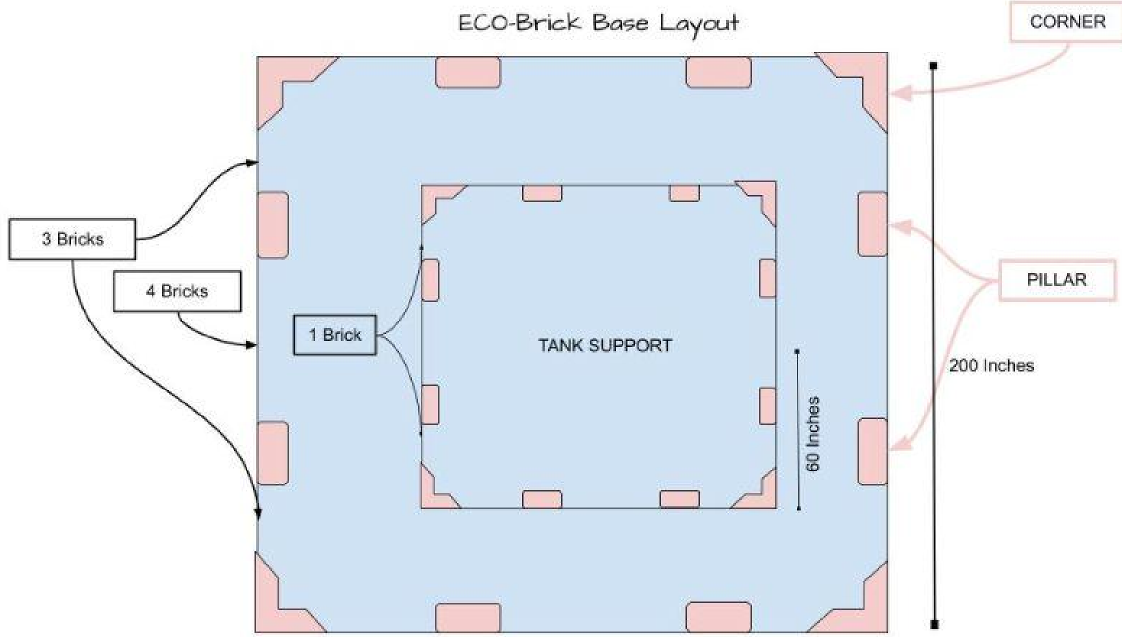


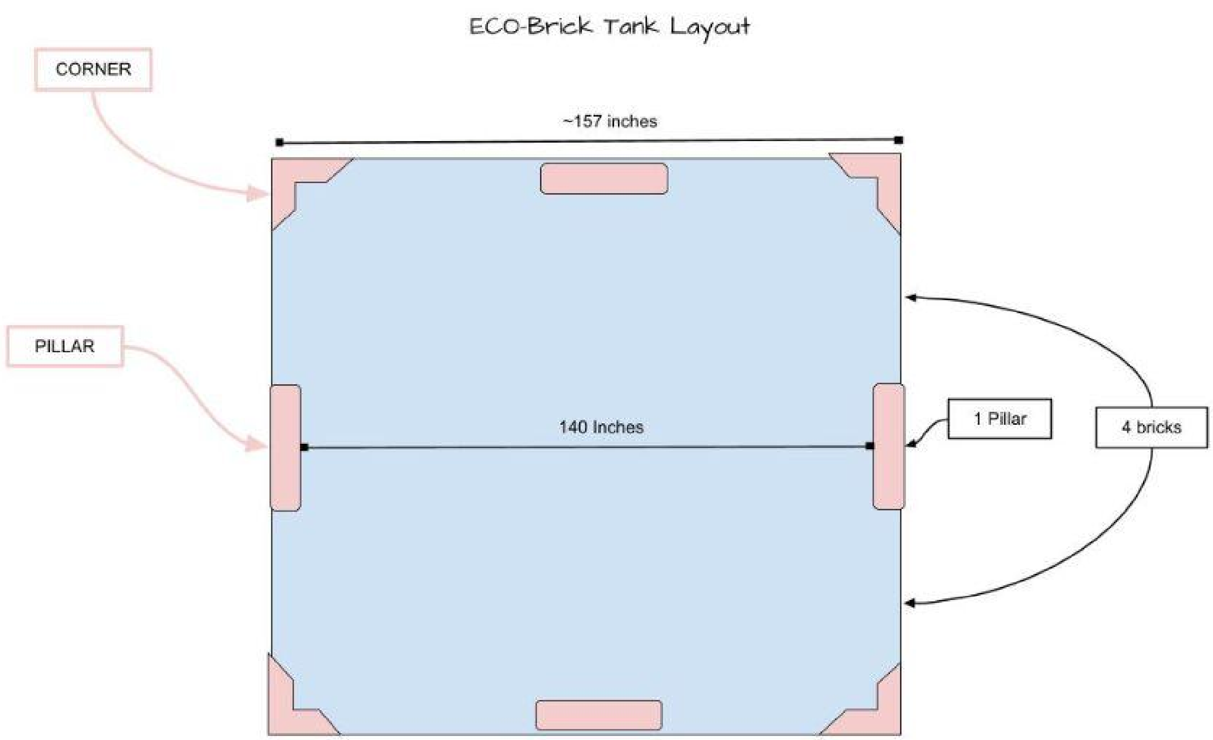
10.9. Manual Tools List

Tools List:

10.10. Pivoted full scale design




ECO-Brick Base Layout
CORNER
3 Bricks
4 Bricks
1 Brick
TANK SUPPORT
PILLAR
200 Inches
60 Inches


ECO-Brick Tank Layout
CORNER
~157 inches
PILLAR
140 Inches
1 Pillar
4 bricks

10.11. Full Scale Cost Analysis

Item	Unit Cost	Quantity	Total Cost	USD	
Hosing(30ft)	GHS 120	5	GHS 600	$60	
Bricks	GHS 8	800	GHS 6,400	$640	
Delivery Fee				$200	?
Concreate	GHS 83	20	GHS 1,660	$166	
Sand (Ton)	GHS 1550	1	1550	$155	
Fill (ft^3)		463			?
Gravel (Ton)	GHS 1050	1	GHS 1050	$105	
Drill / Saw		1	GHS 2000	$200	?
Tarps (m^2)	GHS 100	30.25	3025	300$	?????
Elbow Joint	GHS 46	1-3	GHS 138	$13.80	
Piping	GHS 46	20-60ft	GHS 138	$13.80	
Bamboo	GHS 0		Free	$0	
Cuppelings for hose	GHS 46	5	GHS 230	$23	
Hose Nosel	See Valves				
Valves	GHS 55	2	GHS 110	$11	
Epoxy	XXXX	1-2 tubs	XXXX	XXXX	
Rebar	GHS 62	48	GHS 2,976	$297	
Labor					
			Final Cost USD	$2,185	

