Building Infrastructure

Team: Urban Farming

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Introduction

Problem Statement

Peace Garden & Farms, run by Marty Henderson, is working to make fresh produce more available and affordable to the Gary, IN community. This is in an effort to reduce food injustice in lower income and minority areas. The Peace Garden & Farms started their efforts by farming using hoop houses but is now looking to expand and maximize their current farming area by adding a large set of rooftop gardens. Their location is the site of a former US Army Reserve training center. The building itself was built in the late 1970s. In order to move forward with this plan, it is necessary to know if the current building structure has the capacity to withstand the additional demand of the rooftop gardens. In addition to understanding the feasibility of the project currently, Marty would also like to have an irrigation system in place for the rooftop gardens. Putting in an irrigation system makes it necessary to understand the building's current drainage systems, the types of irrigation systems available to us, and exactly what type of irrigation system Marty wants.

Community Partner

Our Community Partner is Peace Garden & Farms, an organization that helps provide nutritious food to food deserts, like the one in Gary, Indiana. They also have a reentry program that helps get people back on their feet after a rough patch in their lives. The combination of these good intentions helps drive their cause and enables them to actively create a better future for all involved.

Our personal contacts with Peace Garden & Farms are Marty and Chris. Marty is the leader of the rooftop garden project and Chris is a member of the reentry program. Most of our communication is done via GoToMeeting (similar to Skype) during class where we review our week's work and get information on how the project needs to progress.

Stakeholder Analysis

Marty- Marty is interested in building a series of rooftop gardens to supplement Peace Garden & Farms. He wants to be able to provide a source of fresh produce to the population of Gary due to the current lack of options in the area. A rooftop garden is of interest to him because it will provide a space to grow hard-to-find fresh produce for his community. In addition, Marty wants to be environmentally friendly and use rainwater run-off instead of letting it go to waste. Finally, he wants these rooftop gardens because they do not take up space on the ground surrounding the building, meaning he can use that space to grow other plants, like trees, that will not fit on the rooftop garden.

Peace Garden & Farms Employees- The people that are currently working at Peace Garden & Farms have an interest in building the rooftop garden because some of them are in Marty's reentry program and Marty is looking to expand that program. Building this rooftop garden will give Marty the opportunity to expand his program as he will have a need for more workers in the gardens. The expansion of this program will benefit its members because it gives them an opportunity to gain both work experience and skills.

Corner Stores/Convenience Stores - Corner stores are a convenient and fast source of food, being some of the only sources of food for community members due to the lack of typical grocery stores. Peace Garden & Farms will be working with local corner stores to make their nutritious food easily accessible by placing it in the stores. This will both provide consumers with a healthy alternative and help these stores grow their sales.

Local schools and afterschool programs - Marty and Peace Garden & Farms have partnered with local schools and afterschool programs to teach kids about sustainable gardening practices and food nutrition. School groups and afterschool programs will be making visits to Peace Garden & Farms and working in the rooftop gardens.

Customers/Community Members - Peace Garden & Farms teaches the importance of growing and eating healthy food, and sells the food that it grows to help combat food deserts. Currently, the number of customers is solely limited by the amount of fresh produce that is produced. If this limiting factor is increased, then there will be more customers who will have access to affordable, healthy food. Healthy food paired with healthy choices can create a healthy lifestyle that reduces the chance diabetes, heart disease, and other chronic illnesses.

Objectives and Goals

The main objectives for the structures team is to find an irrigation and drainage system for the garden, to find professionals to inspect the building when we get the drawings, to come up with a plan for rooftop safety and rooftop access and finally to create an estimated cost for all of this. We plan to accomplish this by meeting with professionals and creating decision matrices to decide on irrigation, drainage, rooftop safety and rooftop access solutions.

Project Scope

The scope of the structure team contains finding out if the building can sustain the gardens and to determine effective drainage and irrigation systems. Our stakeholders, Peace Garden & Farms and Marty, aim to help the community of Gary to take a step forward in becoming self-sufficient in food production. The building must be able to support the weight of the gardens and other essential elements required to support the gardens, such as irrigation and drainage systems. Proper methods of roof access must be determined as well to make the transportation of materials to the roof, and the safety of the workers, the best it possibly can be. The team needs to incorporate these factors into the calculation of the structural integrity of the building.

EPICS Design Phase

The Urban Farming Project is currently finishing the specification development phase with hopes that next semester will be able to begin conceptual design phase. Our team is the first to work on this project and therefore most of our time has been spent researching background information on the project in order to develop a better understanding of what is expected of the team. We have finished the research for an irrigation system, drainage system, safety requirements, roof accessibility, and structural information.

Decision matrices were made for irrigation, which found drip irrigation to be most effective, and another for roof accessibility options. A table was completed estimating the different loads on the roof: dead loads, live loads and superimposed dead loads. With all of this research complete and loads estimated, the team next semester can now begin the conceptual design phase using the research provided from the specification development.

