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GLI FOOD STORAGE FACILITY PROJECT



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Table of Contents

SUMMARY	3
INTRODUCTION	3
Background	3
Objectives	4
Problem Description	4
REQUIREMENTS AND JUSTIFICATION	5
Storage Capacity	5
Cost Effective	5
Materials and Labor are locally sourced	6
Environment Control	6
Low energy lighting	6
CONCEPTUAL DESIGNS	7
Sizing	7
Environment Control	8
Ventilation	8
Cooling	10
Insulation	11
Lighting	13
Material and Building Limitations	13
FINAL DESIGN	13
Final Approach to Design	13
Sizing	15
Insulation and Structure	15
Ventilation and Cooling	17
Lighting	19
Drainage	19
Materials	20
TESTING SUMMARY	20
Solar Chimney Calculations	20
Green Roof Load Calculations	21
Surcharge Loading Calculations	21
Anchoring	21
Conclusion	22
Summary	22

Possible improvements	22
Appendix	24
Appendix A.....	24
Appendix B.....	25
Appendix C.....	25
Appendix D.....	26
Appendix E	27
Appendix F	30
Appendix G	31
Appendix H.....	40
Appendix I	Error! Bookmark not defined.

SUMMARY

The University of Colorado, Colorado Springs team was tasked with creating a food storage facility for the Entusi Resort and Retreat Center operated by Global Livingston Institute located in the Lake Bunyonyi region of Uganda. The original task was to specifically create a design for GLI's Entusi. After a research trip was conducted, the approach and solution changed. The local farmers in the Lake Bunyonyi region are currently keeping their crops on the floor of their homes. In extreme cases, some farmers even stored crops in the same room they sleep in. This can become a dangerous issue due to the fumes that a potato excretes once it begins to rot. During the rotting process, potatoes give off a noxious solanine gas that can make a person unconscious if they inhale enough. The team was able to visit the location and learn from the local farmer's agricultural practices. The approach to GLI's problem changed and a food storage facility was designed for the farmers. The team designed a facility equipped with lighting, ventilation, cooling, drainage, storage shelves, and insulation aspects. The team was tasked to ensure the food storage facility was made with only local materials with the ability to be built using only hand-powered tools. In Uganda, the team was able to visit GLI's model farm located on a peninsula of Lake Bunyonyi. This model farm allows farmers to see various GLI agricultural systems and structures so that they may implement the ideas on their farms. The same concept will be used for this design. The food storage facility was designed to be built at GLI's model farm. Local farmers will then be able to observe the crop storage facility and discuss with GLI's Farming Cooperative staff about various aspects of the design. This will give them an understanding of the purpose of every piece of the design and build their own food storage facility as they best see fit. The overall design includes a 10ft by 10ft by 7ft structure consisting of wood which will be built within a hill. The hill will have a portion dug out to allow for the structure to fit. The roof of the facility will be made of tin sheets with wooden crossbeams underneath. There will be a black plastic tarp placed in between the dirt and the main structure. This tarp was included to prevent water damage and allow water to flow to the drainage system implemented. The drainage system replicates a French drain design. It uses PVC pipes buried in gravel to drain water out of the facility. Due to the size and cost the team did not feel the need to implement actual lighting. Instead, the small size of the facility allows for lighting to solely come from sunlight through an open door. Inside the storage facility pallets on the ground will be used to store sacks of potatoes that are too heavy to carry far off the ground. There will also be a table incorporated inside that will contain a lip so that individual potatoes could be stored before they are placed in sacks. The team has included a bill of materials as well as a detailed procedure for the GLI staff and local farmers to be able to build the design on the model farm.

INTRODUCTION

Background

The University of Colorado, Colorado Springs (UCCS) provides a mandatory course for the seniors in mechanical engineering titled Engineering Design. This is a two-semester course in which students are tasked with solving a problem for a company or professor. Students are given the initial problem and are then asked to determine their advisor or customer's parameters and requirements. Once those are identified the team can begin creating conceptual designs, one of which will then become the final design. Afterward, if applicable, they can begin testing and prototyping the finalized design to create a final report. The final presentation of the design is showcased and presented to the other teams and sponsors. This report is regarding the project completed by five UCCS students, Denzil Afriyie, Charlie Kieffer, Krystall Corbaley, Katerina

Reynolds, and Joseph Behrend. The team worked with Global Livingston Institute for two semesters to provide them with a design for the problem tasked.

Global Livingston Institute (GLI), named after Johnston R. Livingston is a non-profit organization that began in 2009. While working out of various locations globally, GLI's main office is located in Denver, Colorado. Johnston is a visionary entrepreneur and philanthropist from Colorado. His idea was to get students and the community to strategize and rethink how the population approaches international development. Their main goal is to work with locals in Uganda to create jobs, education, and community development as well as to engage students and community leaders in their efforts. GLI is currently operating out of the Entusi Resort & Retreat Center on Lake Bunyonyi in Uganda, about two hours southeast of Kabale. The average temperature for the year is 21.1°C with the high being 21.8°C and the low being 20.2°C. The average amount of rainfall is 1155 mm a year. While there is no humidity data for the lake, the nearest city of Kabale has an average humidity of 78% for the year.

Currently, GLI's Farming program has given local farmers loans to create more economic productivity. These loans are intended to help farmers increase their crop output. GLI collects these crops and brings them to a larger market outside of the area. This is done because most farmers cannot transport their crops to larger markets due to transportation issues. Also, GLI's transportation of the farmer's crops protect them from middlemen that may exploit them. Due to an increase of crop productivity, GLI is looking for a crop storage facility that will allow them to store crops before bringing them to the market. Hence, the farmers will be able to sell the crops when their market value is higher, approximately a month or two after harvest.

Objectives

The objective of this project was to design a food storage facility given the requirements listed below. As mentioned previously, the facility will be placed on the model farm where local farmers will visit and determine the parts of the design they would like to incorporate in their storage facility. Originally the team was tasked with designing a food storage facility for the resort, but this changed once the team visited Uganda and spoke to the locals. The team was able to better understand the project and, thus, it was decided that the storage facility would be placed on the model farm. The resort would then follow the same procedure as the farmers and use the facility as a preliminary concept. Once they have made modifications as they deem necessary, they will have the locals and those working at Entusi construct the storage facility which may include other products besides crops. As demand grows, they will build onto the facility to allow for more food storage.

The farmers living in the rural areas of Kabale have seen the need to innovate and improve the quality of their lives. Most of the population rely on farming as their main source of income. This comes with some challenges in terms of sustainability and cost of living. Issues such as modern sustainable farming processes, ergonomics, food transportation, and food storage are just a few. The storage facility allows the farmers to have a centralized location to keep their crops so that they are not stored on the dirt or in their homes. This will create a healthier living environment and prolong crop storage, allowing for better economic return.

Problem Description

The local farmers at Lake Bunyoni need an affordable storage facility for the crops they yield due to losses in profit and safety. The crops are currently being stored on the floor of their homes. In some cases, the farmers even sleep with them due to a lack of space. With potatoes emitting a

dangerous gas as they begin to rot, it is best for farmers to not keep potatoes in their homes. The storage facility will most importantly keep the potatoes out of the homes of the farmers ensuring their safety. Storing the potatoes on the floor of their homes may also lead to faster rotting times leading to less overall return and less income. The UCCS team was fortunate enough to visit the site in which the facility will be built, allowing them to get a perspective on the available materials and a better understanding of the local environment.

REQUIREMENTS AND JUSTIFICATION

Storage Capacity

The first requirement was for the storage facility to be large enough to hold crops for an increasing number of farmers. This requirement was in place because GLI expects the crops per farmer to increase over the years as the farmers receive loans and farming training from Entusi as part of Cooperative Farming. In addition, GLI also expects that more farmers from the area will join the Cooperative Farming Initiative. Currently, there are eleven farmers part of this initiative, with an expected increase of about two to three farmers per season. There are two harvest seasons per year, and it is anticipated that farmers will consistently join GLI's farming program for about five years. Thus, it is estimated that a maximum of forty farmers will be part of the Cooperative Farming Initiative. At the moment each farmer brings between one and five sacks of crops, each sack weighing about sixty-five kg. To address this, a tree breakdown diagram, shown in Appendix A, was created to help synthesize an engineering parameter for the storage requirement. First, it was determined that the design must at least meet the storage capacity for the eleven farmers currently part of the initiative. In addition, the design initially was made to meet the storage capacity for a maximum of forty farmers or be easily and inexpensively enlarged to meet the requirements in the future. This plan was changed after traveling to Entusi and understanding the constraints more fully. It was decided that a storage facility for the farmers would be built on the model farm. This way the farmers could see and build the facilities on their property with their modifications if necessary. An additional storage facility could be placed at Entusi with the same essential design but instead would employ different building materials. Mathematical estimations were completed to predict the amount of space required for the crops. The first calculations completed were to estimate the weight of the crops provided by the farmers. Then, various assumptions were made to determine the density of the space the crops would consume such as the size and weight of a potato. These calculations considered factors such as crop density, space between individual crops, and space between the sacks. More in-depth explanations of the estimations are provided in Appendix B. The initial space allocated for potato storage was calculated to be 3.5 m³ and the initial space allocated for bean storage was calculated to be 4.75 m³. The final space for potato storage was calculated to be 12.5 m³ and the initial space for potato storage was calculated to be 17.5m³. The initial total storage capacity was determined to be 8.25 m³ with a final maximum storage capacity of 30 m³, the tree diagram in Appendix A shows how these numbers were gathered. However, the max final storage capacity does not need to be initially met if it requires only 50% of the initial cost to expand. This was agreed upon with sponsors. The current requirement was to store at minimum the crops of farmers currently part of the program. If considered too costly initially, the structure should be cost effective to expand. This would give the sponsors time to determine whether a larger storage facility was necessary.

Cost Effective

Initially, GLI discussed their ability to invest in the structure. GLI has limited funds, however, they are willing to invest a decent amount of money if it can be justified. Thus, the design needed to

be as cost effective as possible with every aspect justified. The team created a set of requirements to best describe this cost-effective requirement. Since the maximum capacity of the design was expected to be fully used in five years, it was decided that the total price of the facility needed to be completely paid off in five years. To further break down this cost, it was determined that the average price of components/building materials for the full completion of each mandatory requirement needed to be paid for in two harvest seasons. The monetary value was the 90% of sale funds kept for the GLI farming initiative after the crops were brought to market and other expenses were paid off.

Materials and Labor are locally sourced

The third requirement was that the building materials needed to be locally sourced. There were two main reasons for this requirement expressed by various voices. First, using only locally sourced materials would keep costs low since nothing would have to be imported while supporting local businesses. This would aid in the completion of the cost requirement of the project. Second, using locally sourced materials allow the structure to blend in with the local architecture. A list of available materials was given by the project's other voices: bricks, treated wood, concrete, and tin/iron sheets. It was determined that the materials of use would be treated wood, PVC, tin, tarps, and nails. Bricks and concrete were not chosen due to their high cost.

When discussing with GLI, an emphasize was placed on the limitations standard building methods. This limitation resulted in the fourth requirement which was that the construction of the storage facility needed to be completed by locals that work at the Entusi site or local craftsman. No heavy machinery is available at the site and therefore the design should not require the use of such machines.

Environment Control

The major goal of the crop storage facility is to provide a space that will extend the longevity of crops stored for the community to increase economic growth. Thus, the fifth requirement was that the food storage facility must be able to store a variety of local crops for an expectable amount of time. Currently, farmers produce various crops and have nowhere to store them which as previously mentioned can be detrimental to their health and incomes. The preservation of crops allows GLI to bring them to market up to two months after the harvest season when the value of the crops is higher. This would allow GLI and hence the farmers to earn more for each unit of the crop. It was determined that potatoes and beans would make up most of the crops provided by the farmers. Thus, the design needed to create a suitable environment for potato and bean storage. It is important to note that this environment would be suitable for a variety of other crops as well. Potatoes and beans need to be kept at a constant cool temperature of 7°C – 13°C. Furthermore, they need to be kept in a dark location to prevent the chemical reaction from chlorophyll which results in the rotting of crops. Ideally, the beans need to be stored in drier conditions than the local climate for their best preservation. To further preserve the crops for a goal of two months, the designs must be waterproof, keep crops above floor level, and have a ventilation system. A tree breakdown diagram for this requirement is provided in Appendix C.

Low energy lighting

The final requirement was that the storage facility needed low or no energy to function but still have a lighting system. Due to location and logistics, the solution should not be reliant on an energy source should something fail. Thus, it was determined that the solution should have nonelectrical sources of lighting for daytime use and a separate source of lighting for nighttime

use. This was determined because most crop transportation in and out of the storage facility would occur during daytime use. For security and unexpected circumstances, nighttime lighting should be provided.

CONCEPTUAL DESIGNS

About half of the work completed for this senior design project occurred before the research trip to Entusi, Uganda was accomplished. Thus, initial engineering parameters and requirements made for this project were developed from information provided from outside sources rather than the local end-users. This resulted in a misunderstanding of the actual, realistic engineering parameters. The engineering team completed conceptual design generations before the research trip to have something to start with and then modify if necessary. A nontraditional approach was taken to conceptual design generation, rather than create concept solutions for the entire project, research was completed on individual methods that would accomplish the determined engineering requirements. Thus, numerous ideas related to the various engineering parameters were researched and understood. These various research topics broadly included environment control, lighting, sizing, and material limitations. These potential solutions would then be reconsidered during and after the research trip was completed. Solutions that best met the requirements were compiled. Then, the solutions to the various aspects of the project were combined into one final design.

Sizing

The original requirement given to the team was that the storage space had to be large enough to hold crops for an increasing number of farmers with the facility being shared amongst them. When the project began there were eleven farmers with an estimated increase of two to three farmers per season. Each farmer is estimated to bring in between one and five sacks of crops, with each sack weighing about 65 kilograms. The original design was created for forty farmers, which was the amount GLI expected to have after 5 years. The final size of the storage facility was calculated to be between $8.25 m^3$ to $30 m^3$.

The team was able to visit the location where the storage facility will be built. The design for the original location was to be funded by GLI, which gave design flexibility due to a relatively large budget and low cost of supplies. Once in Lake Bunyoni, various observations led to a change of approach. It was noted that current farmers would keep their crops on the floor outside or in the same room that they would sleep in. This created an unhealthy environment for farmers and their families. Furthermore, the high cost of transportation and time around the lake was not fully understood until after engaging with farmers part of the Farming Cooperative. These two main factors resulted in the reconsideration of the approach to the problem. The team decided one option for the completion of the project would be to create a storage facility that could be built by farmers rather than GLI. This approach would differ from the original intention for the design but could solve the challenges noticed while engaging with the farmers. This design would be built on GLI's model farm as an example so that farmers could see and learn how to create their crop storage facilities. Although farmers may not be able to build the design exactly the way it would be built at the model farm, this design would expose farmers to various feasible ways to approach their crop storage problems. This option would change the initial approach to the problem given by the sponsors but would still accomplish the overall mission of their Farming Cooperative Plan.