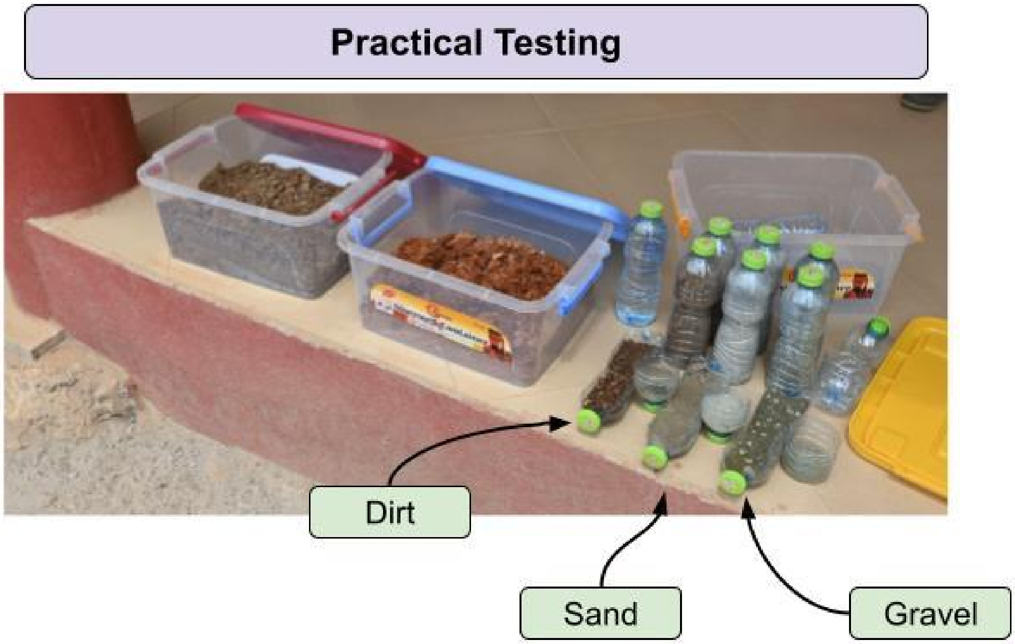
10.12. Half Scale Cost Analysis

Item	Unit Cost	Quantity	Total Cost	USD	
Hosing(30ft)	GHS 120	3	GHS 360	$36	
Bricks	GHS 8	400	GHS 3,200	$320	
Delivery Fee				$200	?
Concreate	GHS 83	12	GHS 996	$100	
Sand (Ton)	GHS 1550	0.5	775	$78	
Fill (ft^3)		200			?
Gravel (Ton)	GHS 1050	0.5	GHS 525	$53	
Drill / Saw		1	GHS 2000	$200	?
Tarps (m^2)		16	GHS 1600	160$	
Elbow Joint	GHS 46	1-3	GHS 138	$13.80	
Piping	GHS 46	20-60ft	GHS 138	$13.80	
Bamboo	GHS 0		Free	$0	
Cuppelings for hose	GHS 46	3	GHS 230	$23	
Hose Nosel	See Valves				
Valves	GHS 55	2	GHS 110	$11	
Epoxy		1-2 tubs			
Rebar	GHS 62	32	GHS 1980	$198	
Labor					
			Final Cost USD	$1,406	

10.13. Final Design Cost

Item	Unit Cost GHS	Quantity	Total Cost GHS	USD
Hosing(30ft)	GHS 120	1	120	12
Bricks	GHS 7	65	455	45.5
Tank	1000	1	1250	125
Concreate	Donated	N/A	0	0
Sand (Ton)	Donated	N/A	0	0
Fill (ft^3)	Free	N/A	0	0
Gravel (Ton)	Donated	N/A	0	0
Waterproof flooring	GHS 32/Yard	3 Yards	96	9.6
Elbow Joint	GHS 8	2	16	$1.60
Piping	GHS 80	1	80	8
Bamboo	Free	N/A	0	0
Couplings for hose	GHS 46			
Valves	GHS 55			
Labor Cost	GHS 100 per Mason per Day	2 Mason ~3 Days	600	$60
			Total:	**Total:**
			2617	261.7

10.14. Practical Testing



10.15. Lesson Plan Template

<table>
<tr><td>Level:</td><td>Time:</td><td>Subject:</td><td>Topic:</td></tr>
<tr><td colspan="4">Learning Objectives: By the end of this lesson, students will be able to…..
➢
➢
➢</td></tr>
<tr><td colspan="2">Materials:
1.
2.
3.
4.
5.</td><td colspan="2">References:
➢
➢
➢
➢</td></tr>
<tr><td colspan="4">Lesson Outline</td></tr>
<tr><td>Stage</td><td>Content/Procedure</td><td>Timing</td><td>Additional Notes</td></tr>
<tr><td>Introduction</td><td></td><td></td><td></td></tr>
<tr><td>Presentation</td><td></td><td></td><td></td></tr>
<tr><td>Practice</td><td></td><td></td><td></td></tr>
</table>

Discussion			
Extra Opportunities for Practice with Concepts:			

10.16. Completed Tasks 1/7-1/20

- During our initial meeting with Francesca, the headmistress of the junior secondary school, we were able to confirm what she would like done with the garden: a new fence that goats can't break through, a newly plowed field so that fertilizer can be added to the soil and new beds can be prepared for planting, and an irrigation system for the dry season. We were also able to confirm the types of crops that the school is currently growing and would like to grow in the future. She also shared that they rotate the crops to ensure appropriate nutrients remain in the soil so we considered that when designing.
  In addition, we presented the idea of a drip irrigation system (which was our initial plan) and the idea of a collection system, water tank and a hose to Francesca. She specified that she would prefer the hose system as it would allow for more crop rotation, and would better accommodate the different water requirements of each crop. In addition, the hose could be detached from the system and brought inside to prevent potential theft.

- Two of the team visited the Nelplast brick factory and obtained information regarding how the bricks are used in construction and their exact components. They were also able to bring some bricks back for us to experiment with before placing the order for the amount we will need for the design.
- The team generated a design for the tank and determined the most ideal location for the collection tank. This design was then brought to Francesca and approved though she also expressed concern that, without a proper fence, the children of Dwenase would play with and around the collection tank. As this is a safety concern, we need to speak to Osabarima and his advisors about the importance of constructing the fence swiftly.
  It was also noted that there was a dead tree near the desired location of the tank that if it were to fall, has the potential to damage the system after its completion. To solve this, we need to speak to the head farmer, Kwasi, to determine the best way to cut down or uproot that tree. In addition, since Francesca would like the garden plowed as well, we hope to be able to solve both problems at the same time.
- The team also met with the local masons to discuss how they would construct the concrete pad that the collection tank would sit on. This information was then used to help determine the amount of cement we need to order so that we have the appropriate materials to construct the approved design.
- Two of the team visited other local water tank structures and spoke to the local water authority about their design and construction. This information helps to generate the construction plan of our own design and determine the appropriate materials and the necessary amounts.
- The team also visited the local hardware store with the intention to confirm the presence and price of necessary materials. However, most of the materials needed for the project were not able to be purchased there and it was determined that we would have to travel further in order to obtain the required materials.

10.17. Completed Tasks 1/23-1/27

- This week, the team received drone footage of the junior secondary school's garden. With this footage, we were able to create an aerial map of the beds and crop locations as well as the stumps and trees that Madam Francesca would like removed.

- The team also met with Osabarima about the cost of materials and to confirm the budget he shared before arrival in Dwenase. Osabarima confirmed that the budget for the project is 500 USD. After this, the team was able to decide that the budget was not sufficient for the system we were initially planning to build which necessitated further conversations of how to proceed.
- The day after our conversation with Osabarima, the team met with Professor Sagna, Sam Yusuf and Professor Krueger about how the given budget was not sufficient for the irrigation system to water the entire garden throughout the entire dry season. As such, a discussion was had about different options moving forward given the time and budget constraints. It was decided that there were two main options.
  The first would involve the team constructing a 2,000 Liter tank and catchment system that would either water the garden for about two weeks or a single bed for a larger portion of the dry season. Lesson plans would also be developed to help engage the students of the junior secondary school with scientific and engineering concepts related to the system. The team would also ensure that the plans for the larger system were meticulously detailed so that a future group could obtain the necessary funding to build the complete system. The second option would be to only generate lesson plans and detail the plan for the larger system. After much discussion, it was determined that the team would ask Madam Francesca and Osabarima which option they would prefer. From there the team will work on whichever scenario is chosen.
- Regardless of which option was chosen by Madam Francesca and Osabarima, the team would need to develop lesson plans so research was done on the Ghanaian education system, learning styles, teaching styles and how to write a lesson plan. This allows the team to get a better idea of what types of activities and lessons would be most appropriate for the concepts that will be ultimately chosen to present to the students.
- On Wednesday night the team met with Osabarima and Madam Francesca to hear their thoughts on the two options for moving forward with our project. Both Madam Francesca and Osabarima preferred the option where we would construct a smaller tank in combination with our lesson plans and passing along a detailed design to a future team to construct.