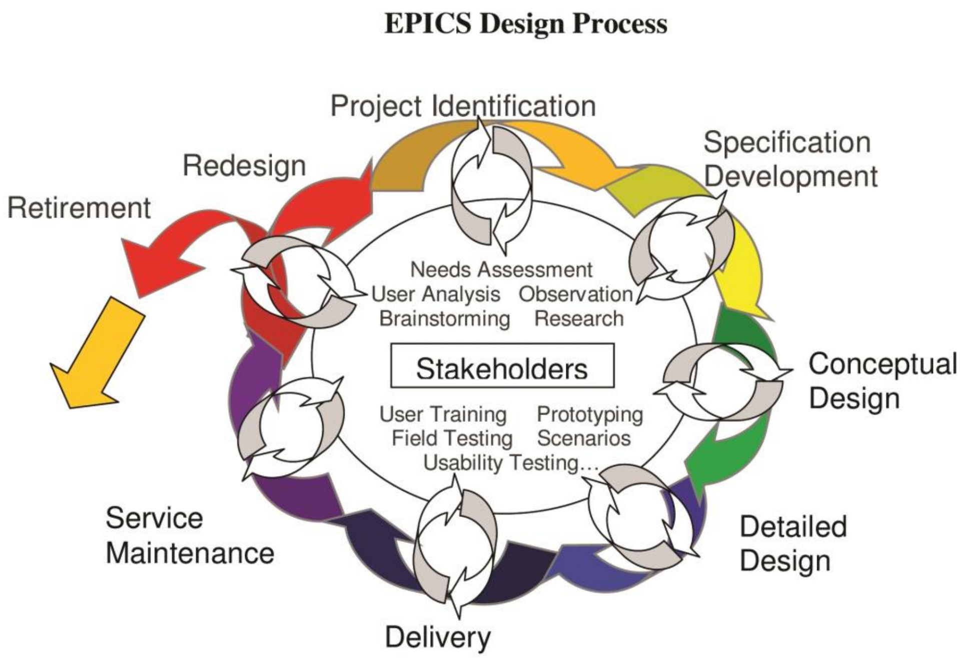

Figure1.EPICS design phase

Materials and Methods

Our main goal for this semester is to start determining whether or not the training center is able to support the additional weight of the rooftop gardens, and if not, how additional roof support can be installed.

The first step to meeting this goal was to research the project and how rooftop gardens were to be designed and created. We started this process by learning about Marty's desires for the project; he would like there to be a rooftop garden on each of the three of the roofs of the building. From the site visit we were able to determine that the building's structure is made from concrete and masonry. Additionally, it has steel beams supporting the roof of the gymnasium. While on the site visit, we also had a chance to meet with a representative from Omni Ecosystems, a company that designs and installs custom rooftop gardens. From this meeting, we learned that the typical weight of their specially formulated dirt can be anywhere from 15 to 50 lbs. per square foot depending on the type of dirt and the depth of the garden. Omni showed us their garden and irrigation system and also shared a lot of information with us, such as roof weight load factors and safety. The team researched rooftop gardens then developed a list of major aspects that needed to be incorporated. These important aspects are irrigation, drainage, structural support, building and city codes, and rooftop safety and access.

In order to determine the best course of action this semester, we started with a Gantt chart that showed our objectives and goals. Our original goal was to find the demand of the gardens compared to the capacity of the building. Throughout the semester, however, the plan, along with our goals and the focus of our project, changed as we encountered obstacles and setbacks. In week nine, we made a semester plan to help us plan out the rest of our semester in addition to the existing Gantt chart. This was also when we found out that we would not have the building drawings for at least year, and our goals for the semester were forced to change. The new main goal for the semester was to talk to professional engineers to figure out who would be willing to take on our project once we got our drawings. We also wanted to determine the best irrigation and drainage systems for the roof and our final goal for the semester is to come up with a cost estimate for Marty.

Our second step was to sort through the building (architectural, civil, structural, and MEP) drawings to find the relevant structural and plumbing drawings and to get familiar with them in order to understand what we are working with. We then split the structure team into two smaller teams: one will focus on the structural integrity calculations and will work with the structural drawings and the other will focus on researching and providing a decision matrix for potential irrigation and drainage systems.