Environment Control

When approaching the problem of environmental control for the crop storage, the issue was broken down into two sub-issues, ventilation and cooling. To maximize the shelf life of a potato and other potential crops that are supposed to be stored in the crop storage facility, a cool and dry area needed to be devised. More specific environmental goals are discussed in the Engineering Parameters section of this report. To accomplish these objectives, systems for ventilation and cooling were researched.

Ventilation

The purpose of pursuing ventilation was to determine a method that could adequately reduce moisture build up in the storage facility. This would increase the time it would take for mold or bacteria to build upon the crops, increasing shelf life. Multiple proven concepts were investigated. Although many concepts were explored, only ones with little to no electricity usage were considered.

The first concept explored was a simple but effective strategic placement of windows or natural openings in the design. Depending on the various geographic conditions, the careful placement of windows may allow for relatively consistent airflow in the structure from the environment. Factors such as no electrical usage and low material cost made this concept a possible design. Proven designs of strategic layouts of buildings include the Dogtrot house, Figure 1.

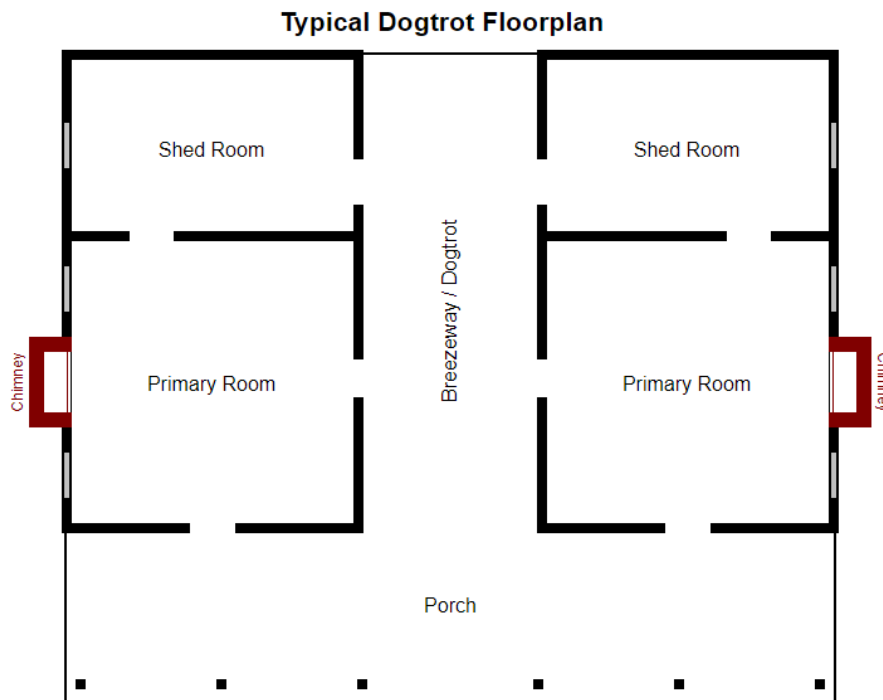


Figure 1: Dog Trot House Layout,
https://upload.wikimedia.org/wikipedia/commons/9/9e/Typical_Dogtrot_Floorplan.svg

This layout promotes air circulation through the middle of the house using a breezeway and then releases incoming air through windows in the primary rooms. To effectively use this concept, a rather consistent natural airflow is required. After the research trip, it seemed plausible that

consistent natural air flows existed in this area. There were various reasons for this assumption. First, the rather subtle changes in seasons along the equator promote consistent winds. Second, many of the potential farms in need of this storage design lie along or close to the shores of Lake Bunyonyi. This very deep lake stays at a constant temperature and can promote natural winds from air temperature differences. Furthermore, many of the farms in this area are located on the steep valley slopes which descend into the lake. These steep valley slopes reduced the angles of which wind can blow on buildings because the ground offers a natural backing to the building. This would allow for more consistent wind directions, making the planning of strategic windows simpler.

The next concept explored was passive ventilation through solar chimneys. This concept works by constructing a sun-exposed chimney-like structure next to a building. The sun-exposed chimney heats the air within it which then rises out of the chimney. The low pressure created in the chimney then sucks air from within the building out into the environment. Natural inlets throughout the building allow outside air to seep into the building, creating a ventilation cycle. This process is used in installations such as outhouses. In this case, the passive air ventilation is used to extract fumes from the outhouse.



Figure 2: PVC Solar Chimneys on an outhouse at a school on Lake Bunyonyi

These systems were observed in Entusi, Uganda, Figure 2. There was one major factor analyzed which contributed to the effectiveness and possibility of this concept. Exposure from the sun is essential to create a temperature difference within the solar chimney to generate passive ventilation. After the research trip to Entusi, it was determined that although eight months of the year were rainy seasons, the storage of crops was most needed during the four months of the dry season. At the beginning of the two-month dry season, crops would be harvested and stored for the entirety of the dry season. During this dry season, sun exposure is very consistent which would create the temperature difference needed for very effective ventilation. Although during the wet season, lower sun exposure would reduce the effectiveness of the solar chimney, it was determined that a lesser number of crops would be stored during this time. These crops were not

to be sold but rather to be used for farmer's personal use. Thus, the ventilation system would not have to run as effectively during the wet season because there would be fewer crops, thus, less moisture to ventilate.

It was important to note that the natural humidity of the air was considered when brainstorming ventilation concepts. The relatively high humidity from the geographic location close to the equator and the proximity to Lake Bunyonyi was considered. Initially, it was determined that the use of passive ventilation systems such as strategically placed windows or solar chimneys was not ideal because it used humid air from the environment.



Figure 3: A Farmers house. Note the only forms of ventilation were openings near the ceiling of building

After gathering information from the research trip to Entusi, it was also determined that a type of passive ventilation was only economically feasible. Figure 3 shows a farmer's house in Uganda that uses openings in the ceiling for ventilation. Electricity and economic restriction of farmers would not allow the use of any kind of dehumidifier system. In addition, the effectiveness and efficiency of dehumidifiers would be very low because construction methods in this area result in very permeable buildings.

Cooling

An effective ventilation system can maintain the temperature inside of a structure with the temperature of the outside environment, however, it was determined that the outside environment was too warm for natural crop storage. This was especially true for the dry season when storage was most needed.

The first system considered an extension of the passive solar chimney system. The traditional solar chimney design uses pressure differences to suck the air out of the building. This air is then

replaced by air which seeps through natural openings in the building. Instead of allowing air to flow in from openings in the building, the air can be naturally cooled beforehand. This is most effectively done by attaching pipes to the building and then running the pipes through a naturally cool area before opening to the environment.

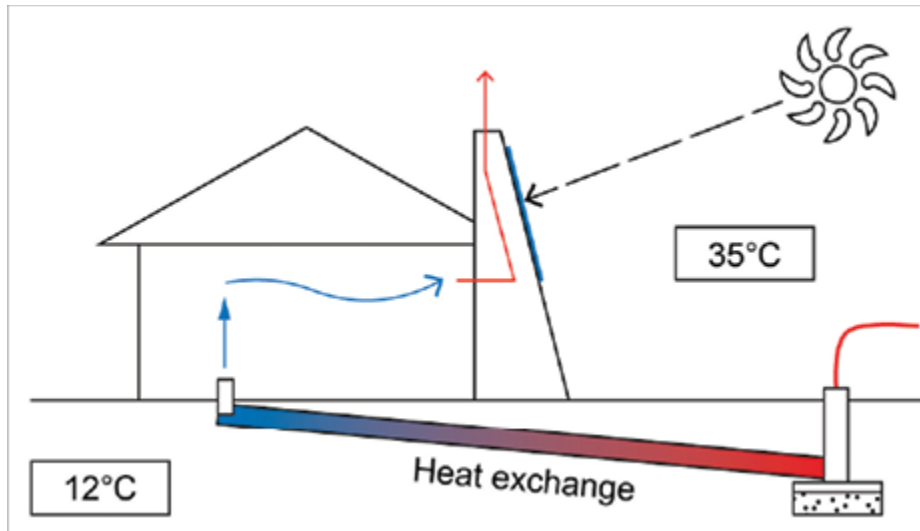


Figure 4: Passive Cooling System, <https://www.yourhome.gov.au/passive-design/passive-cooling>

Figure 4 shows a passive cooling system and how the heat is exchanged throughout. As low pressure is created in the solar chimney due to a temperature difference, the air is sucked out of the building. The low pressure in the building sucks air from the pipes which have cooled the air from the outside environment by running it through a cool location. The creation of a cool location can be accomplished in a few ways. The simplest way is to run the inlet pipes relatively deep into the ground. Dirt is a natural insulator which means it prevents heat from the sun and the environment from transferring deep within it. Thus, there exist naturally cool locations at depths not far from the surface. By running the inlet pipes through deeper, cool soil, the air sucked through the pipes cools before entering the building. This can also be accomplished by running the inlet pipes through deeper water. This seemed like a plausible idea due to many farmer's proximities to Lake Bunyonyi.

The last cooling method considered was evaporative cooling. This method of cooling reduces the temperature of an area through the evaporation of a liquid. This process occurs because heat is absorbed from the area where the liquid is present to cause evaporation of the liquid. Many present evaporation methods use electricity, making them unfeasible. Although, consideration was made to redesign a non-electrical evaporative cooling system due to the large water supply from Lake Bunyonyi.

Insulation

In order to maintain or preserve the environment created by any cooling or ventilation system, some sort of insulation was deemed essential. This was especially true for this area which has a consistent temperature of 21.1°C for the entire year. The inside of the storage facility needed to remain at a lower temperature to produce the best possible circumstances for the longevity of the food being stored. After the research trip, insulation was considered very important thanks to a better understanding of the financial limitations. Planned cooling and ventilation systems were not

expected to be as advanced as desired, thus any limited environment created from these systems needed to be preserved as long as possible.

The initial insulation idea was to use traditional fiberglass insulation that can generally be purchased at hardware stores. While researching materials on-site, standard fiberglass insulation was not readily available. Therefore, it would need to be shipped in and would increase the cost of the total facility. The cost factor from this shipped material vastly limited its feasibility.

Next, various present crop storage facilities were researched and considered. It was determined that many materials that are typically used in America were not readily available at Lake Bunyonyi. Although, there was one, traditionally non-commercial storage facility considered. This was the conventional root cellar. This is a very common type of storage location built underground or partially underground to store foods. This building uses the natural insulation provided from the ground to keep the area inside cool, without any additional materials or electricity. This was deemed a very favorable option because it would contribute little to the overall cost of the project yet provide effective insulation. The issue with this structure was the building of the foundation or the hole in which the root cellar would be placed. Limited tools and funding for labored workers were thought to provide some difficulty in creating the space in the ground required for this idea.



Figure 5: Green Roof example on a above ground house:<https://cabaus.org/2018/04/20/green-roofing-everything-need-know/>

The next idea considered was a Green Roof, Figure 5. A Green Roof provides insulation from direct sunlight by absorbing heat in a living layer of dirt and plants on the roof of the structure. This type of roofing layer is often used in above-ground structures but was highly considered for this project. The Green Roof has the potential to reduce the internal temperature of the structure by up to 3.4°C. Furthermore, if matched with a partially submerged building design, the practicality of a green roof makes the system cost-effective and requires a minimal amount of extra material. This seemed favorable because it could provide insulation on the top of the structure if a deep enough hole could not be built for a fully underground insulated structure. One limiting factor considered with the Green Roof concept was the extra load applied on the roof of the structure. This needed to be compensated with a stronger base structure which would most likely result in an increased use of materials.

Lighting

Initially, lighting was deemed to be an important component to the success of the storage facility since it could be accessed at night and would provide security measures. The biggest limiting factor was that the lighting had to use little to no energy. A few options were explored including the GravityLight, chlorinated water bottles, windows, and a skylight.

The GravityLight is a lighting system that requires no external power and is marketed for use in developing regions. The system has a pulley and weight so that after the weight is raised it begins to fall generating kinetic energy and thus lighting the bulb. This would then allow the farmers to only need the light when they need it in place of dangerous kerosene options. Unfortunately, it is also \$69 USD which is extremely expensive for a family in Lake Bunyoni that may not even make that amount in a month.

The concept of chlorinated water bottles is simple. Plastic disposable water bottles are filled with chlorine and water then placed into ceilings or walls of the structure. They then amplify the natural sunlight coming in to provide more lighting. This ended up not being a viable option since the lighting is primarily needed for night purposes and there needed to be minimal sunlight to reduce spoilage of the produce. Windows and a skylight were therefore not preferred options either due to the natural sunlight.

Material and Building Limitations

When the project was assigned to the team, the GLI representatives made it clear that they must use locally sourced materials. The materials found via research included bricks, wood, and concrete. These were the materials the team began their research with. It was noted later in the process that concrete would be too expensive for the local farmers. If GLI decided to create their own storage facility for their resort they would update the design to include concrete and brick walls instead of wood for more durability.

The team was also limited to using the building tools available to them. It was stated that only handheld materials such as hammers and drills would be available for building. No heavy machinery such as cranes and bulldozers would be available. This limited the materials for building as well since there is only so much that can be done without heavy machinery.

After the research trip to Lake Bunyoni, there were some observations made when interacting with local farmers. Although resources were rather limited, members of the Farming Cooperative were committed to putting effort into at-home projects of their own in order to improve their livelihood. This dedication gave the design limited construction time constraints, allowing for slower building methods to be a more feasible option. This option could make up for the lack of resources and building tools as it opens up more time-consuming options.

FINAL DESIGN

Final Approach to Design

The original approach to solving GLI's Farming Cooperative problem was to design a crop storage facility for their Entusi Resort location. After Entusi's Farming Cooperative leaders went to buy potatoes from local farmers, they planned to store the potatoes at the desired crop storage facility until bringing them to a larger market. This crop storage was needed because many of the potatoes would go bad before reaching the market. This would reduce the revenue earned for GLI and reduce the amount they could pay the farmers for their potatoes. After the research trip

to Lake Bunyonyi, Uganda, the team got a better understanding of the local situation and problem at hand. There were many new factors that were not understood before the trip. On the trip the entire collecting, buying, and transporting to the market process was observed. Furthermore, the team visited various farms and farmer's homes. Discussions were held with the farmers to better understand current storage and farming practices. Also, the team asked for their opinions and concerns. Experiences like these led to a team meeting and a reevaluation of the problem. It was determined that the degradation of the potatoes did not solely occur while being stored at the Entusi location. Instead, most of the decomposition of potatoes may have occurred in the 4-5-day period after harvesting. After harvesting the potatoes, many farmers would store their potatoes on the floor of their house until the Entusi staff came to buy from them. During the dry season, the farmers' homes would reach very hot temperatures which dramatically increased the decomposition rate of the potatoes. Furthermore, farmers would often live and sleep next to rooms filled with their potatoes. Rotting potatoes caused sanitary issues and created unhealthy living spaces. This was exacerbated by the fact that the potatoes were stored uncovered on the floor of their houses.