10.18. Completed Tasks 1/31-2/3

- On Monday, while visiting Cape Coast, the team was able to purchase a tarp-like material to use in both the prototypes and the final system. The material is the waterproof flooring that is already in wide use around Dwenase so we know more can be purchased when necessary. We performed experiments to test the water resistance of the material and ensure that it does not leak by allowing water to pool at the bottom of the tarp held up by team members. The water was then allowed to run off, making sure that it did not stick to the tarp. The experiments were successful and provided the information that we needed. Therefore, we intend to use the waterproof flooring material as the tarp in the designed catchment system.
- The team communicated with Madam Francisca about observing a few lessons at the junior secondary school. The goal was to learn about the classroom environment and observe how the students learn so we can design lesson plans that best play to their strengths. We were clear with Madam Francisca that we didn't want to be a distraction for the students and merely wanted to observe to better inform our project.
- Madam Francisca allowed the team to observe two classes on Tuesday morning. We sat in during a science class where the students were taught about electrical energy and basic circuits. As the topics we are developing lesson plans for directly relate to science, it was useful to see and understand how science topics are taught and how the students absorb that information best. We were also able to observe a home economics class taught by Madam Francisca, where we were able to experience a different subject entirely to provide more information on which students thrive best in which environments. Madam Francisca also shared that they would be working on practicals next week and we have tentative plans to return and observe the practicals to better inform the experiments we are creating for the students.
- On Wednesday we were able to set up a meeting with Kwasi and two of the masons Baah and Patrick. We discussed the materials we require and finalized prices. The masons also outlined the area in which the base of the tank will be built and shared that they plan to start construction on Friday provided Kwasi could obtain the necessary materials before then. As Kwasi shared he planned to purchase the materials on Thursday, this seemed like a reasonable timeline.

- As we intend to pass along this project to a future group, we created a contact sheet for this group's benefit. This sheet includes all of the information for our contacts both in Dwenase and at Nelplast and WPI as well as which people respond to which type of communication best. We also included our contact information so if the future team has questions they will be able to contact us directly. We plan on keeping this contact sheet as up to date as possible throughout this process to be handed over along with our final paper and designs to the next project team.
- On Friday, the materials to construct the base of the tank were transported from the funeral grounds to the junior secondary school garden. It is the hope that construction will begin on Monday morning and that the base will be able to cure and set while the team is away the following weekend.

10.19. Completed Tasks 2/7-2/17

- To start the week, the team met and decided upon the topics we would like to teach lessons on at the junior secondary school. We agreed that the topics should both align with the student's curriculum as much as possible and have some relevance to the irrigation system we are constructing. We each selected a topic we felt comfortable with: Taylor is teaching erosion and weathering, Sam is teaching structural stability, Luis is going to talk about light properties and Charlotte is going to teach about the molecular properties of water.
- After selecting lesson plan topics, all group members began individual research on their chosen topic to create the most comprehensive and understandable lesson plans possible. All lesson plans were also decided to have a practical element, something the junior secondary school doesn't have the current materials to accommodate, that would better help students visualize topics.
- During this week, construction began and was completed on the concrete slab base for the tank. Prior to the group leaving for the trip to Mole, the hole had been dug by the masons and they laid the bricks in the appropriate spots. When the team returned, the concrete cap over the bricks had been added and the slab was complete.
- The team also met with Madam Francisca and Mr. Samuel, the science teacher at the junior secondary school, to discuss the lesson plan topics and the timing of these lessons.

Mr. Samuel expressed particular emphasis on the practical portions of the lessons so the team was able to make slight adjustments to place the focus more on the experimental activities and less on the theory aspects. It was decided that Taylor would work with the Form 3 students on Thursday, February 16 and take them through her practical on erosion and weathering. In talking with Mr. Samuel and getting his opinion on what lessons would be most valuable for the students, it was decided that Luis would focus his practical on basic circuits as that was most relevant to what the Form 2 students were learning. It was also determined that Sam would teach a workshop to the whole school with the help of the rest of the team as well as in partnership with Kerry Bushway, Darcy Milligan and Hannah Zink of the Makerspace team. Charlotte's practical would be with the Form 1 students so each class got to experience at least one practical and the timing of both Charlotte and Luis's practicals is still to be determined.

- After this meeting, Taylor worked on completing her lesson and determining that the practical she envisioned was feasible in the given time frame and with the materials she was able to acquire. Thus, she performed a series of tests and was able to decide that the practical would be doable, understandable and valuable for the Form 3 students at the junior secondary school. While Taylor worked on this, the rest of the team worked on developing their lesson plans and materials lists so that all required materials could be located and purchased.
- On Tuesday February 14, Sam, Taylor and Charlotte visited the store in Apinamang and were able to purchase the required materials for their projects.
- In determining the final lessons, Sam decided that his practical would involve basic engineering principles in place of structural stability. The emphasis would be placed on teamwork and problem solving in order to build a tower that can support a rock for a given amount of time using a given set of materials. It was also determined that the materials would include, paper, tape, strips of bamboo of various lengths, some string and some crushed water bottles.
- As planned on Thursday, February 16, Taylor shared her practical with the Form 3 students at the junior secondary school, assisted by Sam and Charlotte. The students asked lots of questions and were very attentive and engaged with the lesson. It was overall a success and the hope is that the materials and instructions can be donated to the

school so that this practical can be done in future years so that more students will benefit from the experience and the visual aid.

- Towards the end of the week, the team was also looking for guidance regarding the final submission. We had been gathering all information and working on a more technical paper that models the standard IQP paper structure for the majority of the term and wanted to be sure that we were meeting expectations. We had a meeting with Professor Sagna about this matter and emailed Professor Krueger at his suggestion. Professor Krueger responded and told us to speak to Professor Sagna and to follow his directive.
- On Friday, February 17, the team alongside the Makerspace team and Simon Rees, engaged all three form classes at the junior secondary school in a lesson and activity about the principles of engineering. We discussed collaboration, problem-solving and creative thinking which are the backbone of any engineering process. The team had the students group up and build towers with a standard set of materials to give them practice with teamwork and the design and construction process. During the lesson the students were very excited and came up with creative designs using techniques the team didn't think of. As such, it was as much an educational experience for us as it was for the students at the junior secondary school.

10.20. Completed Tasks 2/20-3/2

- The first step in finalizing the irrigation system once the foundation was built, was acquiring a tank. To do this, the team met with Kwasi to arrange a time to visit a store and purchase the required 2000 liter polytank. However, upon making it to the store, Kwasi and Osabarima decided that a 1000 liter polytank would be preferable for the system. Therefore, a 1000 liter tank was purchased and brought back to the junior secondary school garden and placed on top of the already constructed foundation.
- Upon acquiring the tank and therefore being able to obtain accurate dimension measurements, the team determined the height that the bamboo poles would need to be. Therefore, we were able to cut the larger stalks to the required length.
- In order to attach the catchment system to the purchased tank, it was necessary that the lid of the tank be adjusted so that a pipe could go through. This pipe acts as the entry point for the collected rainwater into the tank.