Next for the structural team researched weights of potential loads, this included dead loads, superimposed dead loads and live loads. Dead loads are the weight of the roof, the material of the roof and that will not change. The superimposed dead loads are loads that permanently to the roof but are not a part of the roof structure. In this case, soil, that is saturated, hoop houses, and irrigation are included. Live loads are loads that can change over time. Our estimated dead load is 4.36 pounds per square foot. This number includes the weight of the 2 inch polyisocyanurate roof installation which is 0.2 pounds per square foot, the ¾ inch perlite cover board which weighs 0.75 pounds per square foot the weight of the BUR Ply felts which is 0.21 pounds per square foot and finally the asphalt layer which weighs 3 pounds per square foot. The next thing we considered were the superimposed dead loads which depends of the depth of the soil that we chose to use later. The weight of the soil ranges from 32.78 pounds per square foot to 196.68 pounds per square foot when the soil depth ranges from 2-12 inches. The soil weight is determined by taking the density of normal potting soil. It was determined that the pore space is 50%, meaning that 50% of the volume is pore space. This allows for water to fill the spaces. So, the saturated soil density was found by taking normal soil density and adding the density of water multiplied by the pore space, which is 3.15g/cm^3 or 196.68 lb/ft^3. Finally we considered the live loads which included the snow load and the people load. Since Marty wants a public access roof, the people load is automatically 100 pounds per square foot. Examples of potential loads are snow, soil, rain, and hoop houses. We learned that the density of soil when wet can reach up to 3.15 grams per cubic centimeter, which is equivalent to over 196 pounds per cubic foot; the structure needs to be able to account for that. The weight of hoop houses can almost negligible, with the weight of steel bar hoop houses being less than 1 pound per square foot, but if we reinforce the frame with wood to prevent collapse under snow, the weight distribution can exceed 3 pounds per square foot. We also found that snow loads in Gary can reach up to 35 lbs. per square foot. Meanwhile, the irrigation and drainage team researched different systems to consider their benefits, drawbacks and potential weights.

Based on our structural integrity research and roof load estimations we have are expecting that the roof will not be able to support the weight of a garden as is and will have to be reinforced and this will be a costly process. The irrigation team created a decision matrix and determined drip irrigation will be the most effective. The decision matrix criteria and reasoning has been fully explained and the results will be presented to the project partner, Marty. The structures team created a decision matrix to determine the best option for roof access, in terms of moving materials.

The fourth step for structures team will be to complete the structural integrity calculations for the building based on the information from the drawings and research we have done on potential weight loads. We will be working with our advisor, who has a PhD in structures civil engineering, and with a civil engineering professor here at Purdue if need be, to assist us in our calculations. For the irrigation team, the fourth step will be to finish narrowing down different irrigation/drainage systems and finish researching the important criteria for these systems such as cost, efficiency, weight, and amount of labor needed to install them.

The structures team had originally planned to finish the calculations for the max load weight of the building as well as determining the structural integrity in house. As the team does not have the capability to perform these complex calculations ourselves, we had planned on enlisting the help of one of our advisors who has a PhD in structures civil engineering, as well as a Purdue civil engineering professor. However, after realizing the level of difficulty in performing these calculations as well as analyzing the structural integrity when we have very limited knowledge of these applications, we have since decided to work with a professional structural engineer to hire them to finish the calculations in order to ensure the job is done properly. We have spent our time compiling a list of possible engineering firms to work with as well attempting to establish contact with them in preparation for next semester.

Data Collection and Analysis

Rooftop Gardens Research

A rooftop garden is a man-made green space on top of a commercial, industrial or residential building that can be used to produce food. There are several benefits to having a rooftop garden, these include: reducing noise pollution in busy areas, providing insulation to the building that it is on, thereby reducing heat and air conditioning bills and in the case of Gary, Indiana, it will aid in the issue of the food desert that they currently have by providing fresh produce to a larger number of people. Before building a rooftop garden, there are several things that should be considered. The first thing is structural integrity of the building, or can the building actually hold the weight of the garden and everything that is included in this. Most buildings, especially older buildings will need to be reinforced before a rooftop garden can be grown safely. In many cases it will take a professional to make sure the building is structurally sound enough for a garden and reinforcing the building can be costly if that is required.

Another thing that should be considered when planning a rooftop garden is weather in the area. For example, high roofs may pose a problem with high winds damaging plants and young seedlings. In order to negate these effects, something such as a wall or fencing may be beneficial. Another thing to consider is the heat and sun exposure on the roof. Part of the layering that is typically on a rooftop garden is made of a black material that heats up quickly. In order to combat this, more soil is generally added to go between the layer and the plants, but more soil means there is more weight being placed on the roof. In addition, it is important to consider the rainfall and snowfall in the area. The rainfall can help you determine what kind of irrigation system would be the most beneficial to the garden. Knowing what the snowfall is like is necessary in determining the kind of weight that could be put on the building.

Insurance and safety also needs to be considered when considering a rooftop garden. Rooftop gardens are more dangerous than other gardens and because of this, insurance companies will often charge a higher amount for a building with a roof garden than they would charge one without a garden. In addition, a rooftop garden is more expensive in general than a regular garden because there are so many other things to consider, like the reinforcement of the building. Safety also needs to be considered when considering a rooftop garden. The general way in which the issue of safety is addressed is with guardrails. Building codes for the area should also be looked at as they are different for every area. In some areas a permit is required in order to build a rooftop garden.