Figure 6: Potatoes stored in a farmer's house right before being picked up from the Entusi Staff

As a result of these experiences, the team decided in order to best preserve the potatoes, improved storage at farmer's houses and Entusi was necessary. Thus, it was determined that the design solution needed to be feasible for farmers to make, yet effective enough to properly store crops and other goods if constructed with higher quality materials. Thus, it was determined a relatively inexpensive, yet conceptually sound model would be designed at Entusi's model farm. This model would use justifiable and feasible concepts to create an environment for potato storage. Furthermore, the design would allow for flexibility in the materials used. Thus, GLI can

invest more funds in material storage making a more durable structure while allowing farmers to build an economically viable structure.

Sizing

After visiting Lake Bunyonyi, the team gathered information from the local farmers as well as the GLI staff. It was determined that the template design constructed at the model farm would be designed to store potatoes from the largest current farm that is part of the Farming Cooperative program. This was selected as the final size of the design because it gave a reference of how big the largest farmer's storage facility should be. This reference will allow other farmers to gauge how large they would want their storage facility to be. Based on given data from the GLI staff, potato weight, density, and geometric volumes were used to calculate space for the potato storage. Presuming the largest farm would need to store 5 potato sacks of 65 kgs, a 9 m² area would be needed. This was with the assumption that the potatoes are not to be stacked 2 potatoes high or more, which was a common storage practice on Lake Bunyonyi to reduce potato rotting. As a result, it was determined that the model farm would be 10ft wide, by 10ft long, by 7ft tall. The 10ft by 10ft size was chosen to standardize the model according to the materials available, thus, saving time and money. This size allows for adequate space to store the potatoes and provide a walkway. It was determined that a height of 7 ft would be adequate for potato transportation in and out of the storage design. This would limit the overall size of the structure resulting in an easier construction and reduction of required materials.

Insulation and Structure

The overall structure of the final design was determined to be a partial out of ground cellar. The structure itself would be an underground cage placed partially into the hillside. The rest of the exposed structure would then be covered with dirt, except for the door. The roof would be covered with a green roof. Figure 7 below shows the front view of the storage facility. However, the actual facility will be covered with dirt and the tarp, which will cover everything but the doorway. Figure 7 shows the structure in the hillside. It is important to note that Figure 7 shows the entirety of the front face uncovered. When completed, the only exposed section of the of the structure will be the door area. This is done to maximize the insulation properties of soil.

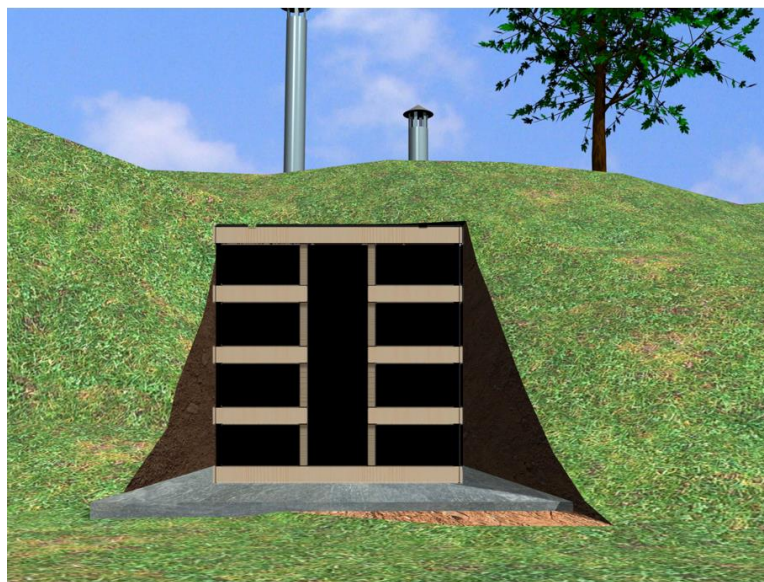


Figure 7: Storage Facility pictured positioned into the hillside

Figure 8 shows the cage like structure out of the ground. It is important to note that a waterproof, black plastic layering sheet surrounds the structure shown below.

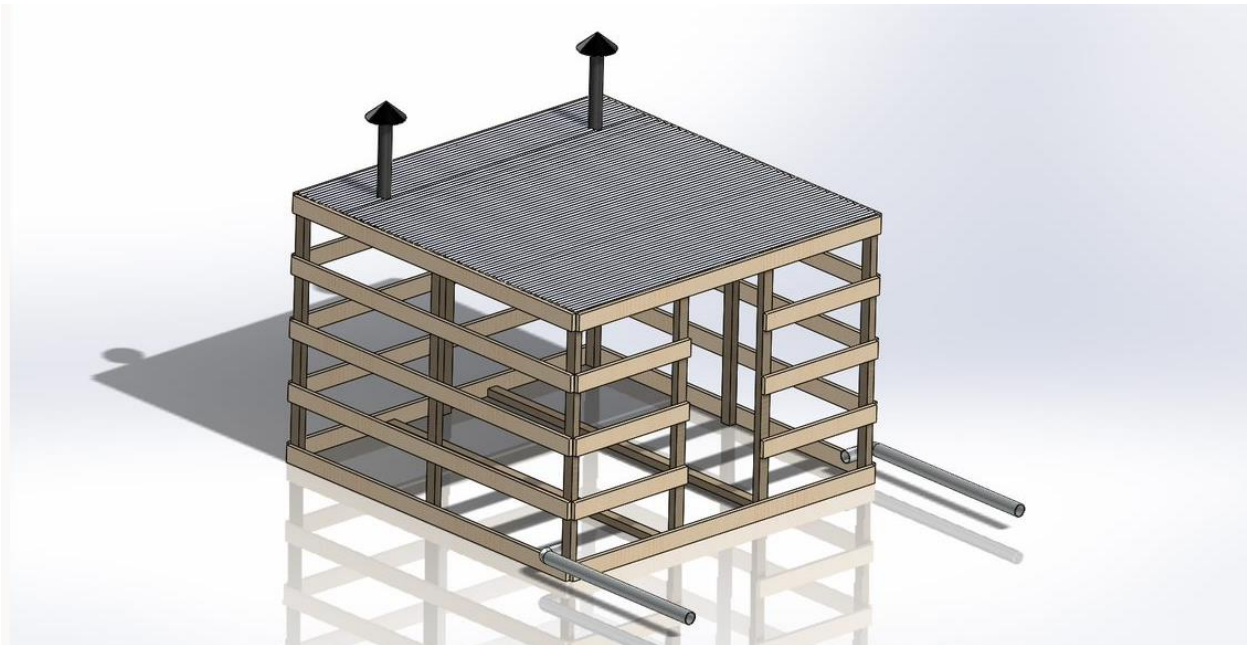


Figure 8: Final Structure without black waterproof layer

There were various reasons for this approach to the overall structure of the design. First, a major discussion occurred about the limited available resources and tools for digging a hole large enough for an underground cellar-like structure. It was determined that, although the hole would be large for a farmer to construct, various factors would make it feasible. First, many of the farmers' lands are on hills, providing a slope for which the structure could be built on. This slope would allow for easier construction of the enclosure because less volume of earth would need to be dug out. Rather than digging a large space straight down into the ground, the slope would allow for more working room, reducing the traditional challenges of digging a vertical deep hole. The remaining exposed structure would be covered with dirt dug from the hole. Second, the soil found around Lake Bunyonyi lacks roots and rocks, making it easier to work with. Two members of the GLI staff leveled an entire 20m by 70m space in three days, showing the easy movement of the soil. Lastly, it was considered that although many farmers may not have the machinery used to traditionally dig out such a large space, they have the time and desire to do so. Thus, if the construction of the hole is easier but time-consuming, it would be completed by the farmers.

This cellar design was chosen because it uses the ground's natural insulative properties to maintain a cool environment. This cellar design provides the best insulation possible with little to no monetary cost, only time investment. Tin sheets supported by wooden beams would be used as the roof of the structure. The green roof would be placed on top of these tin sheets. To reduce the cost of the building and make it a feasible project for farmers to invest in, a cage-like structure was designed to be placed in the hill. Enough wood was used to keep the structure strong to prevent the collapse under heavy earth and artificial loads. Although in Figure 8 there appears to be a lack of solid wall material between the dirt surrounding the structure and the storage space inside, a water resistance plastic wrap would be placed over the structure. This would prevent the

water and dirt from entering in between these spaces, yet dramatically reduce the cost of the structure as opposed to wood lining the entire structure.

Wooden pallets would be designed to use as lower shelving. This would raise the potatoes off the ground, reducing interaction with soil and moisture. Furthermore, ventilation through the potatoes would be more effective as air would be able to flow from underneath and through the stacked potatoes. These factors would contribute to a decrease in the decomposition rate of the potatoes. Lastly, the movement of potatoes in and out of the structure would be made easier because farmers would not have to bend over to a floor level to place and collect potatoes.

Ventilation and Cooling

For the final design, a solar chimney with an underground passive cooling system was used. This system was chosen for several reasons. First, it was the most cost-effective option and required no electricity to function. Second, this method best works with the cellar-like structure. Two PVC pipes would be placed on the roof of the structure and would run through the green roof so that 1-2 feet would be exposed to the open sun. These PVC pipes would act as solar chimneys and will be painted black to best absorb light radiated from the sun. The rise of the heated, energetic air would create a low-pressure area at the top of the structure and suck the air out of the structure. A passive cooling system would be created by running PVC pipes through the ground. One end of the pipe would be open to the natural environment and the other end would enter the bottom of the structure. Thus, when the solar chimney creates a low-pressure area at the top of the structure, air would be sucked in through the passive cooling pipes. These pipes would take air from the outside environment, cool it by running through the dirt, then release it right to the potatoes.

Figure 9 shows the black painted PVC pipe coming through the tin roofing of the structure. It has a cone covering the pipe to prevent water from entering the structure. Part of the solar chimney will be covered in the green roof insulation, but a majority will be exposed to the sun. Two solar chimneys are to be installed on either side of the structure. This was done to ensure proper ventilation for crops stored on both sides of the structure. Additionally, the solar chimneys were placed at the back of the structure to suck air out of the back. The cooling inlet pipes enter the building at the front of the structure, as shown in Figure 9. This was intentionally done to allow for ventilation across the structure to prevent stagnant spots.

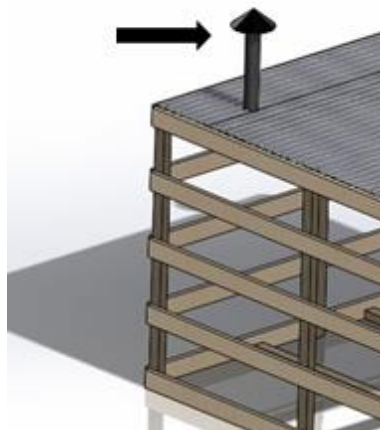


Figure 9: Solar Chimney at the top, rear end of the structure

Figure 10 shows the passive cooling pipe. The pipe would allow air into the front of the structure. Most of the pipe is to be covered in the dirt from backfilling and the covering of the front face of the structure. This is where the cooling of the inlet air would occur. It is important to note that a netting needs to be placed at the end of the inlet pipe to prevent small animals from climbing into the structure.

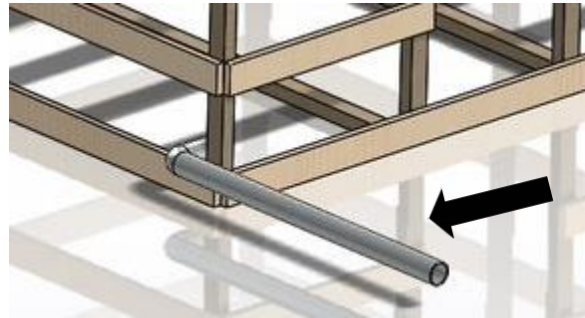


Figure 10: Passive Cooling inlet pipe

It should be noted that the integration of this system is very feasible for various reasons. First, solar chimneys are an already proven and used concept around Lake Bunyonyi. In addition, PVC pipes, which are the main components of these systems, are low cost and readily used through the Lake Bunyonyi area. Second, the construction of this system with the underground cellar would be relatively easy. The addition of the solar chimney would be simple because little work would have to be done to create space in the green roof for the PVC piping. For the passive cooling pipes, little extra digging would have to be completed to have them run through the dirt. This is because most of the pipes would be covered with soil used to cover the exposed part of the structure. The rest of the pipes would most likely be covered during backfilling of the structure.

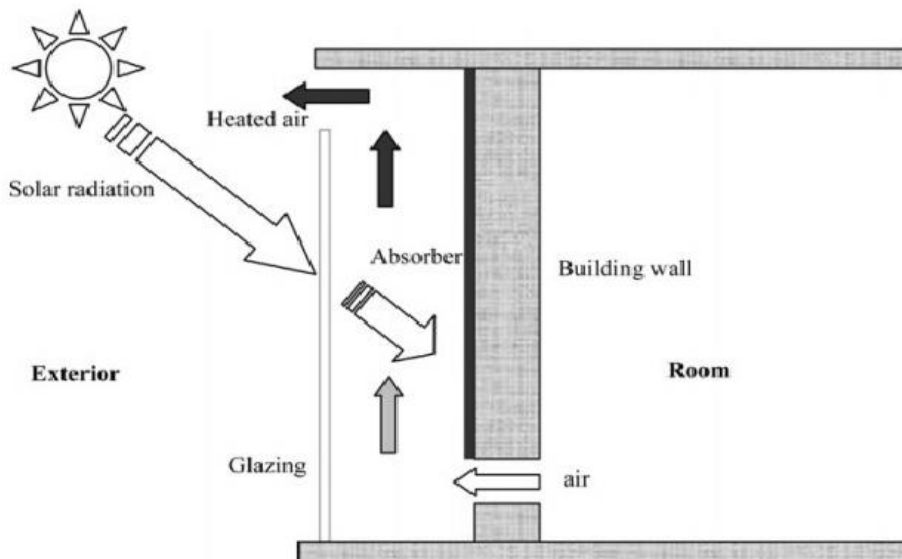


Figure 11: Solar Chimney Flow Chart, https://www.researchgate.net/figure/Schematic-Diagram-of-Solar-Chimney_fig11_260479826

Lighting

After speaking to the locals, it was determined that due to budget constraints there would not be an additional lighting system implemented. Instead, the rather small size of the storage facility would allow lighting to solely come from the door opening to the storage facility. An unintentional positive attribute to this limited lighting and cellar-like design is that very light natural light will reach the potatoes during storage. This will help reduce the decomposition rate.

Drainage

One consideration not taken when creating the requirements was drainage. When specifying requirements, the assumption was that the structure would be above ground, thus drainage would not be an issue. For the final cellar-like design, drainage needed to be considered for various reasons. First, water runoff from rain above the structure could leak in. Second, if the water is not drained properly, it may cause a substantial softening of the soil, resulting in ground shifts. This can place unintended shear forces on the design. To enhance water drainage and prevent these problems, two design features were added. First, the structure would be built at a slight slant in the same direction as the hill. The Green Roof and ground would guide water down the hill. Figure 12 shows a picture of how a green roof would be used for the structure.