- Now that all the materials had been obtained, the team could build the catchment system. To do this, the tarp first had to be attached to the bamboo poles. The team folded the tarp into the desired shape and wrapped three of the four edges around a different bamboo pole. These corners were then secured with duct tape and a nail through the tape and tarp to provide added support.
- Once the tarp was attached to the bamboo, the team was able to mark out the spaces in the garden where the bamboo poles would need to be secured to the ground. These spaces were marked so that the team could determine how best to safely and securely put the bamboo in the ground.
- Since this task was outside the team's expertise, the local masons who had constructed the foundation were consulted. Through conversations with the masons the team was able to explain what needed to be done and the masons could offer their knowledge on how best to go about securing the bamboo. In the end, an action plan was developed that could be executed by the team and the masons for putting the bamboo posts into the ground.
- Upon arriving at the garden on Monday, February 27, it was discovered by the team that the materials for the catchment system had been stolen. As there was no time to return to Accra to purchase an additional tarp (could not be bought in the Dwenase area), the catchment system could no longer be built. As such, in combination with Professor Sagna, the team brainstormed possible solutions so that once the team had left Dwenase, the students and the teachers at the junior secondary school could still complete the system once appropriate materials were acquired. It was decided that creating a manual would be the best solution, so that both the catchment and delivery systems could still be added and the irrigation system could still be completed even after the team returned to the United States.