Indiana Building Codes

Throughout this project we understood that because this is a construction project there will be state building codes we will have to follow when designing and constructing this project. Rather than summarizing the Indiana building codes for the future Epics Urban Farms team we wanted to narrow down the important sections of the 690 page book. The Indiana Building Code, 2014 Edition (IBC, 2012 Edition, 1st printing) ANSI A117.1-2009 is the current adopted Indiana building code. Chapter 16 deals with structural design which will be extra important to pay attention to for designing this garden. However there are also several other chapters of interest for a project for a project like this. The following is a link to the IBC 2012, table of contents, which may help remind and organize other areas of this project that will need to be considered: **https://codes.iccsafe.org/content/IBC2012/toc**

Along with structural concerns about roof top modifications, there are also ingress and egress concerns, use (change of use) and occupancy use, fire rating/protection concerns, existing building and structures, etc.

Also, after meeting with a professor here at Purdue who has had experience in the same field we are currently working in, she referred us to the following book which talks about designing to meet the structural needs of a building. The following is a link to the *ASCE 7-16: Minimum Design Loads and Associated Criteria for Buildings and Other Structures*
https://ascelibrary-org.ezproxy.lib.purdue.edu/doi/book/10.1061/9780784414248

Subsurface irrigation

Subsurface irrigation is a type of drip irrigation in which the tubing used for water delivery is placed in rows beneath the crops in the soil. Subsurface irrigation has been shown to have many benefits including an increase crop yield, crop quality, and it allows for farmers to continue growing their crops without worry during a drought (The Toro Company). The system can use a variety of different materials for water delivery but the most common is PVC piping. While these systems are meant to last for several years, they require maintenance to be able to last this long; and without proper maintenance problems such as emitter clogging, root intrusion and mechanical damage can all easily become issues (The Toro Company). While the system has a high initial cost of around $500-$800 per acre, it can be expected to last for many years with proper maintenance (University of Nebraska).