Figure 12: Green Roof example on a residential home

Second, French Drains are to be implemented. The French Drain would be built of PVC pipe and have holes throughout the length of it. Ditches would be dug underground for the PVC pipes. Then, the pipes would be placed at an angle in the ditches and surrounded by gravel. The gravel would allow water to seep into pipes, then the pipes would run the water outside the structure. The gravel also prevents the soil and other debris from clogging the holes in the PVC pipe. Understanding the lack of quality of materials, it was assumed that, even with perfect construction, water leakage during rain would be inevitable. Thus, the French Drains were designed within the storage structure. This was done because the pipes would clear out water flowing around the outside of the structure but also any water which leaked into the structure. Figure 13 shows an example of a French Drain.

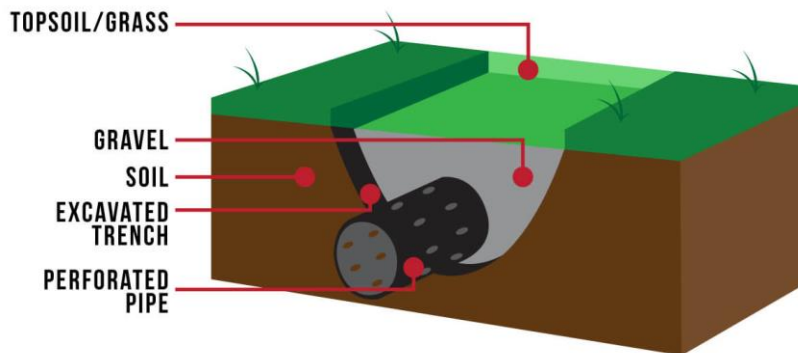


Figure 13: Example of French Drain

Materials

The final design will include the following materials: wood, tin, black tarp, PVC, nails, and gravel. The local farmers would use wood for the walls and the overall structure of the facility including interior shelving and pallets. Tin was incorporated for the roof. It was determined that a C-tarp would be used in between the soil and structure to prevent water damage and pest infestation. From the trip to Lake Bunyoni, the team realized that the local structures used PVC pipes for their systems. This validated the feasibility of the PVC pipes for the Solar Chimneys, passive cooling system, and French Drain. Due to cost restrictions, nails would be used instead of screws. The gravel will be used to filter the water into the French drain. All materials were considered relatively inexpensive by GLI staff and approved for usage. A cost breakdown of each material and how much is necessary for a build is included in Appendix F.

TESTING SUMMARY

Due to the nature of this senior design project, a prototype or finished model was never constructed. Instead of testing, various calculations were performed to prove the validity of the design. Calculations were performed for structural forces and all non-proven concepts. Various assumptions were justified.

Solar Chimney Calculations

Calculations are shown in Appendix D. There were various assumptions made for the calculation of the Solar Chimney's effectiveness. First, it was assumed that the temperature inside the entirety of the Solar Chimney was the same and that the temperature of the environment was constant. These were fair assumptions to make because the diameter of the tube was relatively small compared to the length, thus temperature gradients within the cross-section of the tubes could be neglected. Furthermore, changes in density with relation to pressure were neglected because they had a much lower relative effect compared to changes in temperature. A temperature difference of 2°C from the inside of the pipe to the outside was used. This was assumed as a conservative estimate if the pipes were to be painted black. A value of .5 was used for the minor energy loss coefficient from the inlet pipes. This resulted in an exit air velocity of $.0508 \frac{m^3}{s}$. This means that all the air within the structure would fully ventilate in 10 minutes and 29 seconds. This was considered a short enough time for a full ventilation cycle. In addition, even lower

temperatures differences between the Solar Chimney and the environment would result in acceptable ventilation cycles.

Green Roof Load Calculations

Calculations in Appendix E were performed to ensure that the structure would not collapse from the weight of the Green Roof and miscellaneous forces. It is important to note that Euler–Bernoulli Beam Theory assumptions were made. First, a distributed load for each beam was calculated. The density of dirt, gravel, and water were taken and used to determine the applied force per meter for each beam. It resulted $3188 \frac{N}{m}$. A simple beam calculation was completed to determine the max normal stress applied to a fixed end beam. This calculation shows max normal bending stress of 28.7 MPa, well within the max tensile bending stress of the Eucalyptus wood. Its max tensile strength is 50.3 MPa and resulted in a factor of safety of 1.75. Next, more accurate calculations were performed. These calculations assumed that the beam was simply attached at both ends and was treated as a composite beam. This beam accounted for the thin tin sheet above it but was treated as a flat plate. This would result in a conservative estimate because the actual tin sheet used was corrugated, which would be stronger than a flat thin sheet. Also, the load applied to the beam was updated. On top of the distributed load, a point load from a 70 kg mass was placed in the middle of the beam to replicate a man stepping in the middle of the structure. This was taken as a safety measure. It resulted in a max bending stress of 21.9 MPa for the wooden beam and 172.3 MPa for the tin sheet. This resulted in factors of safety of 2.3 for the wooden beam and 1.3 for the tin sheet. Thus, it was determined that the number of beams used with tin roofing was substantial for the design. Yet, it would be recommended that clear markings were made to prevent people and farm animals from excessively stepping on the roof of the design.

Surcharge Loading Calculations

Surcharge loading is the calculations that soil has on a structure that below the earth's surface. Using the lowest yield strength of eucalyptus and the max soil density in calculations found in Appendix E, the max load that the soil could apply to any of the 2in x 6in x 10ft beams at the base of the structure was 12.6 MPa at a depth of 10ft into the ground, and a board of eucalyptus can withstand a load of 44.8 MPa in a side loading scenario. The factor of safety for the beams in side loading is 3.5. With most structures aiming for a factor of safety of 1.5, the building strengths exceed the minimum for a safe structure, and do not need extra reinforcement at the base.

Anchoring

After creating a final design that lays partially underground, certain new problems needed to be considered. One of these issues was whether the design needed to be anchored. Anchoring is essential for many inground and above-ground structures. Anchoring is used to prevent the movement of a structure due to the natural land shifts. In terms of cellar-like structures, land shifts can push structures out of the ground and cause flooring/wall damage. These factors were considered. It was determined that for the final design, anchoring was not necessary. This was determined from comparisons to various anchoring articles construction guides. The final design can withstand buoyant and hydrostatic forces because it has a heavy Green Roof to counter any upward forces from soil movement. In addition, about only half the structure is dug into the ground, thus the force from the soil movement will not be as great as for normal cellar designs. It is important to note that the rest of the design is covered in dirt that doesn't apply the same forces as the soil that is part of the hillside. Lastly, since the final design doesn't have proper flooring or

walling, land movement won't create cracks as in typical cellar designs. The cage-like design, constructed of slightly bendable wood, will be able to shift with slight land movements.

Conclusion

Summary

The UCCS team created a design for a food storage facility to be located on a model farm in Uganda, Africa. The storage facility will be built inside of a dug-out hill on the model farm. The need for a cool, dry place to store crops in the heat and humidity of Uganda sparked the idea for a food storage facility within a hill. The walls will be made of wood and the roof will be made of tin sheets with a black tarp in between the walls and the dirt to keep the soil and moisture out of the facility. There will be a French drain beneath the facility to help the rainwater drain out. A solar chimney will be located on the roof to keep the ventilation regulated. A gap will be left for the potential of adding a door if the individual farmers choose to do so. Inside the facility, pallets will be placed on the ground for the storage of sacks of potato and a table will be placed three feet off the ground for the storage of individual potatoes.

The requirements given to the team by the GLI sponsor was to create a food storage facility large enough to contain enough sacks of potatoes for farmers, be cost-effective, use only locally sourced materials, local labor, environment control, and contain low energy lighting. As can be determined by the description of the design, all the requirements were met. The storage facility the team designed is large enough to hold several sacks of potatoes as well as have the capability to hold loose potatoes. The cost required to build the full food storage facility is \$112.59USD. The materials used to design the food storage facility can be found locally and the labor required is solely manual labor with no heavy machinery necessary. The food storage facility uses a solar chimney to regulate the ventilation and a French drain is used to assure that there is no water build-up when it rains, these criteria meet the environmental control requirement. The final requirement, that the storage facility will contain low energy lighting, is met by not including any external lighting and using the door opening as the main source of lighting.

Possible improvements

The design was created with the local farmers in mind. Some possible improvements can be made depending on the local farmers and what they would like to include in their food storage facilities. The following improvements are also recommended for the Entusi Resort because they have the extra funds and would possibly want more protection for their crops.

The first improvement the team decided would be to implement a door. The initial design did not include a door because it would increase cost for the local farmers. A door is a simple addition that would provide more protection such as limited lighting, protection from wildlife, and excess moisture.

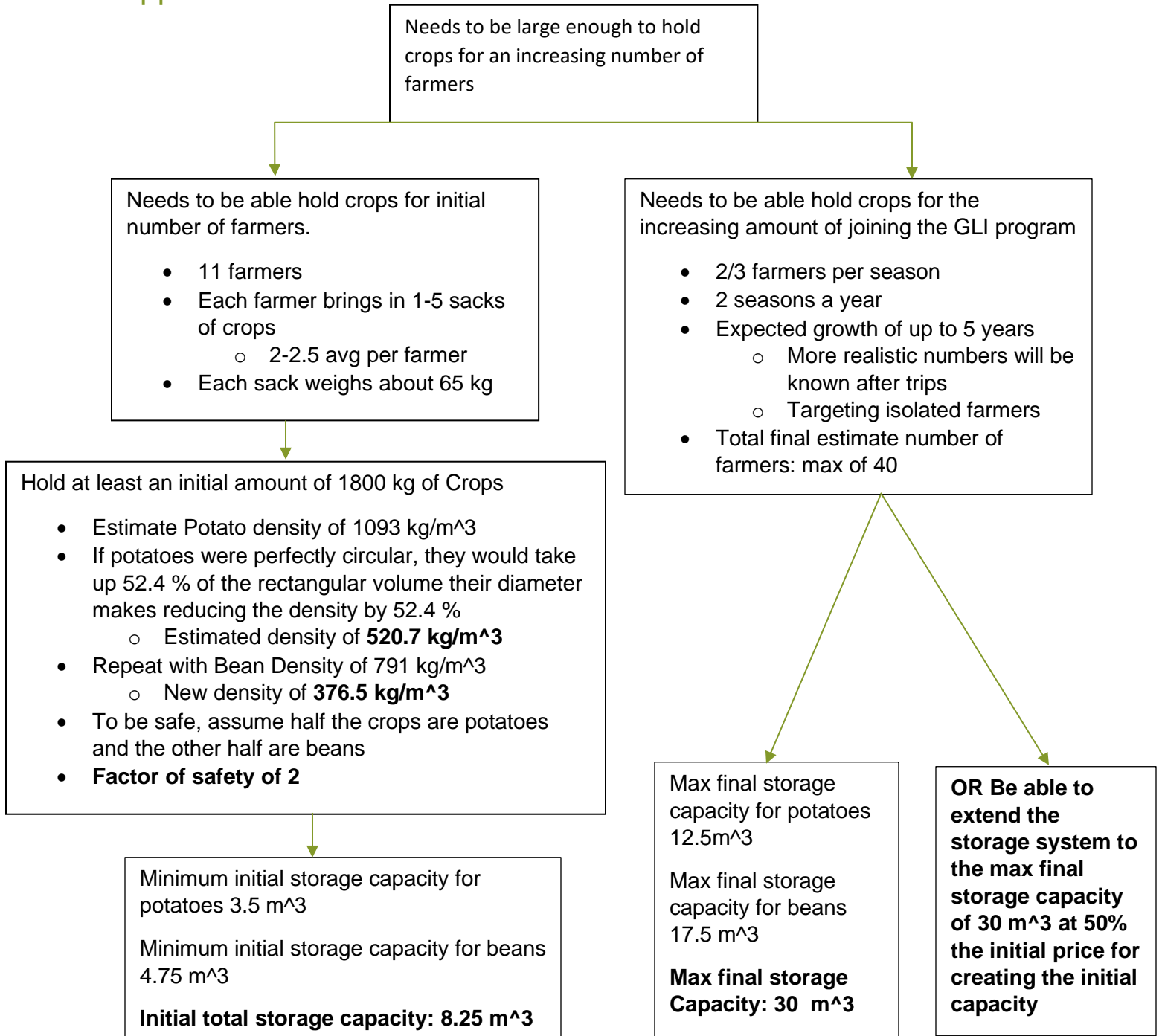
The next improvement is to create the walls of the food storage facility out of concrete or cement. This will allow for better ventilation and cooling inside the food storage facility. The addition of cement for the walls of the food storage facility would add a large amount of costing and may not be doable for the local farmers.

The final improvement that was considered was to create a bigger opening in the hill to allow the food storage facility to be placed as deep as possible. The idea would be to have the storage

facility completely submerged into the hill. This would allow for maximum cooling as the sun would not be hitting any of the walls and would only come in through the door opening.

Appendix

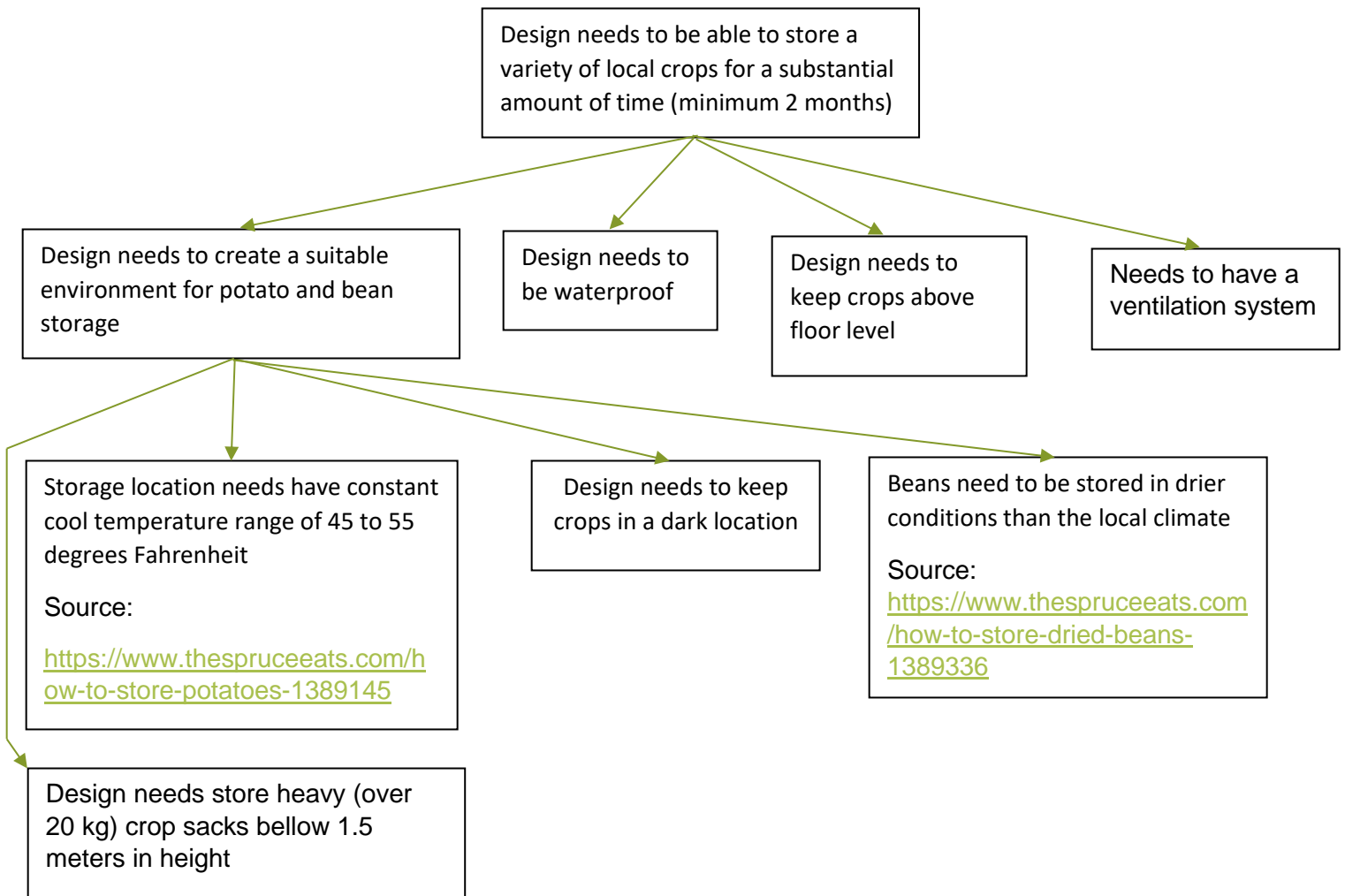
Appendix A



Appendix B

Various calculations were completed to estimate the space the crops would take up. First, it was assumed that each farmer would bring an average of 2.5 sacks of crops with each sack weighing 65 kilograms. Thus, the initial weight capacity and final weight capacity for the crops was predicted to be 1800 kg and 6500 kg respectively. After discussing with the sponsors and completing further research, it was assumed that half of the crops would be Irish potatoes and other half would be beans. It was assumed that the density of Irish potatoes is 1093 kg/m^3 and the density of beans are 791 kg/m^3 . Next, it was assumed that the beans and potatoes were perfectly spherical. Next, it was calculated that the spherical crop would take up 52.4% of the space in a cube with side lengths equal to that of the diameter of the sphere. Thus, the density of the potatoes and beans were reduced to 520.7 kg/m^3 and 376.5 kg/m^3 . These densities and the weight of the expected potatoes and beans were used to calculate the volume which the crops are expected to take up. Then, a safety factor of 2 was applied to take error and extra space into account.