10.21. Manual

WORCESTER POLYTECHNIC INSTITUTE MARCH 2023

MANUAL GARDEN IRRIGATION SYSTEM

CHARLOTTE ADAMS LUIS ALDARONDO TAYLOR MCGINTY

Materials

Eco-Bricks

Sand, Gravel, Fill

Hosing

Standard Bricks

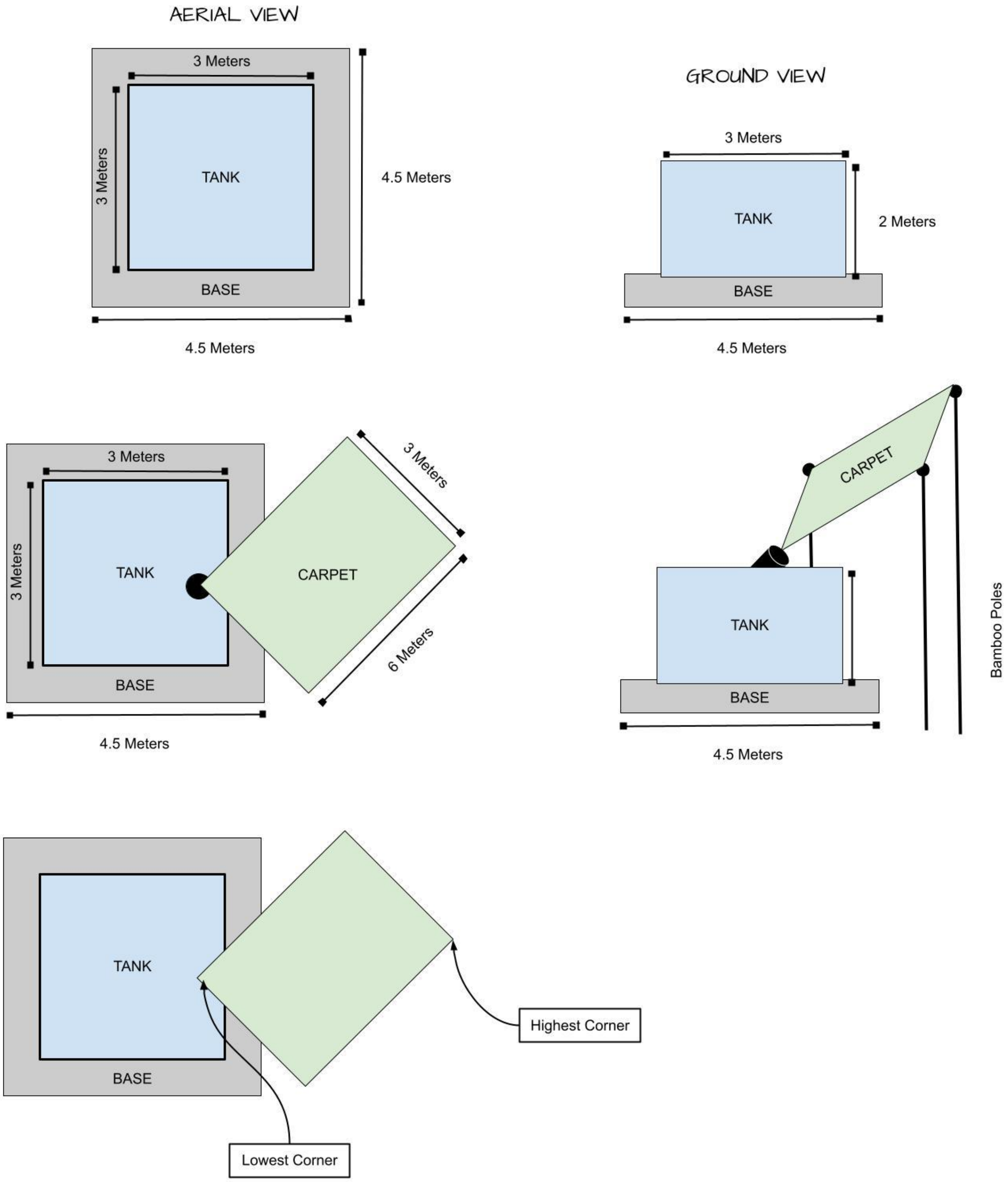
Valve

Concrete

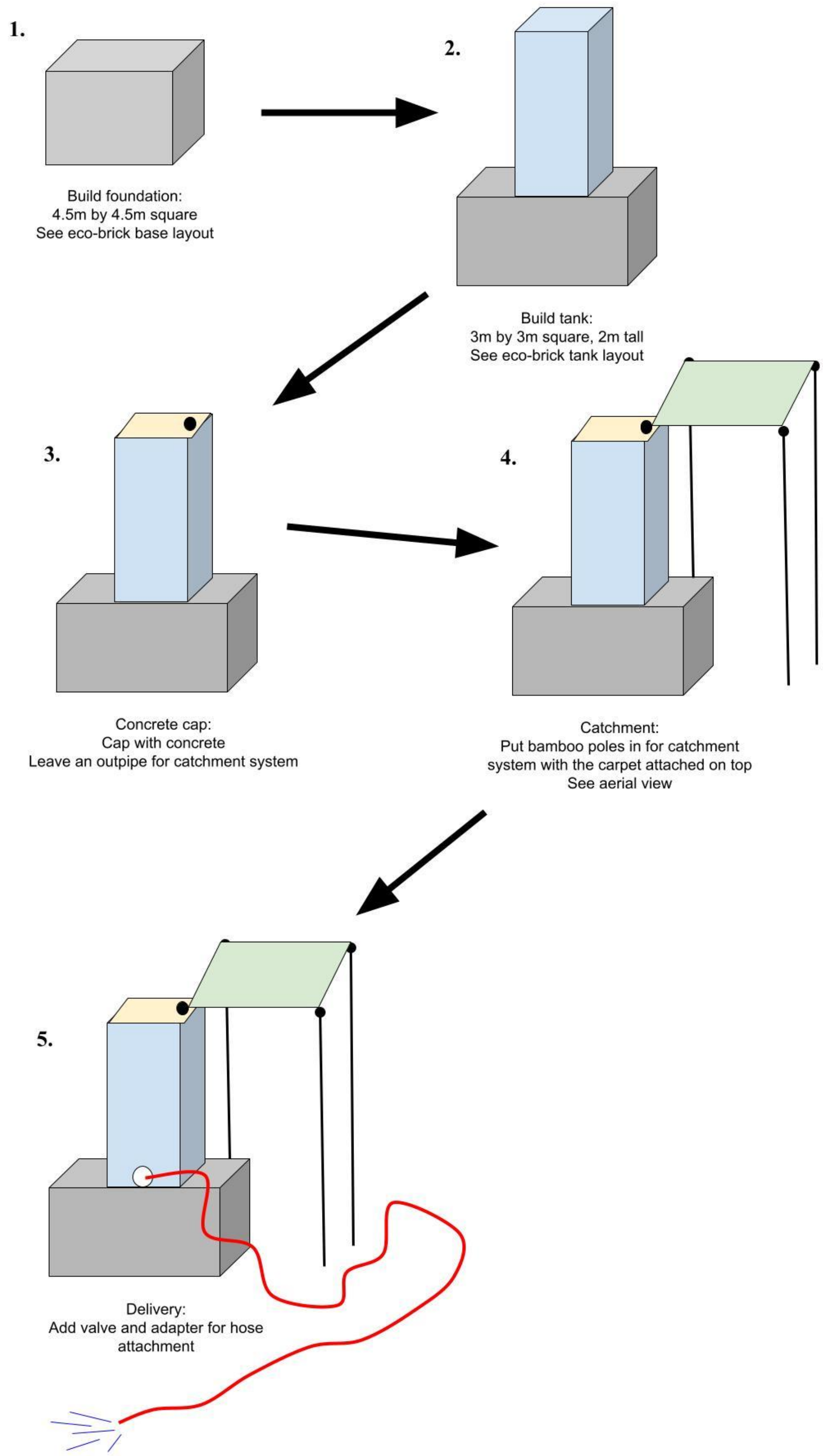
Bamboo

Carpet

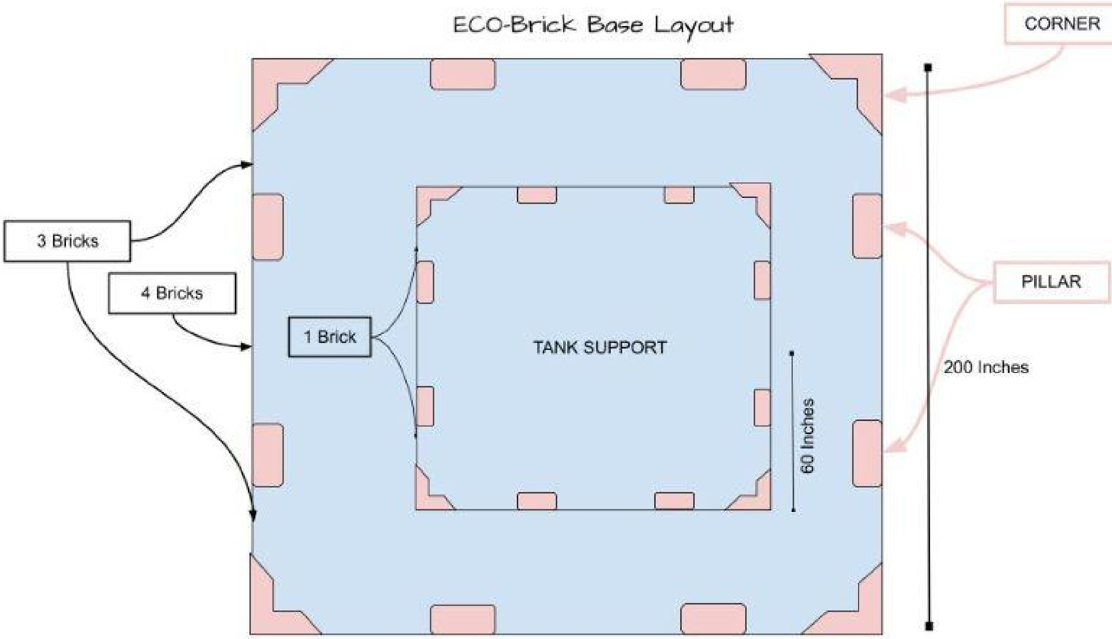
Full Tank Design

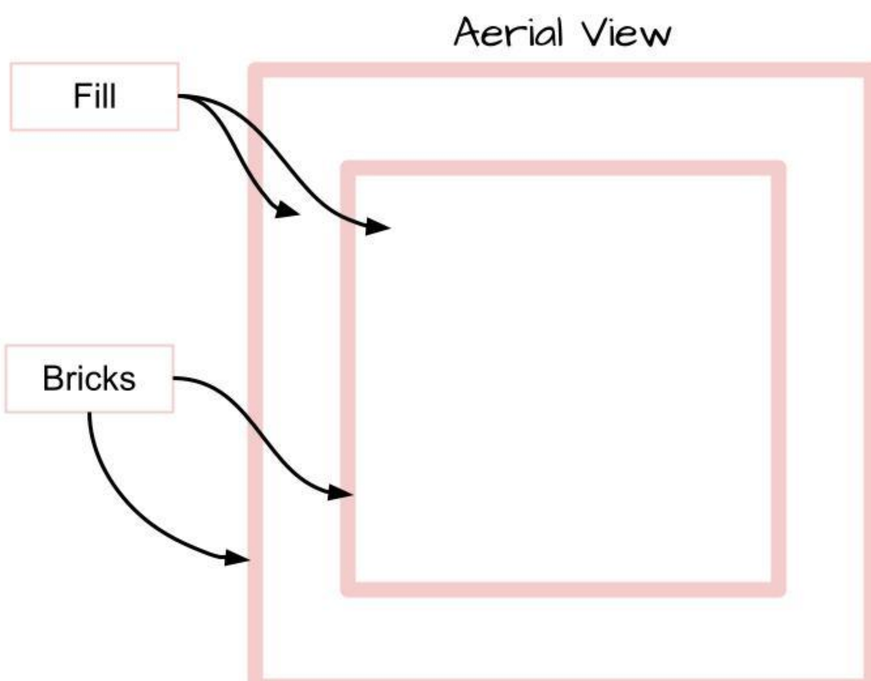


Step-by-step Procedure

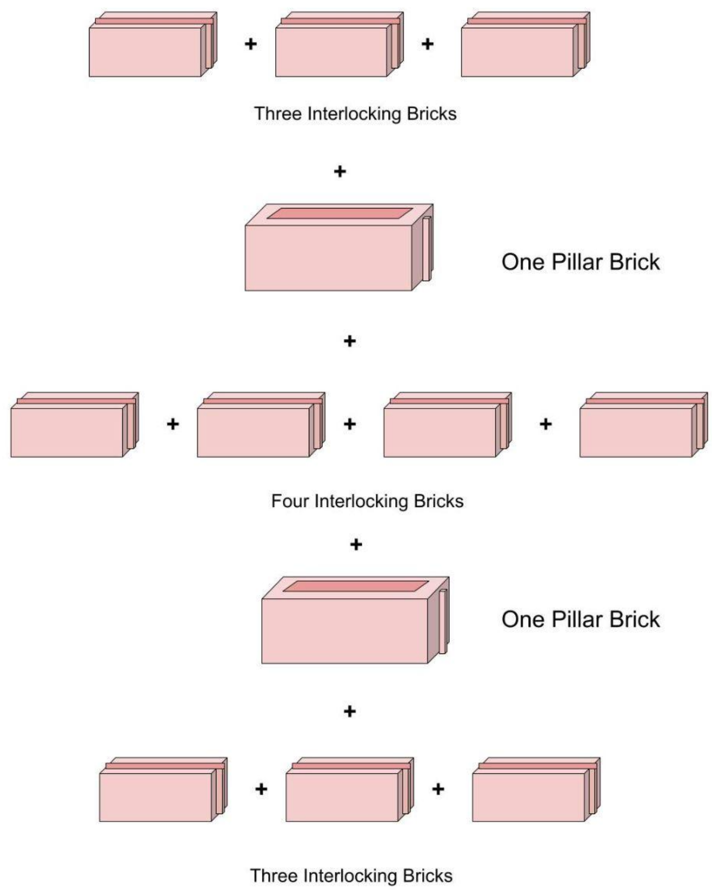


Foundation

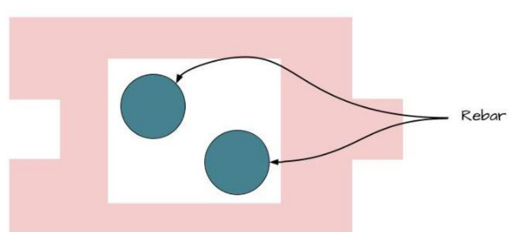

ECO-Brick Base Layout
CORNER
3 Bricks
4 Bricks
1 Brick
TANK SUPPORT
PILLAR
200 Inches
60 Inches