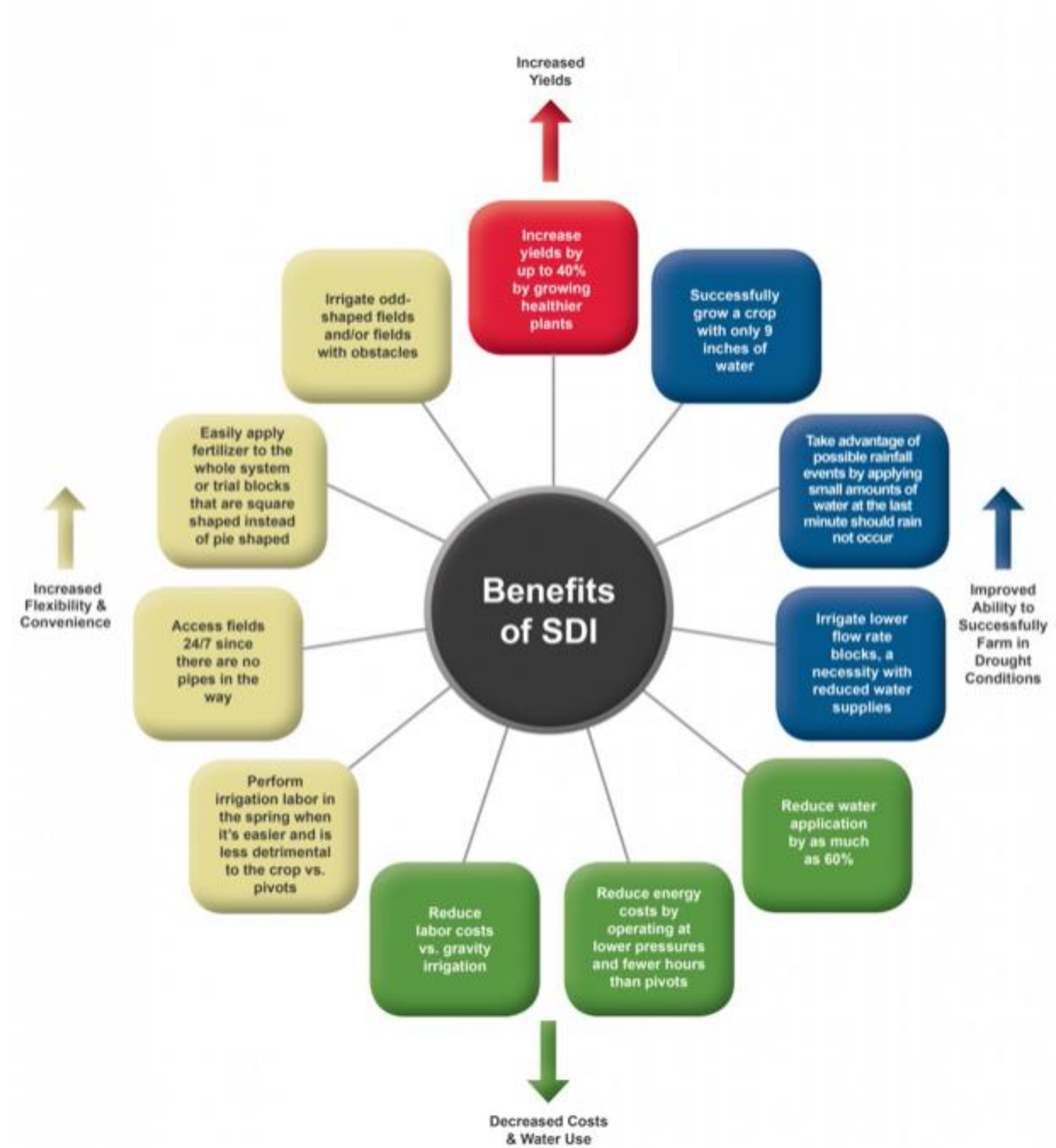

Figure 2. This image shows the benefits of using sub-surface irrigation systems (The Toro Company)

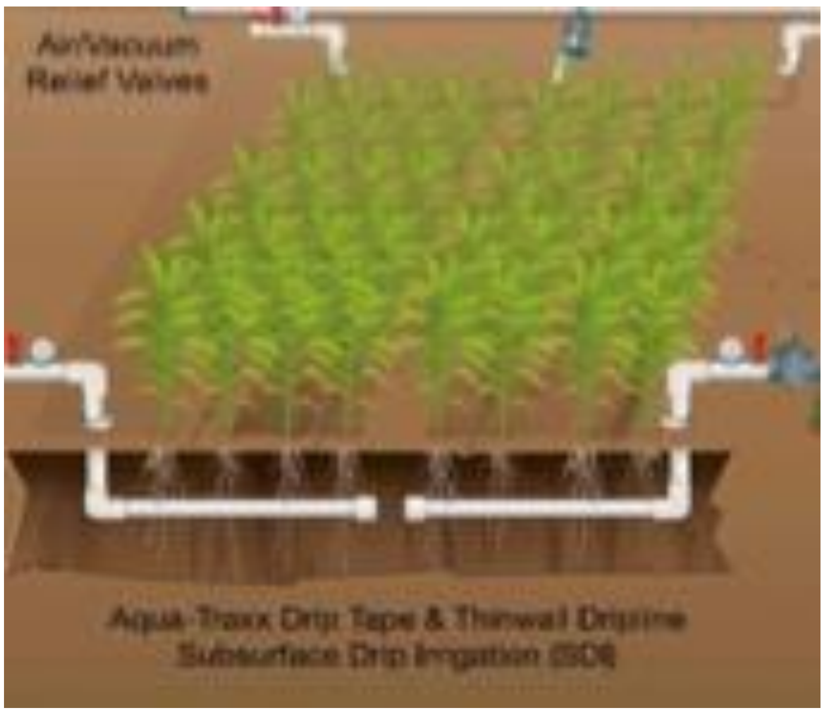

Figure 3. This image shows the typical layout of an SDI block in corn (The Toro Company)

Drip Irrigation

Drip Irrigation uses a low pressure pump system to circulate water along an irrigation line made of drip tape. This drip tape is a thin and flat rubber tubing with small holes placed every 6-12 inches. These holes allow a small amount of water to be emitted with a high frequency and minimize the amount of water lost. Having the tape placed directly on the soil eliminates any issues with wind or other external factors interfering with water placement as all the water is dripped directly into the soil. While it is the most efficient method of irrigation by far, the startup cost is also extremely expensive. The initial price of a system such as this could be anywhere from $1,200 to $1,700 per acre. In addition to this, annual costs can easily reach $300 or greater depending on the amount of drip tape being used. However, if a system used drip tubing instead of drip tape, it would cost a maximum of $2,100 initially but would also have the capability of lasting 12-15 years with proper maintenance. The flow rate for these two methods also varies as drip tape has a maximum water output of 0.84 gal/h while drip tubing has the ability to put out 1.80 gal/h (OSU). Knowing the water requirements for the plants being used is critical in ensuring that the best piping choice for the situation is used.