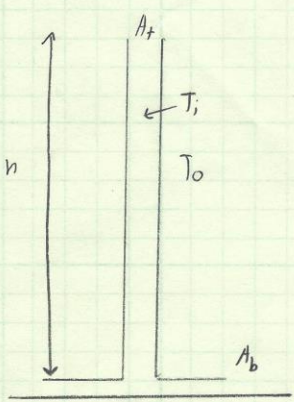
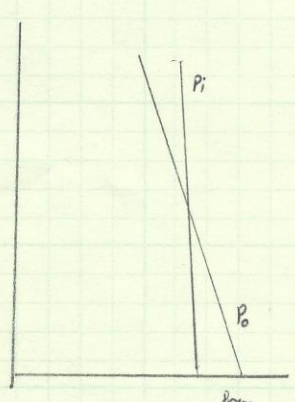
Appendix C



Appendix D

Solar chimney calculations

Solar chimney calculation

hydrostatic equilibrium eqn $\frac{dp}{dz} = -\rho g$

assume T_i and T_o are constant through their respective regions $\Delta p_o = \rho_o g h$
 $\Delta p_i = \rho_i g h \Rightarrow$ ignore Δp

$\Delta p_o = (\rho_o - \rho_i) g h = \rho_i g h \left(\frac{T_i - T_o}{T_o} \right)$

$u_2 = \frac{u_1 A_1}{A_2}$

Bernoulli's eqn: $\Delta p = \frac{1}{2}(\rho u_2^2 - \rho u_1^2) \approx \frac{1}{2} \rho u_2^2$

$\rho_i g h \left(\frac{T_i - T_o}{T_o} \right) = \frac{1}{2} \rho u_2^2 \rightarrow$ assume inlet $u_1 \ll u_2$

$\left[2 g h \left(\frac{T_i - T_o}{T_o} \right) \right]^{1/2} = u_2$ (estimation)

$.5 \rightarrow V_L \left[2 \cdot (1 \text{ m}) (9.81 \text{ m/s}^2) \left(\frac{296}{21+273.15 \text{ K}} \right) \right]^{1/2} = u_2 \quad T_o \text{ avg} = 21.1^\circ \text{C}$
Solar standard tube inlet

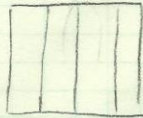
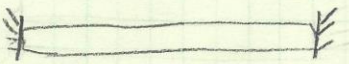
$u_2 = 8.09 \text{ m/s} \rightarrow 2 \text{ inlets, } 4 \text{ inch diameter } \sim 10 \text{ cm}$
.2m

$u \cdot A = \dot{V}$
 $2 \times (8.09 \text{ m/s}) \cdot (\pi \cdot (0.2 \text{ m})^2) = 0.508 \text{ m}^3/\text{s} = \dot{V}$

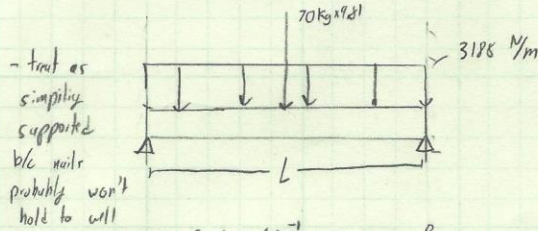
$V = \frac{2 \text{ m} \times 8 \text{ m}}{4 \text{ m}} \cdot \frac{V}{\dot{V}} = \text{time to cycle around} \rightarrow \frac{32 \text{ m}^3}{0.508 \text{ m}^3/\text{s}} = 629.6 \text{ s} = 10 \text{ min } 29 \text{ sec}$
w/ 2°C distance

Appendix E

Beam loading calculations

Design Specs	Beam Theory: Roof Ceiling Analysis
<p>Force estimation:</p> <p>10st x 10st area (3m x 3m) → 5 supports</p>  <p>→ Curr/hold 2x10st as weight as a even dist load → ignore strength of metal sheet → thus ignore its weight factor</p>	
<p>→ 2st x 10st x 6 in gravel → 2st x 10st x 6 in dirt</p>	<p>treader. - beam with fixed ends</p> 
<p>apply distributed load:</p>	<p>point load:</p>
<p>Max normal stress: $\frac{wl^4}{384EI}$ → at center</p>	<p>max normal stress: $\frac{Pl^3}{192EI}$</p>
<p>$E = 10,000 \text{ MPa}$ Given based off other woods</p>	
<p>square $I = \frac{w^4}{12} = \frac{(.1 \text{ m})^4}{12} = 8.3 \times 10^{-6}$</p>	
<p>$w = A \cdot \rho = 2st \times 6in \sim .60m \times .15m$ $\rho_{gravel} = 1346 \frac{kg}{m^3}$ $\rho_{soil} = 2000 \frac{kg}{m^3}$ $\rho_{water} = 1000 \frac{kg}{m^3} \rightarrow .60m \times .04m$</p>	<p>$w = (121.14 \frac{kg}{m} + 24.0 \frac{kg}{m} + 180 \frac{kg}{m})$ $w = 3188.25 \frac{N}{m}$</p>
<p>$\Delta_{max} = \frac{3188.25 \frac{N}{m} (3m)^4}{384 (10,000 \times 10^6 Pa) (8.3 \times 10^{-6} m^4)}$ $\times .99 \frac{1}{m^2}$ $(9.81 \frac{m}{s^2}) (1000 \frac{kg}{m^3})$</p>	<p>$= .0081 m$</p>
<p>$\sigma_{max} = \frac{Mc}{I} = \frac{(wl^2)}{12} \cdot \frac{w}{12}$</p>	<p>$= \frac{wl^2}{w^2} = \frac{3188.25 \frac{N}{m} (3m)^2}{(.2m)^3} = 28.69 \text{ MPa} = \sigma_{normal max} \text{ (Bending)}$</p> <p>→ Joint the wood, no weight from person, handle handling → water → stone → dirt</p>

take load of standing person into account as well...



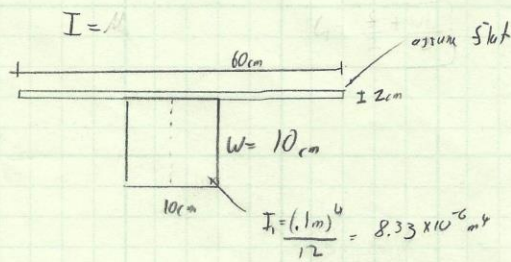
BC: $\left. \begin{array}{l} V/2 \\ W(0) = 0 \\ M(0) = 0 \end{array} \right\}$

$$W(x) = -S \left\langle x - \frac{L}{2} \right\rangle^{-1} + -w \langle x \rangle^0$$

$$V(x) = -S \left\langle x - \frac{L}{2} \right\rangle^0 - w \langle x \rangle^1 + C_1 \quad C_1 = \frac{S}{2}$$

$$M(x) = -S \left\langle x - \frac{L}{2} \right\rangle^1 - \frac{w}{2} \langle x \rangle^2 + \frac{S}{2} x + C_2^0$$

$$M_{max} \text{ at } x = \frac{L}{2} = \frac{w(L)^2}{8} + \frac{S L^2}{4} = M_{max}$$



→ run with factors of safety, we're good
→ steel assumption may be a little snobby, but it is good run with smaller values

$$I_2 = \frac{bh^3}{12} = \frac{.6 \text{ m} (0.01 \text{ m})^3}{12} = 5 \times 10^{-9} \text{ m}^4$$

$$\bar{Z}_1 = .05 \text{ m} = .05 \text{ m}$$

$$\bar{Z}_2 = .4005 \text{ m}$$

$$E_1 = 10,000 \text{ MPa}$$

$$A_1 = (1 \text{ m})^2 = .01 \text{ m}^2$$

$$A_2 = (.002 \text{ m} \times .6 \text{ m}) = 6 \times 10^{-9} \text{ m}^2$$

$$E_2 = 90 \text{ GPa}$$

steel iron

← okay estimate

considering steel is thicker than what was used for calculations

$$Z_{na} = \frac{\bar{Z}_1 (A_1) (E_1) + \bar{Z}_2 (A_2) (E_2)}{A_1 E_1 + A_2 E_2}$$

$$Z_{na} = .06074 \text{ m}$$

$$I_1' = I_1 + A_1 (Z_1 - Z_{na})^2 = 8.33 \times 10^{-6} \text{ m}^4 + (.01 \text{ m}^2) (.05 - .06074 \text{ m})^2 = 9.483 \times 10^{-6} \text{ m}^4$$

$$I_2' = I_2 + A_2 (Z_2 - Z_{na})^2 = 5 \times 10^{-9} \text{ m}^4 + (6006 \text{ m}^2) (.4005 - .06074 \text{ m})^2 = 9.461 \times 10^{-7} \text{ m}^4$$

$$\sigma_{max \text{ Brading wood}} = \frac{M L_1}{I_1} = \frac{\left[\frac{3186 \text{ N/m} (3 \text{ m})^2}{8} + \frac{6867 \text{ N} (3 \text{ m})}{4} \right] (.04926 \text{ m})}{I_1} = 21.29 \text{ MPa}$$

$$\sigma_{max \text{ steel}} = \frac{M L_2}{I_2} = \frac{\left[\dots \right] (.03976 \text{ m})}{I_2} = 1.7277 \text{ MPa}$$

$$\sigma_z = k_s \gamma z$$

k_s → coefficient of soil pressure
 γ → specific weight of soil mass
 z → depth

$$\gamma_1 = 71 \text{ lb/ft}^3$$

$$\gamma_2 = 156 \text{ lb/ft}^3$$

$$\sigma_z = 71 \text{ lb/ft}^2 (10 \text{ ft})$$

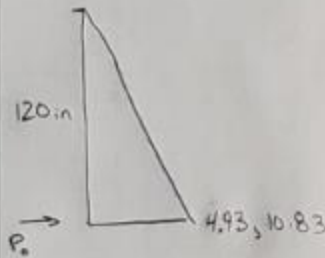
$$= 710 \text{ lb/ft}^2 = 4.93 \text{ psi}$$

$k_s = 1$ (worst case scenario)

$$\sigma_z = 156 \text{ lb/ft}^2 (10 \text{ ft})$$

$$= 1560 \text{ lb/ft}^2 = 10.83$$

$$\frac{1}{\text{ft}^2} \frac{\text{lb}^2}{144 \text{ in}^2} \quad \frac{\text{lb}}{\text{ft}} \cdot \frac{1 \text{ ft}}{12 \text{ in}}$$



$$P_{0,1} = \frac{1}{2} (120 \text{ in}) (4.93 \text{ lb/in}^2)$$

$$= 295.8 \text{ lb/in} \rightarrow \text{Minimum Pressure @ 10ft}$$

$$P_{0,2} = \frac{1}{2} (120 \text{ in}) (10.83 \text{ lb/in}^2)$$

$$= 649.8 \text{ lb/in} \rightarrow \text{Max pressure @ 10ft}$$

$$E_c = 1.85 \times 10^6 \text{ psi} \quad \sigma = 6500 \text{ psi}$$

$$I = \frac{1}{2} (3)(4^3) = 16 \text{ in}^4$$

$$\sigma = \frac{mY}{I} \quad \frac{1.5 \text{ in}}{16 \text{ in}^4}$$

$$m = \frac{PL}{4} = \frac{649.8 \text{ lb/in} (120 \text{ in})}{4} = 19494 \text{ lb}$$