Aerial View
Fill
Bricks

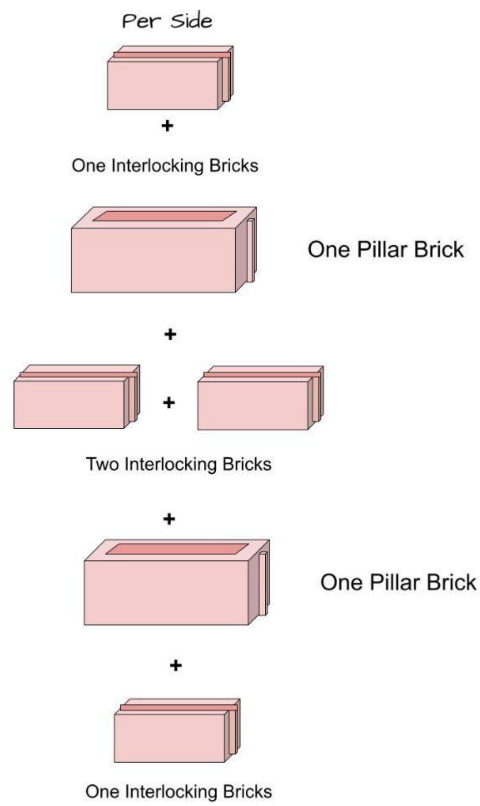
Per Side



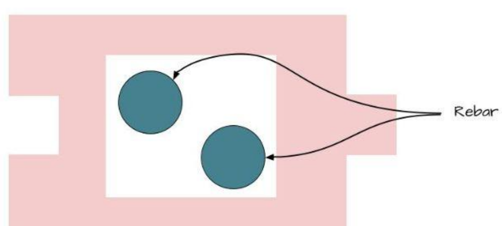
Aerial View



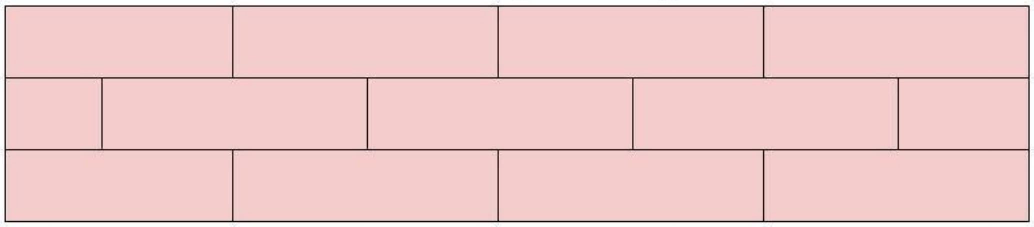
Tank Support


Per Side
+
One Interlocking Bricks
One Pillar Brick
+
+
Two Interlocking Bricks
+
One Pillar Brick
+
One Interlocking Bricks