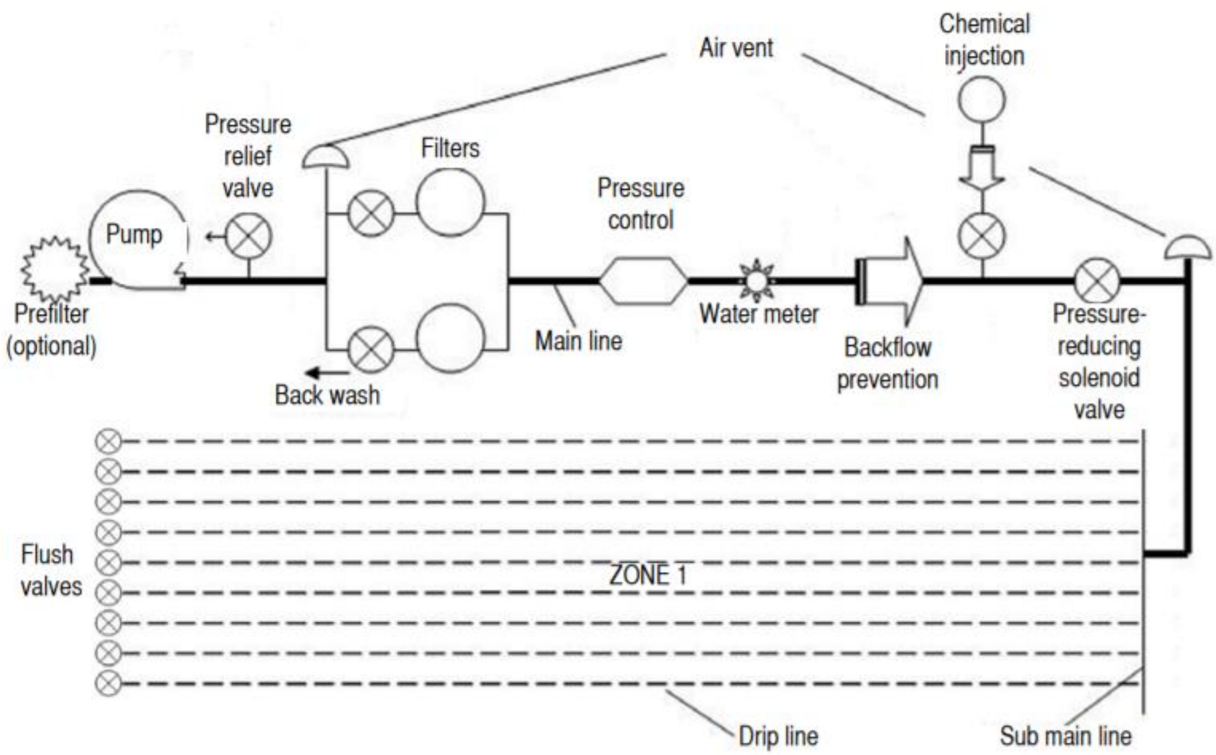

Figure 4. An example of a drip irrigation system (Oregon State University)

Sprinkler Irrigation

Sprinkler irrigation involves a system of pipes, pumps, valves and sprinkler heads to water crops similarly to rain. The main issue with the sprinkler system is the amount of water needed, on average the system uses anywhere from .5 to 20 gallons of water per minute (Hunter Industries). Depending on how the sprinkler heads are spaced, some crops could be overwatered and some could not receive enough to survive. Water efficiency will vary based on wind as the wind can blow the water and prevent it from reaching the crops. A sprinkler system on the roof would need to be built above the crops due to the small amount of soil on top of the roof. The weight of a sprinkler system will vary based on the type of piping and heads used. In below ground sprinkler systems 2 inch PVC pipe is the most commonly used and would result in .72 lbs./ft and cost $11 for every 10 feet of piping used (PVC Pipe Supplies).

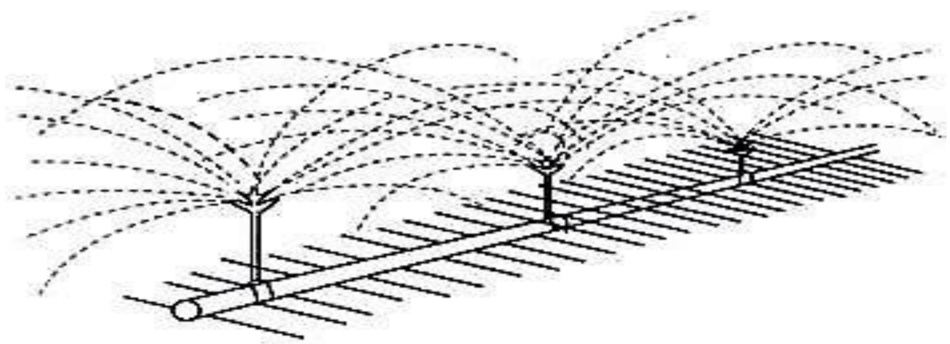

Fig. 6.6. Sprinkler irrigation

Figure 5. An example of a spray sprinkler irrigation system (Your Article Library)

Micro Spray Irrigation

Micro-spray is a cross between surface spray irrigation and drip irrigation. Water is applied to the soil surface in a small spray or mist by an emitter 6-12 inches about the soil surface. Micro-spray maintenance is similar to that of drip irrigation although it uses nozzles instead of emitters to deliver water. Nozzles are subject to clogging and disruption of flow pattern. Nozzles can be blown off due to high pressure; tampering with flow adjustments can result in flows that are too high or too low for the landscaped area being irrigated.

Any type of irrigation in a commercial agriculture system can greatly reduce the climate-related yield risks resulting from water stress. Compared to overhead irrigation systems, micro-irrigation can provide some added measure of reduced risk (Alliance For Water Efficiency) because of its high efficiency. It allows for flexibility in the timing and amounts of applied water and less water is applied, nutrient leaching is reduced.