$$\sigma = \frac{19494 (1.5 \text{ in})}{16} = 1827.6 \text{ psi}$$

$$F.S. = \frac{\sigma_{allow}}{\sigma_{max}} = \frac{6500}{1827.6} = 3.56$$

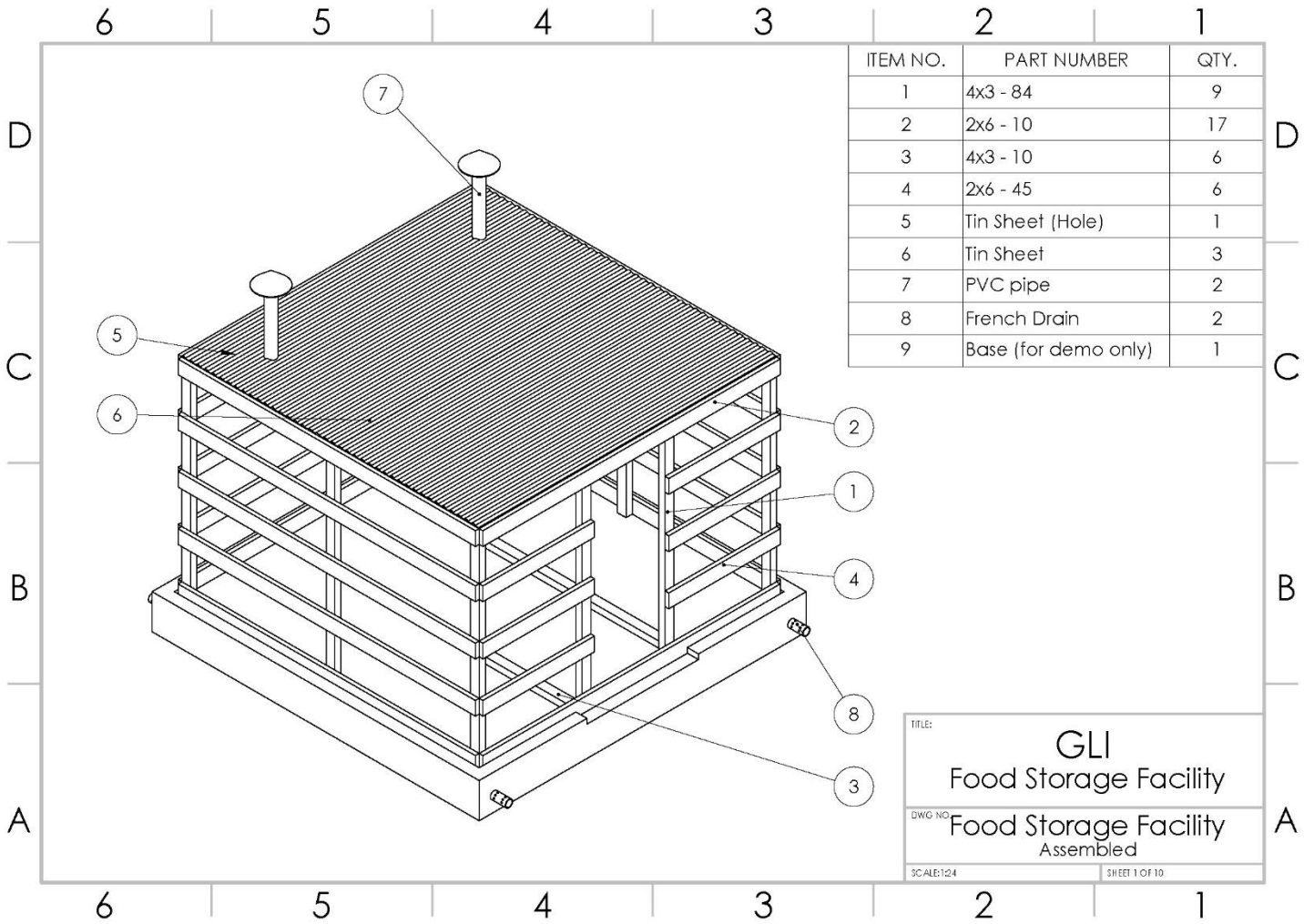
With a max load @ 10ft, and the weakest elements, and no extra support, the 10ft section will not fail under standard earth pressures

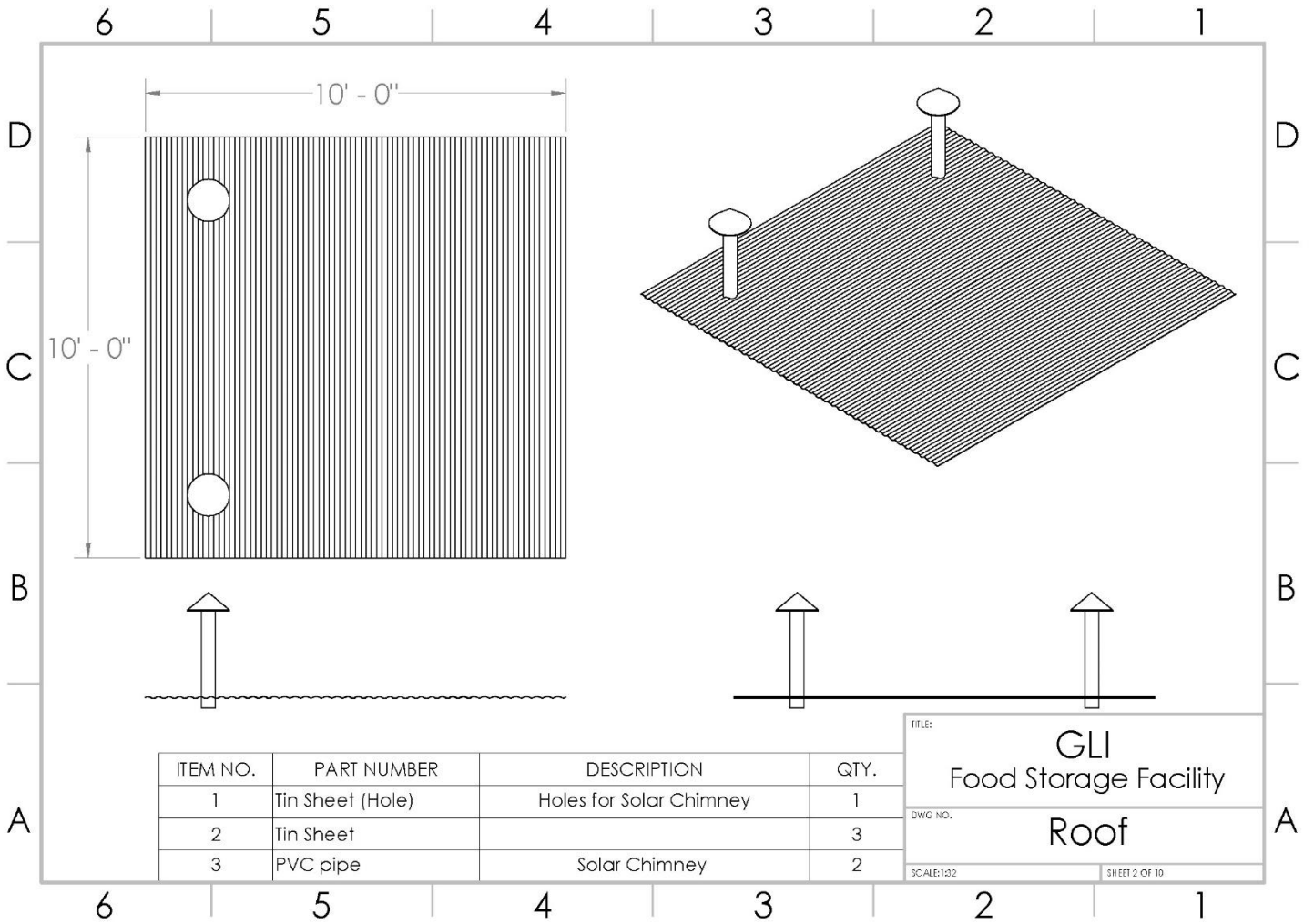
Appendix F Costing

Entusi Materials List						
Item	Size	Cost	Per	Quantity	Total	Comments
PVC Pipe	4" d	35,000.00	Pipe	1	\$ 35,000	Sized the largest pipe possible, cost would likely decrease for smaller diameter sections
PVC Connectors	4" d	8,000.00	Connector	4	\$ 32,000	
Tin Sheets	10ft x 3ft	25,000.00	Sheet	4	\$ 100,000	
Black Plastic	1m x L	2,000.00	meter	38	\$ 76,000	Commonly used in gardening, or use for a water resistant layer
Stain/Water Treatment		40,000.00	Gallon		\$ -	Stain was a bit too expensive, was informed that a likely substitute would likely be oil
Nails		4,500.00	Kg	4	\$ 18,000	
Screws	(Gold)	1.5 in	500.00	Each	\$ -	High quality screws
	(Gold)	2 in	500.00	Each	\$ -	Length did not change the price of screws, just the type of screw
	(Black)	1.5 in	300.00	Each	\$ -	Basic wood screws
Hinges	(Raw)	Tall	3,000.00	Pair	\$ -	Approx. 3" tall
		Mid	2,000.00	Pair	1 \$ 2,000	Approx. 2" tall
Wood	10ft	2 x 6	4,400.00	Board	20 \$ 88,000	The prices shown is what the lumber yard in Kabale City has priced
	10ft	4 x 3	4,400.00	Board	15 \$ 66,000	The villages would source the wood directly, decreasing the overall cost
	10ft	2 x 4	3,200.00	Board	\$ -	
					Total Cost	\$ 417,000 UGX
						\$ 112.59 USD
Tools Needed						
Hammer						
Shovel						
Saw						
Screwdriver/drill						
Shears						

Appendix G

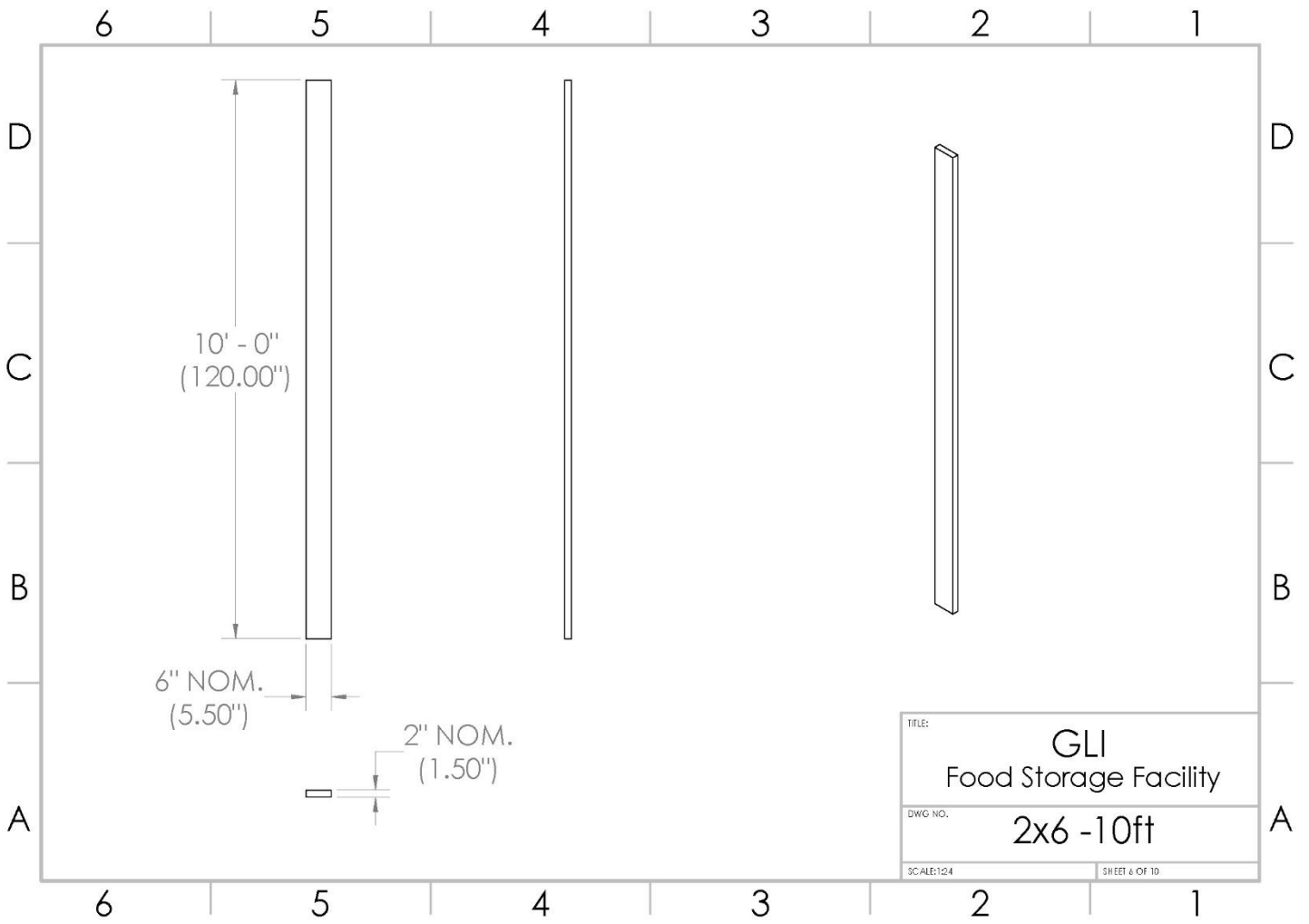
Solid Works Documents –Final Drawing & Bill of Materials