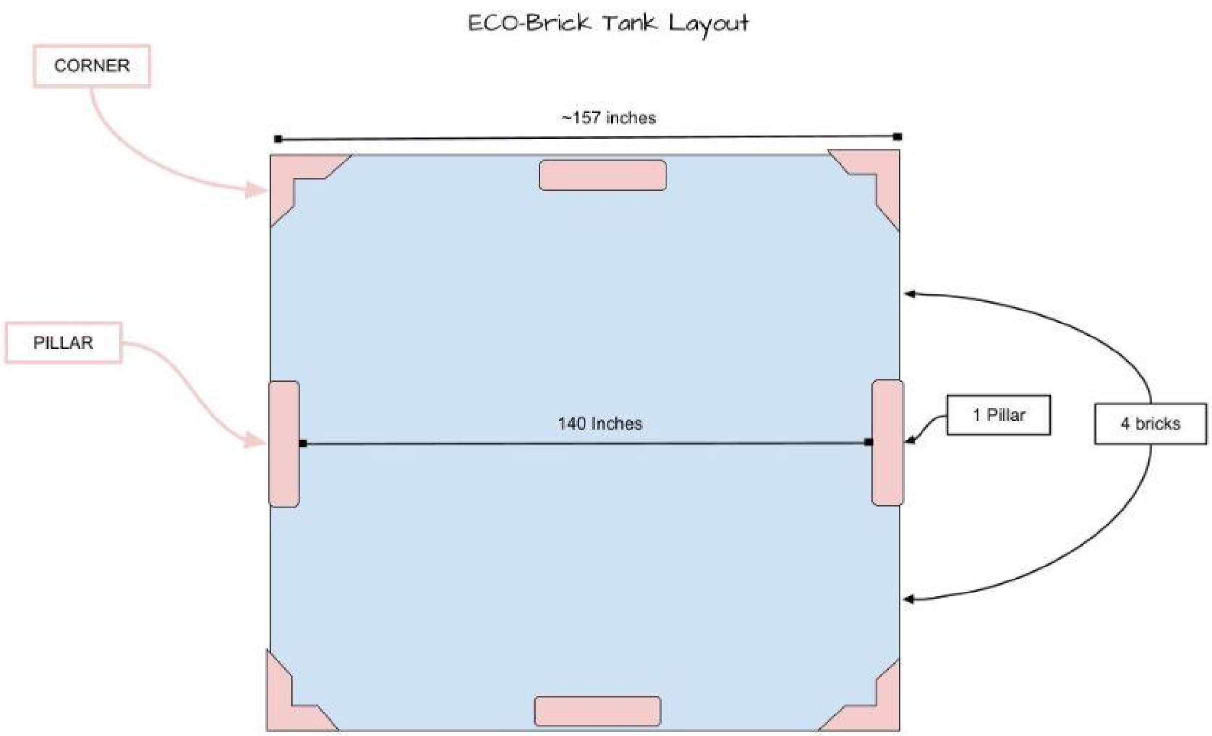
Aerial View

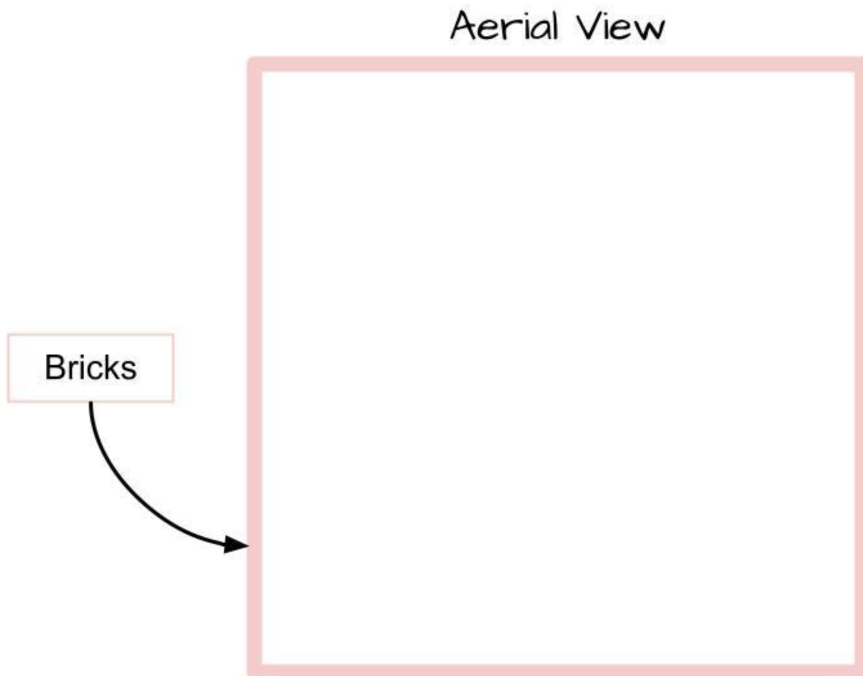

Rebar

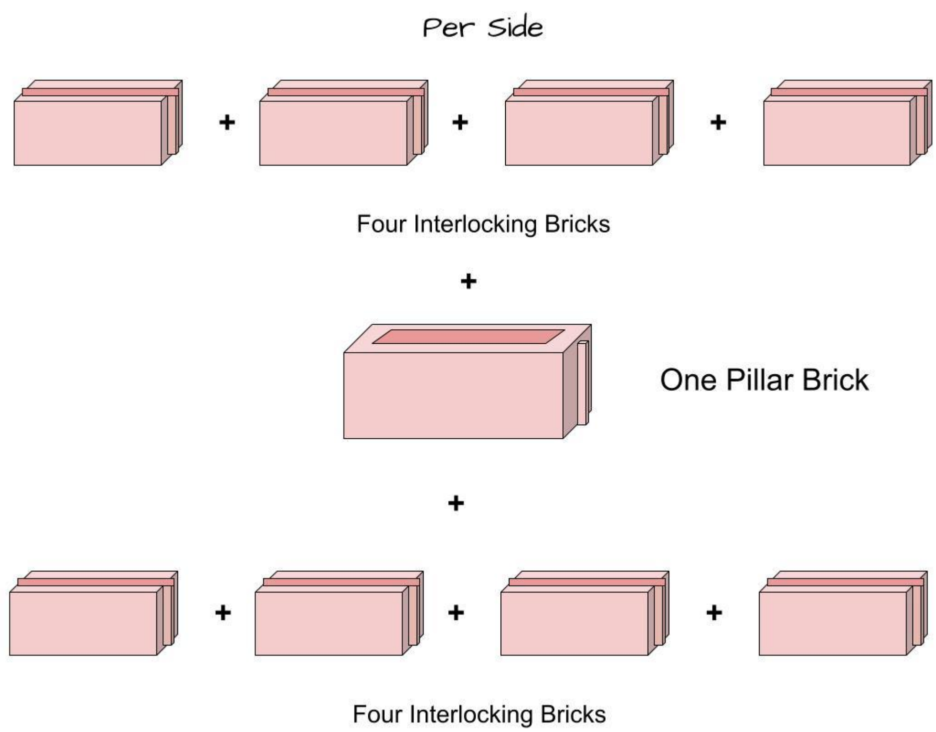
Three Layers High



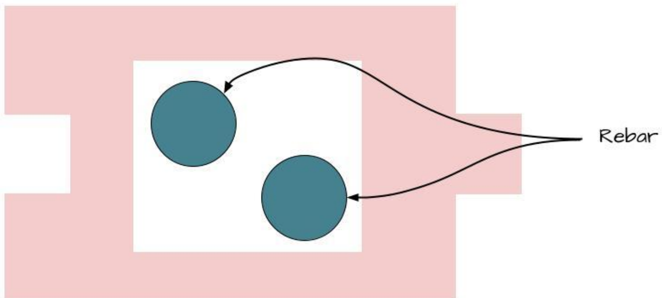
Tank



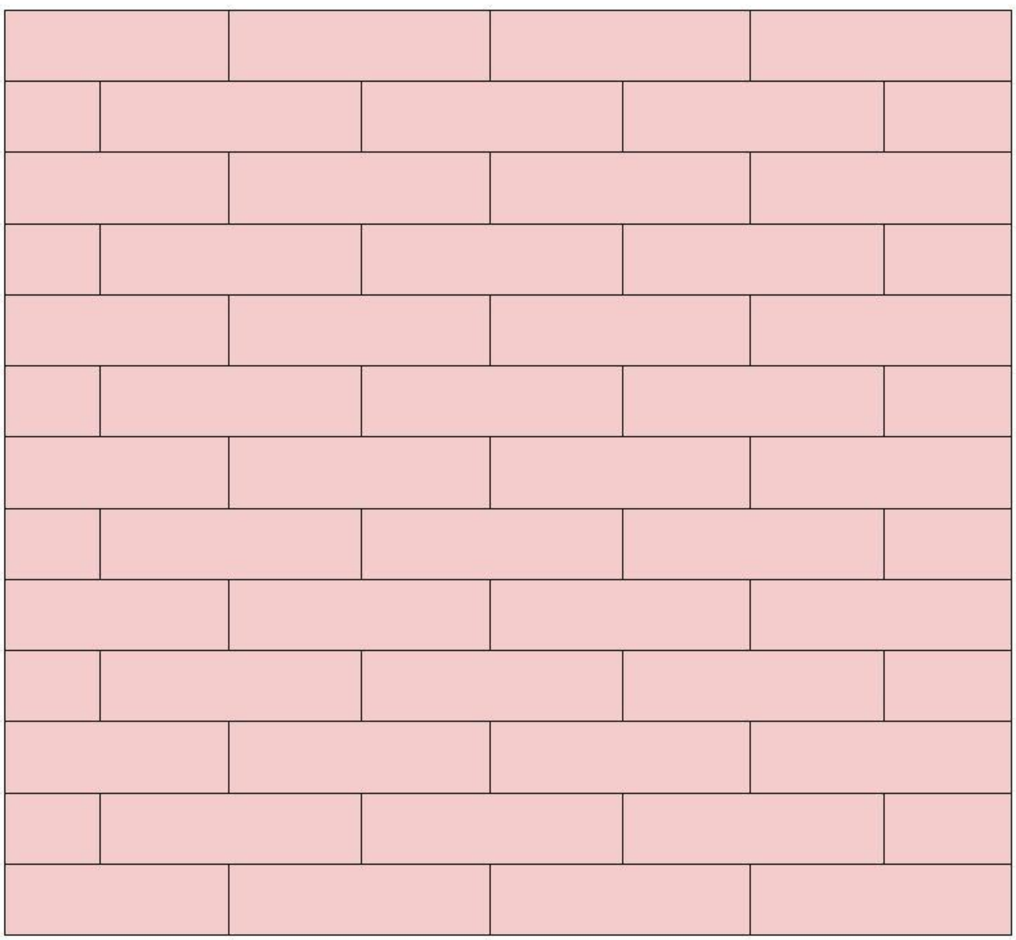

Aerial View
Bricks


Per Side
+
+
+
Four Interlocking Bricks
+
One Pillar Brick
+
+
+
+
Four Interlocking Bricks