- Nutrient applications can also be better timed to meet plant needs.
- Allows for the use of polyethylene mulch.
- Micro-irrigation can be used to protect small horticultural crops from freezes.

The reduced wetting of soil surfaces and plant canopies may result in lower weed and disease pressure. The leading agronomic benefits of micro-irrigation (University Of Florida) are: the use of less water, less pest problems, reducing surface crusting and joint management of irrigation and fertilization.
Low pumping needs, automation (reduces labor costs), and flexibility all have positive impacts on production costs. These systems typically cost around $500-$1000 per acre and can be useful for several years. Like drip irrigation, micro-spray is considered a type of low-pressure irrigation typically operating with pressures between 15 and 30 psi. It is generally considered low volume with application rates of 5 to 70 gallons per hour (GPH) (18.9 LPH to 264 LPH). Micro-spray typically creates a larger wetted area then drip irrigation making it well suited for irrigating ground covers, large flower beds and sandy soil.

Disadvantages of micro-spray irrigation include how it is less likely to be exempt from watering restrictions because it puts out a higher volume of water than drip irrigation. It is subject to evaporative losses and spray pattern disruption in windy conditions. Higher flow rates make it more susceptible to overwatering and runoff and this runoff may result in more weeds.

Irrigation Decision Matrix

Criteria	Weight	**Drip Irrigation**	**Sprinklers**	**Micro-spray**	**Subsurface**
Garden Health	3	4	1	2	5
Cost	4	4	1	5	3
Efficiency	5	4	1	2	5
Ease of Maintenance	2	5	4	4	2
Ease of Installation	1	5	2	4	3
	Total:	**63**	22	48	55

Table 1. Weighted Decision Matrix of Irrigation Systems

As a team we highly recommend the use of an above surface drip irrigation system due in large part to its high efficiency to cost ratio. This system consists mainly of thin drip tubes or drip tape placed on top of the soil and between rows of crops. With a small pump placed elsewhere on the roof, a low pressure flow of water allows the irrigation line to drip water into the soil at a slow and constant rate. The irrigation line is made up of either drip tape or drip tubing, both of which are constructed out of small rubber tubing with holes placed every 6 to 12 inches for water to drip out of. The main difference between these two methods is the rate at which water is allowed to escape the system, drip tape has a maximum water output of 0.84 gal/h while drip tubing has the ability to output 1.80 gal/h. Having the tape placed directly on top of the soil eliminates the need to worry about wind or other external factors interfering with water placement and the efficiency of the system as the water is deposited directly into the soil. Reports pertaining to the implementation of drip irrigation systems have found that these systems consistently perform on level or better with more traditional methods of irrigation. Taking this into account along with the previously stated low water usage, we decided that drip irrigation was one of the most efficient methods of those we researched being beaten only by sub surface irrigation which places the tape underneath the soil to eliminate any water waste. Another benefit of having the water dripped directly into the soil, and only where it needs to be, is that it reduces the chance for weeds to grow as weeds require a decently large amount of water runoff and room to become a problem. By almost entirely eliminating the possibility of weeds growing not only will there be less maintenance required for the garden overall but the ease with which organic produce can be grown increases as well as the use of herbicide is no longer necessary. Subsurface irrigation handles this problem in a much better way which leads us to rate subsurface above drip irrigation in the area of garden health. The cost of drip irrigation is one of the most enticing parts of this method. The startup cost for a drip irrigation system can range from as low as $1,200 per acre with the use of drip tape, to a high of $2,100 per acre in the event of drip tube being used (Oregon State). There is also a rough annual cost of $300 to account for maintenance of the system in fixing or replacing any sections of tubing that may have been damaged during the growing season. This price covers all materials and the installation of the system. In addition, since the entire system is based above ground, installation costs are minimal if not nothing compared to the other systems. The installation could easily be done even by those with little to no experience in irrigation. The system does not require any land to be dug back up for installation, or for its installation to be incorporated during the construction of the garden meaning that the entire system can be constructed to fit the garden however it is designed. Another benefit of drip irrigation is that depending on external conditions and use, the system can last anywhere between 12 to 15 years with proper maintenance. As was previously mentioned, having the entire system placed above ground means that gaining access to make any necessary repairs is the easiest of any system. While the ease of maintenance and installation aren't nearly as important as the efficiency and cost, they are still both good factors to help make a final decision and drip irrigation implements both of these perfectly. With the creation of our decision matrix we found that while drip irrigation is not necessarily the best in every category, it consistently performs better than most other forms of irrigation and has a lot of added benefits that help to make it the clear winner.