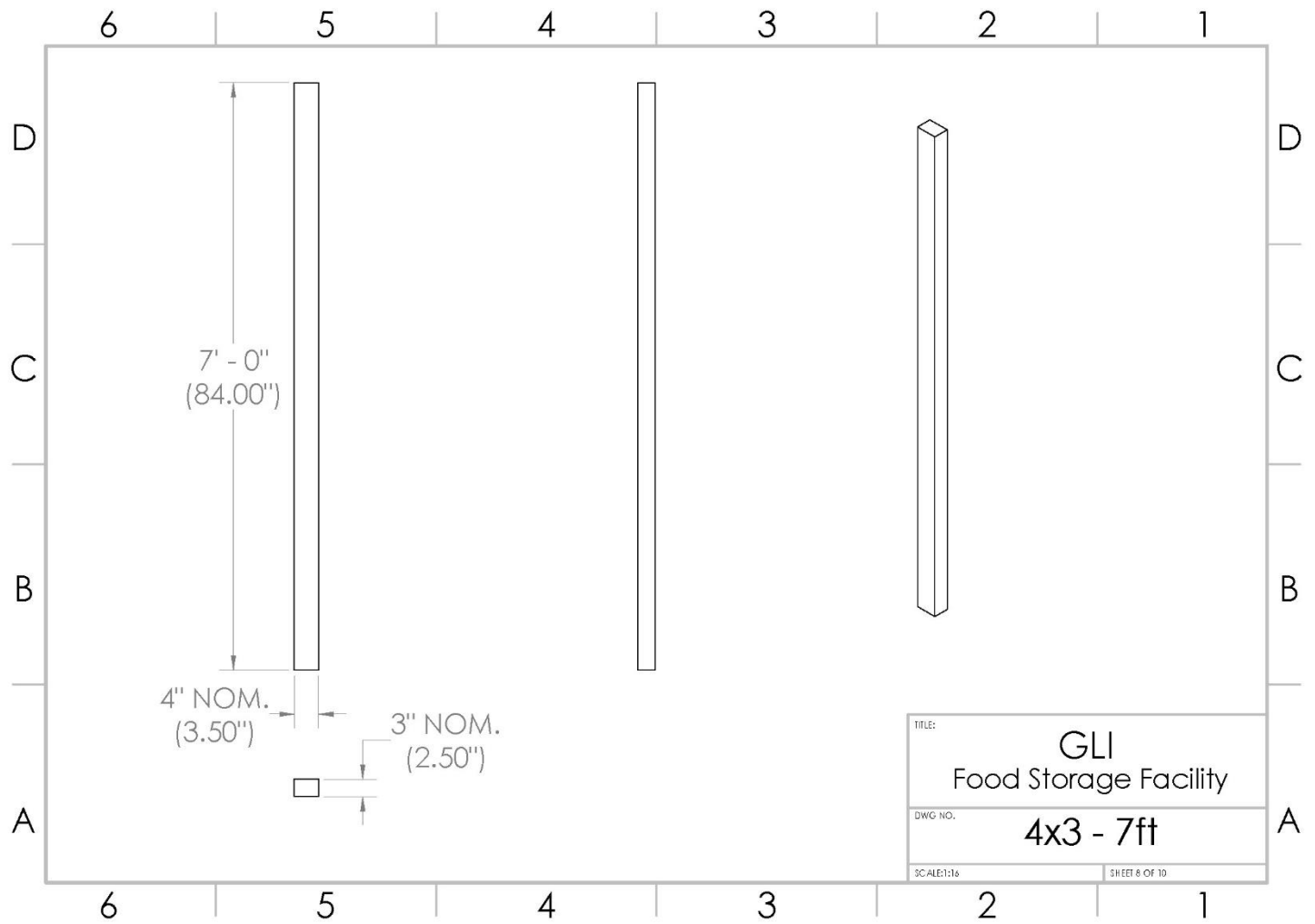


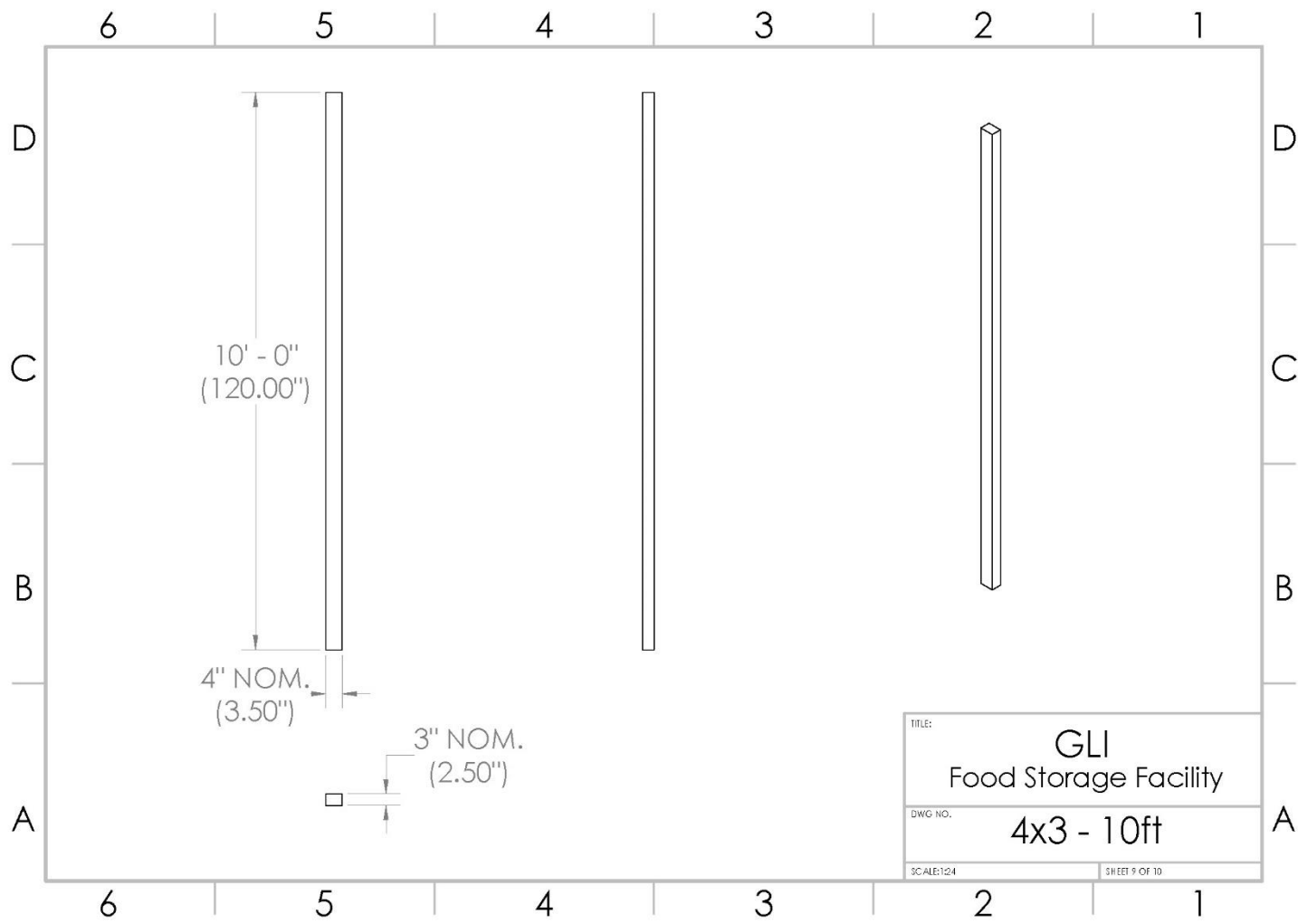


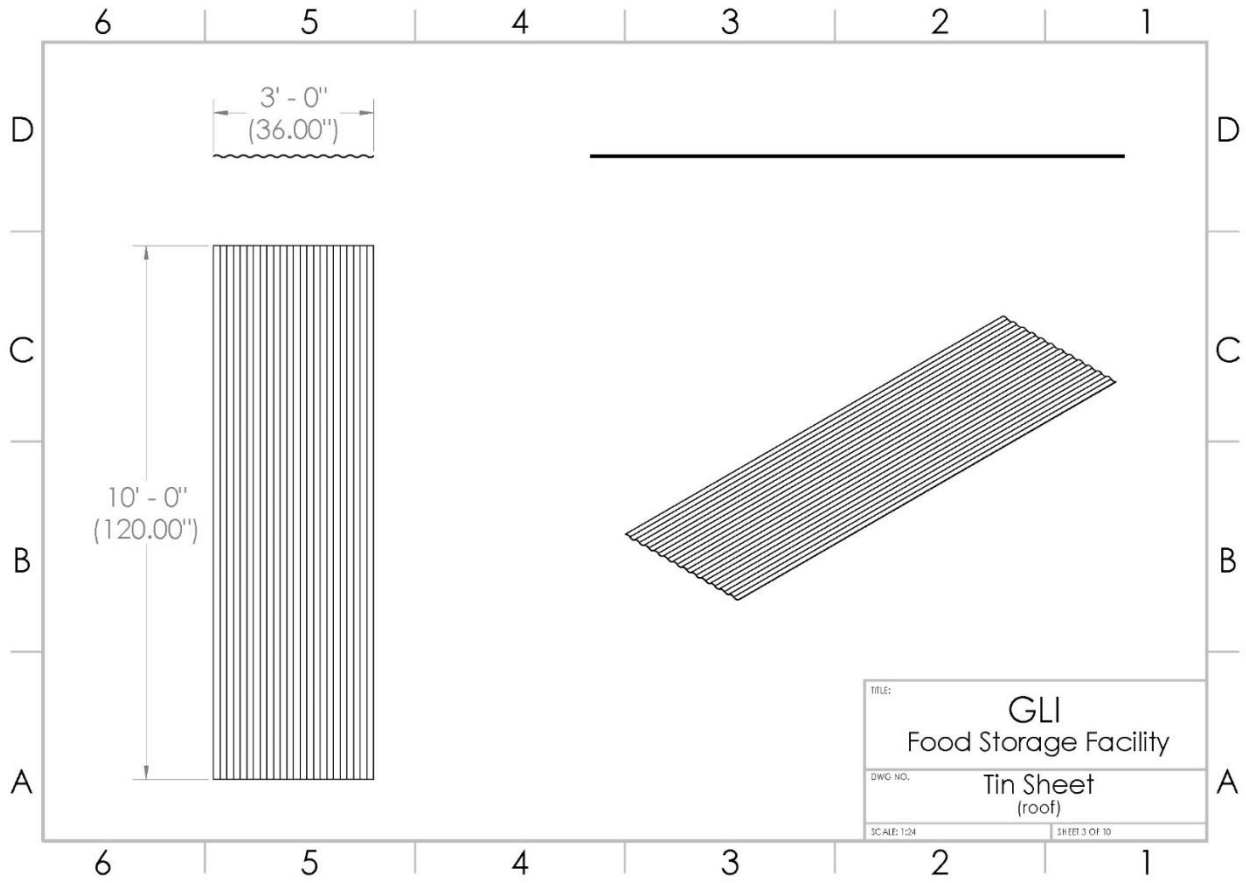
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Tin Sheet (Hole)	Holes for Solar Chimney	1
2	Tin Sheet		3
3	PVC pipe	Solar Chimney	2

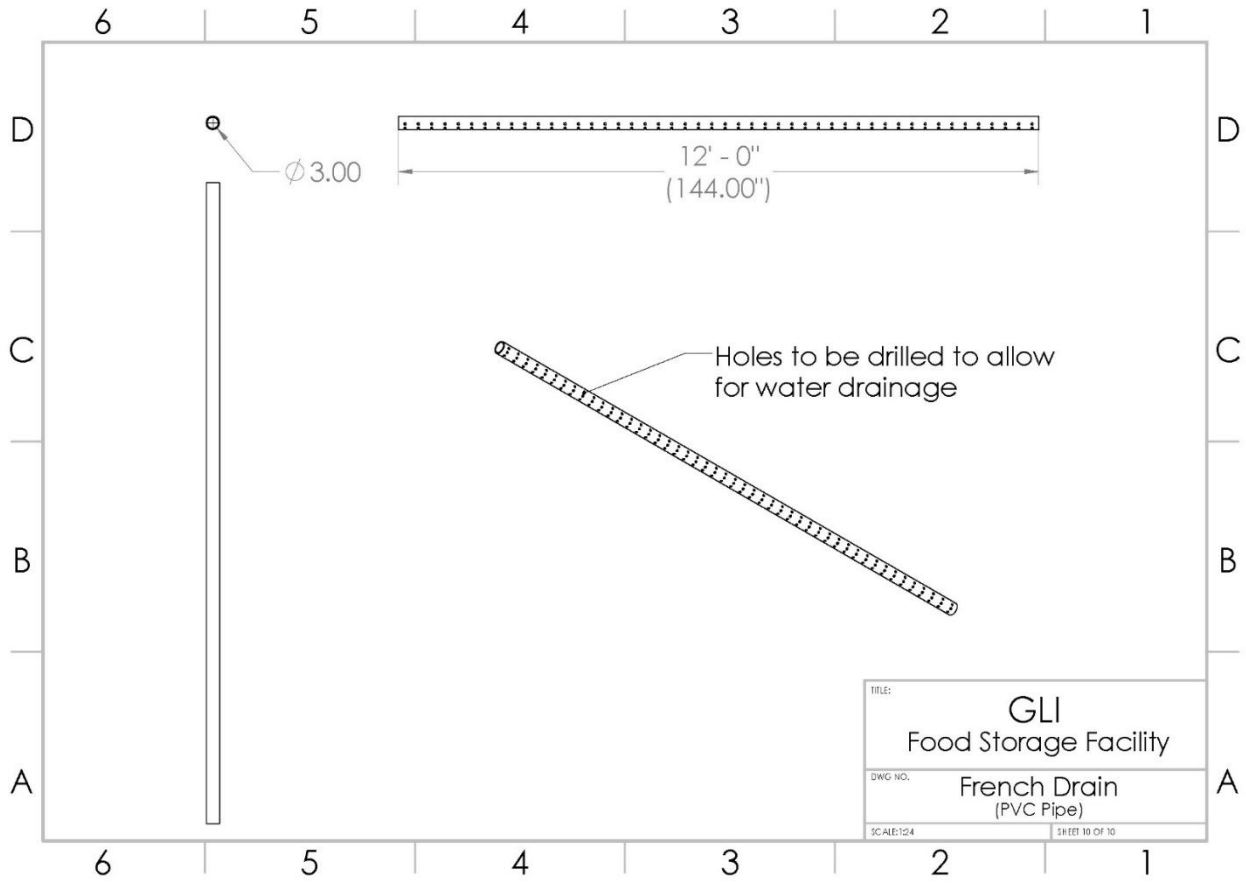
TITLE:	GLI Food Storage Facility
DWG NO.:	Roof
SCALE:	1/32
SHEET:	2 OF 10