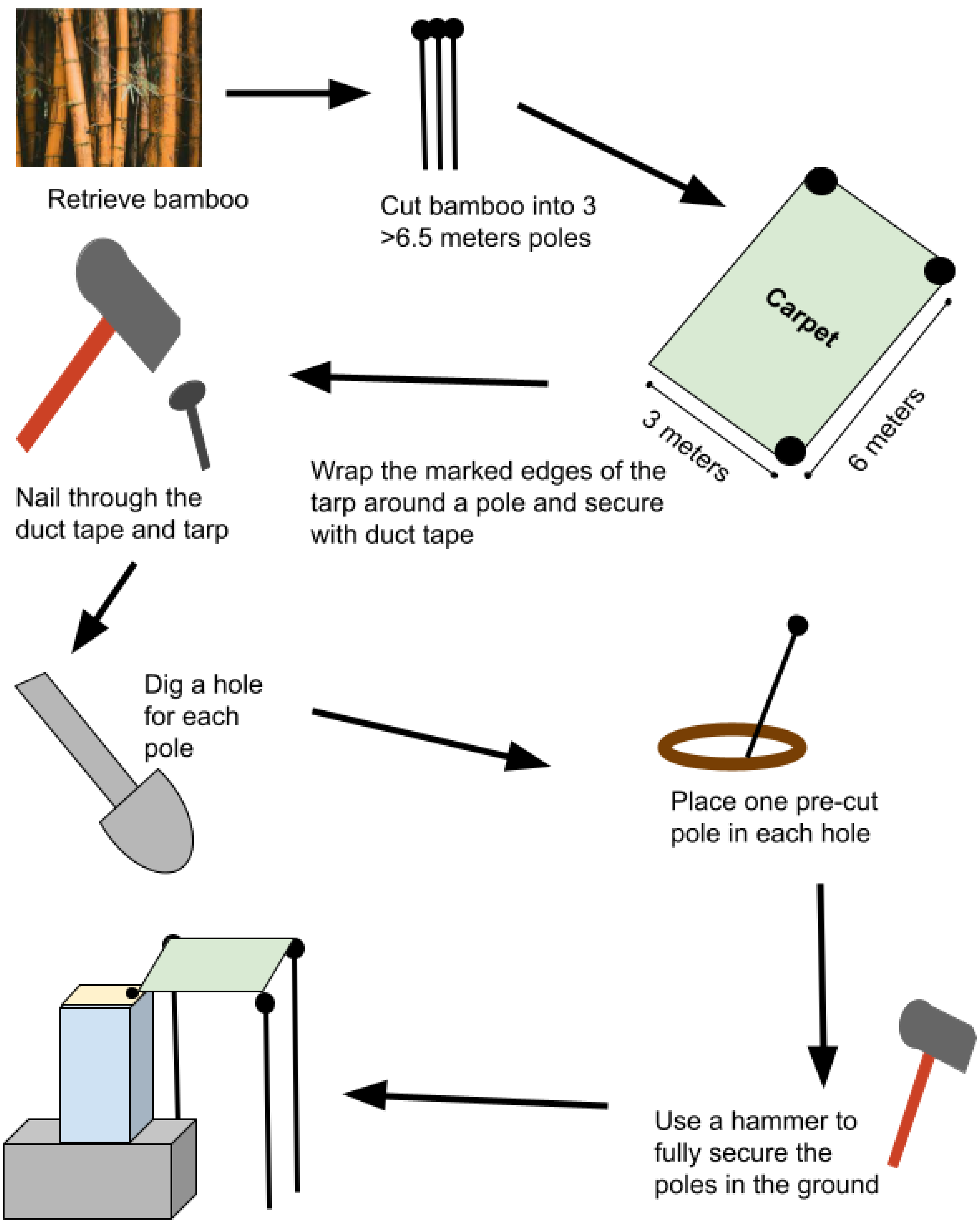
Aerial View



2 Meters High

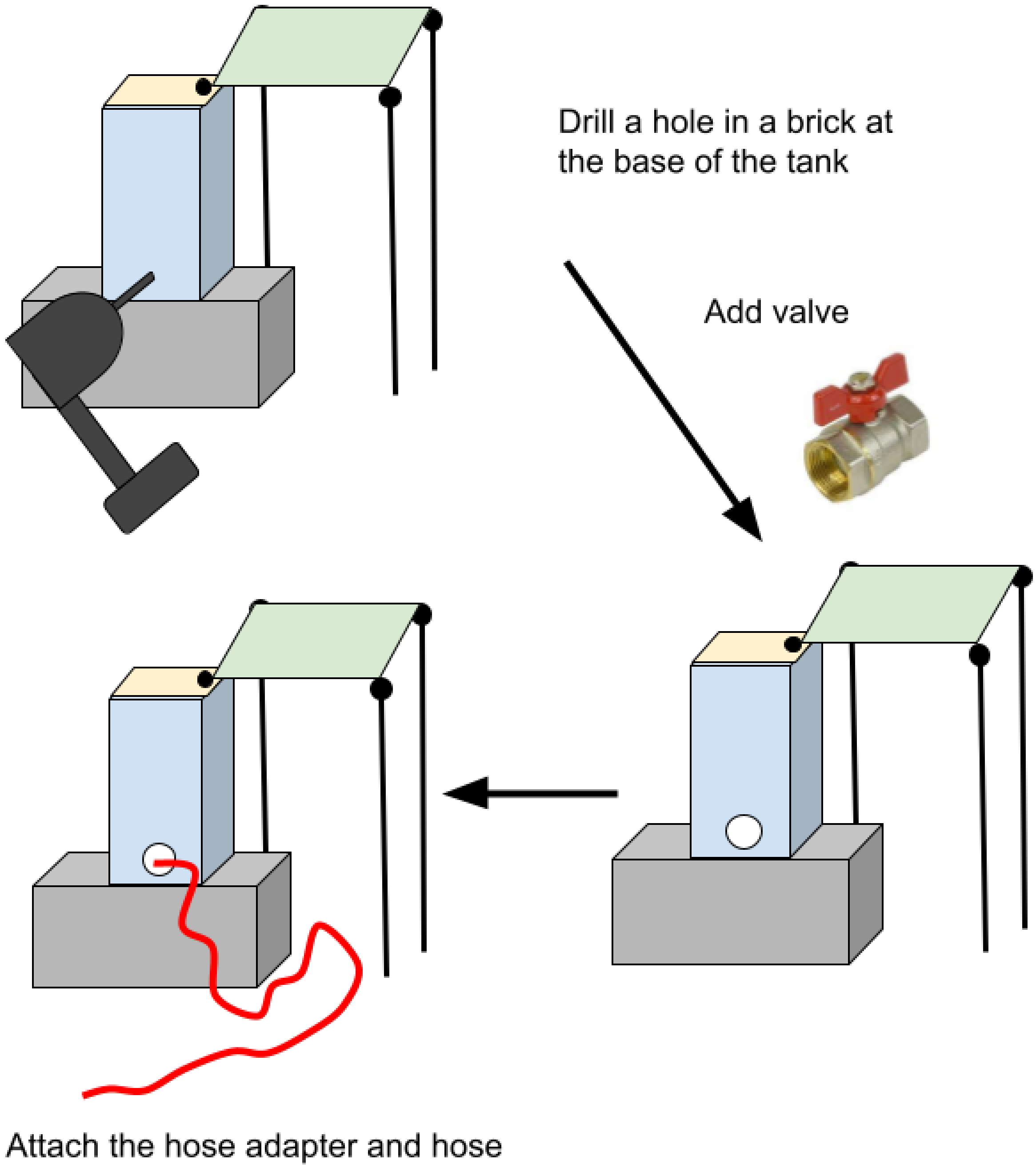


Catchment



Retrieve bamboo
Cut bamboo into 3
>6.5 meters poles
Carpet
3 meters
6 meters
Wrap the marked edges of the
tarp around a pole and secure
with duct tape
Nail through the
duct tape and tarp
Dig a hole
for each
pole
Place one pre-cut
pole in each hole
Use a hammer to
fully secure the
poles in the ground

Delivery


Drill a hole in a brick at the base of the tank
Add valve
Attach the hose adapter and hose