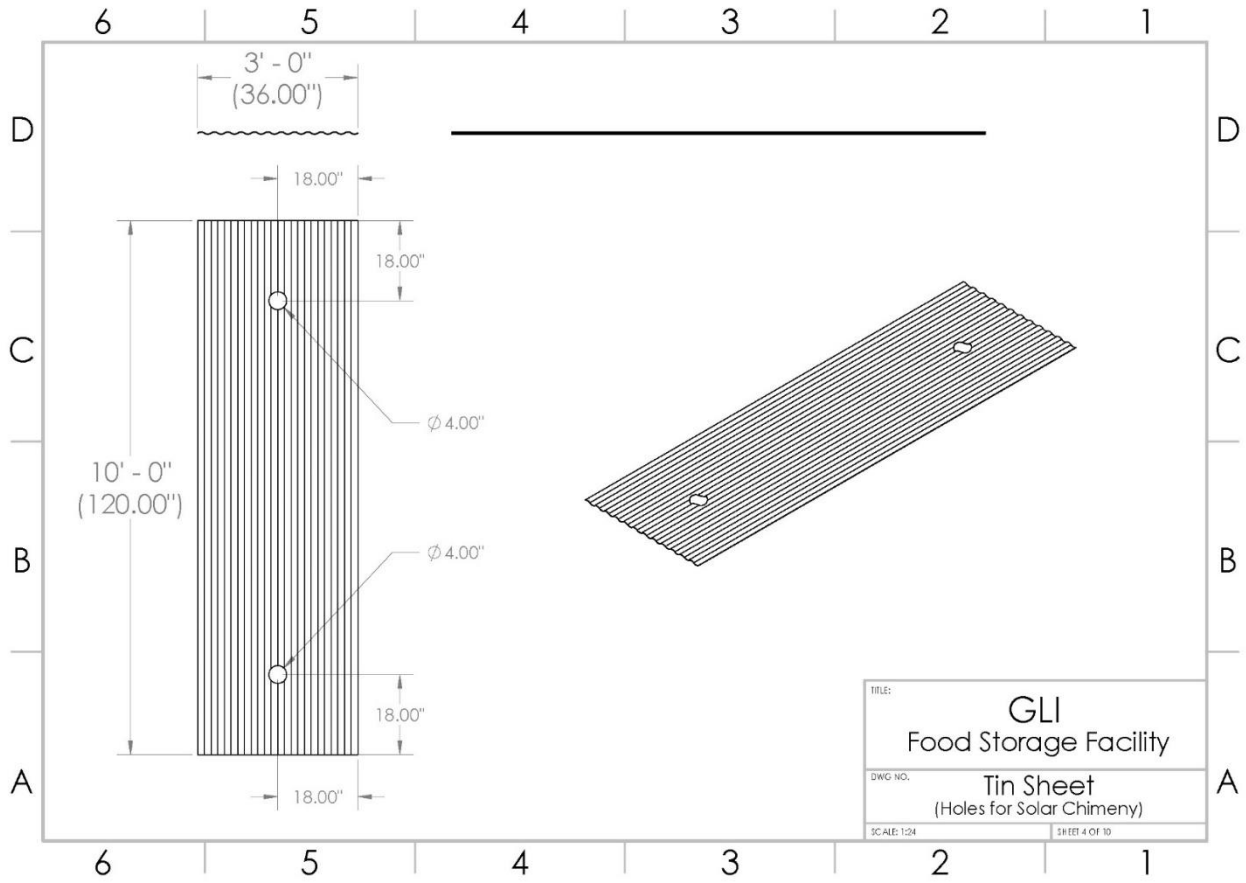


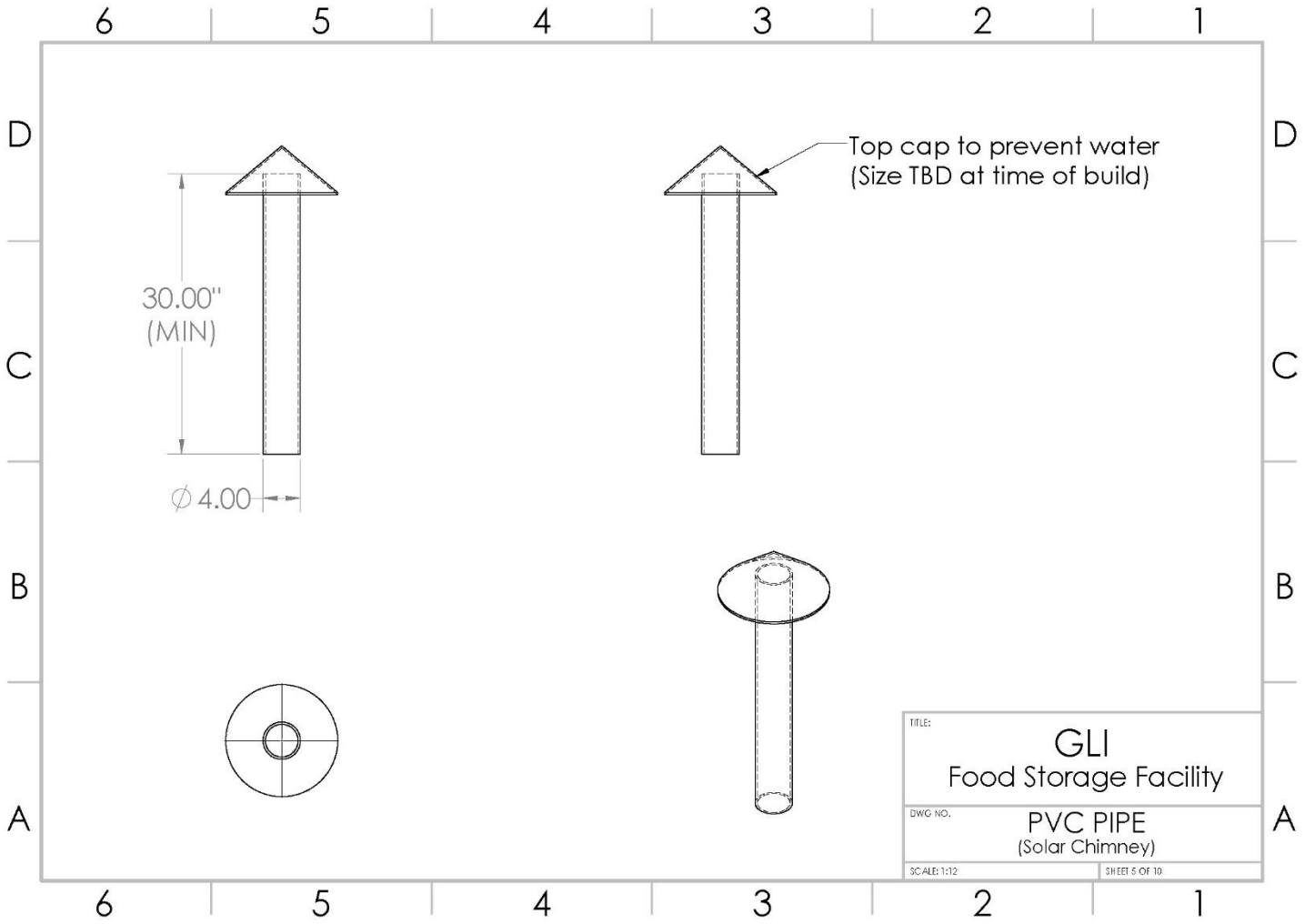












Appendix H

User Guide

Tools: Hammer, Shovel, Nails, Saw, Scissors, Wheel Barrel, Hoe, Spade, string line

Location

- Ridge behind the current tomato bed. There is a possibility that the tomato bed should be relocated further down the ridge
- For general purposes, the design should be built on the steepest accessible space, at least 20 feet above the lake water level
 - Find the location of the base of the door of the structure, then follow the ground/steep land up 3.5-4 vertical feet (or half the height of the structure)
 - Then begin measuring area of storage location using the point marked above. That will be the front face of the +-design

Digging

Step 1: Determine and obtain the necessary tool needed for the task

- Strings or measuring lines, stakes, shovel, spade, Hoe

Step 2: String your line and pound the stakes based on the dimensions specified

- The location where the design is to be implemented needs to be two feet larger in both length and width
 - If the building is 10 ft to 10 ft, then a 12 ft by 12 ft hole needs to be dug
- Insert picture

Step 3: Carve out an outline of the area for digging



Step 4: Loosen earth with a shovel

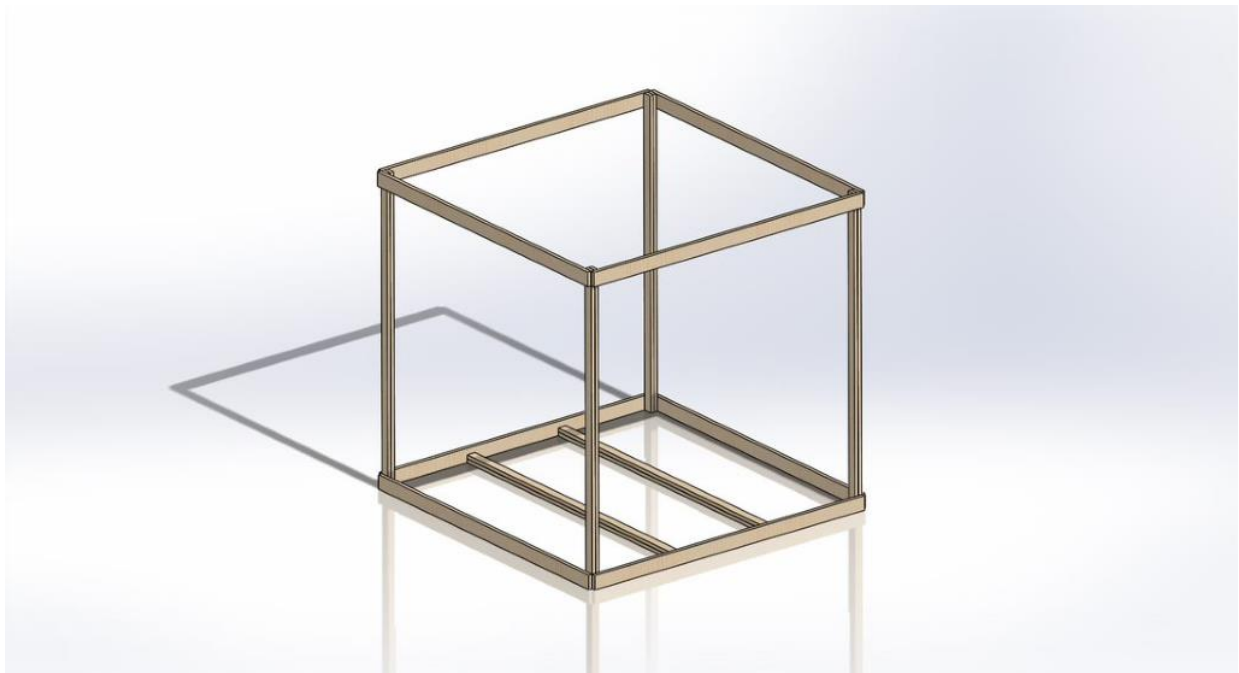
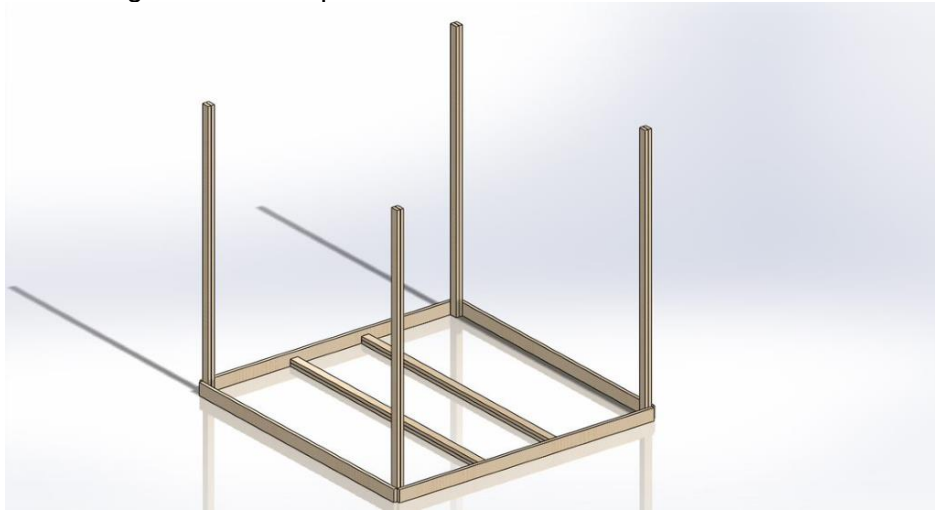
Step 5: Dig from the designated top of the hill downwards

Step 6: Compact the ground using tools at hand (i.e. shovels, spade)

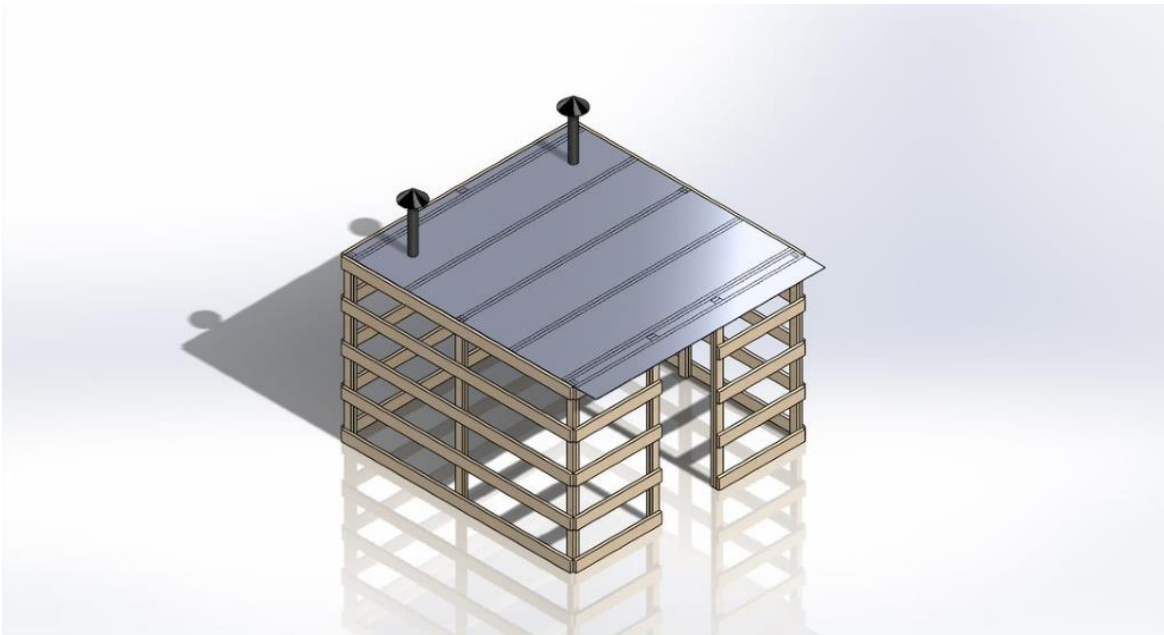
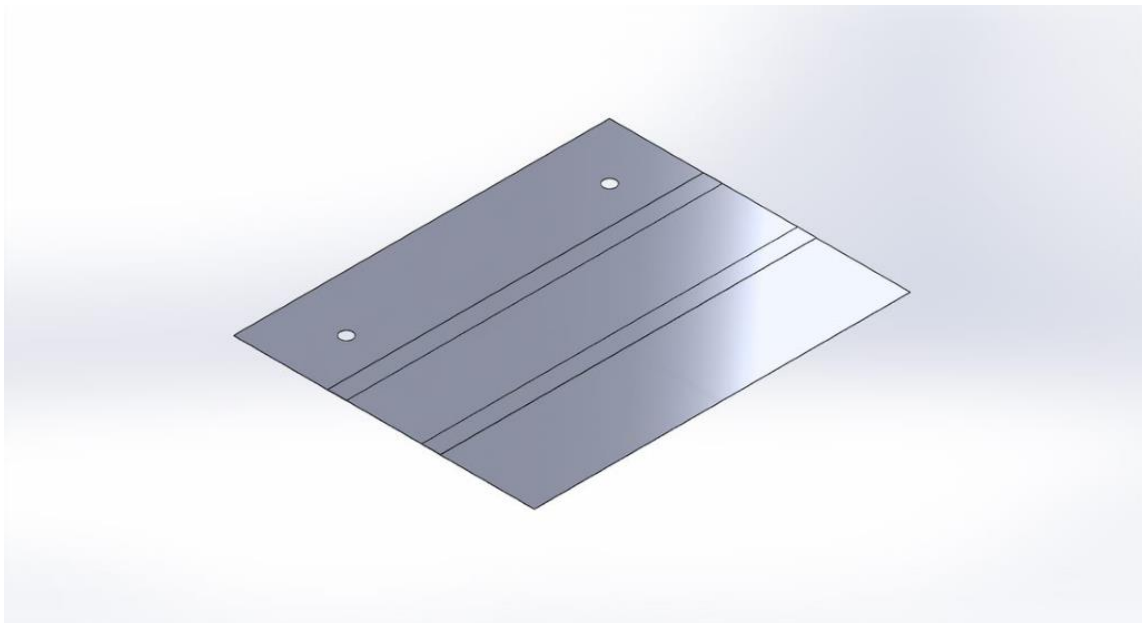
Building

- Build the base of the structure in with the desired dimensions of length and width, i.e. 10ft x 10ft with the 9 pillars
 - Make sure there is a minimum of 6in between the sides of the walls on the hole that has been dug to ensure the ability to build up

-
- The structure is perfectly sound to sit on top of the dug floor, therefore there is no need to dig holes for the pillars



- Attach side walls(2x6) approximately 14” apart from the bottom up. Required fasteners are nails
- Tin sheets will be used for the roof
 - On the sheet that will be used in the back of the building, two holes will need to be cut, that are spaced approximately 6ft apart from each other.
 - Tin snips will be used to cut the holes



- The tin sheets will be attached using 4x3 lumber that will be the length of the building
 - There needs to be 5, 4x3s spaced evenly across to be support for the tin sheeting.
 - Make sure the holes cut from the previous step do not overlap onto the support members
 - The tin sheeting will be attached to the support members using nails
 - Overlap the tin sheets approximately 1-2in over each other to prevent gaps where the green roof could seep through