Drainage

The image below is the layering involved in the rooftop garden, the major and most important are the waterproofing and drainage. There will need to be a waterproofing layer in place to prevent damage on the roof. This waterproof layer is typically dark in color, tar or cement or asphalt, and this will cause the roof and the plants to heat up. To prevent the plants from heating and dying, there needs to be the correct amount of soil or water to cool the plants down. For the drainage layer clay, gravel or drainage plates can be used. Drainage plates would be the best option because it will allow for more control over moving the excess water and there would be minimal piping involved to remove the excess water from the roof. Clay is not a good material for drainage because the pores are too small, so it soaks up all the water and does not release it. For gravel, it would be heavier and harder to control where the excess water will drain to. The drainage plates will prevent soil erosion, it will not allow any soil to pass through with the water that is draining. This is good because it will keep the water barrels clean and less soil will be lost so less soil will have to be replaced.

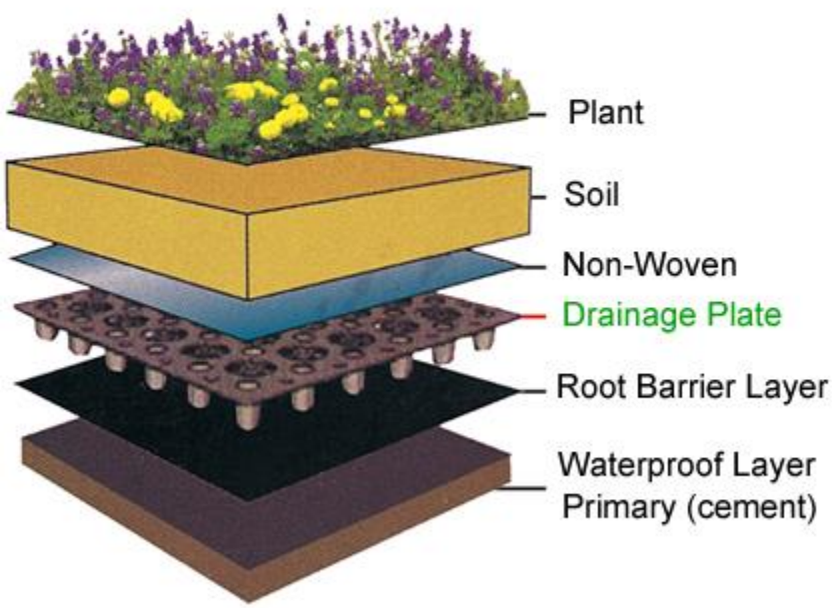

Figure 6. An example of the layering to utilize for the garden.(Greening Solutions)

Gary Indiana Client Building Site Visit

On September, 8th, 2018, the Urban Farm Team went to Gary Indiana to visit Peace & Gardens Farms, where we were able to check out the building and meet our project partner: Marty. We were able to observe the building and take away some important details for our structural calculations. During the visit we observed the structure type of the building to be concrete and masonry, the roof is made out of an asphalt material, and we also noticed that the building's gymnasium roof is supported by multiple steel beams. We were also able to visit Omni Ecosystems, where we saw what finished rooftop garden projects look like and potential design concepts. At Omni we learned about drip irrigation system, conducted further research and have determined it to be the most effective irrigation system for the garden. We also learned about potential live loads and their weights that we will have to look out for such as the dirt of the garden itself, rain, and snow during the winter, and how combined our structure will have to support over 50 lbs. per square foot. Pictures are in the appendix.

Potential Loads Research

To determine potential loads that the roof might face, the team created a spreadsheet with several factors to determine loads to have an estimation of potential soil depths when the team receives information from the building inspector. This will help us determine if the design will or will not need supports for the roofs to keep the building structurally sound.

The roof is compiled of Dead Loads, Superimposed Dead Loads, and Live Loads. Dead Loads are the weight of the roof, the material that make up the roof. This weight will not change. The Superimposed Dead Loads are loads that permanently stay on the roof but are not a part of the roof structure itself. In this case, soil, that is saturated, hoop houses, irrigation, and saturated drainage tiles are included. Live Loads are loads that can change over time. This includes snow load, people load, crops, and wind load. Snow Load is determined from code.

It was deemed through calculations that the weight of an irrigation system, the piping and pumps, and also hoop houses, plastic or metal frames, will both be insignificant in the final calculations. To determine the weight of saturated soil, the density of regular, dry potting soil was found, 2.65 grams per cubic centimeter (Agriinfo). The porosity of the soil is about 50 percent, meaning that there is air within the soil (Agriinfo). These air pockets will allow for water to seep in and saturate the soil. The density of water is 1 gram per cubic centimeter, so 50 percent of that is 0.5 grams per cubic centimeter. The total density of the saturated, regular potting soil is 3.15 grams per cubic centimeter. The density will be multiplied by the volume of the soil and divided by the surface area to determine the pounds per square feet that must be allotted for the soil at certain depths.

For Gary code, the snow load is a minimum of 35 lb/ft^2 and the people load, for a public access roof, is 100 lb/ft^2, and the load for wind load is determined to be not significant due to the fact the roof is fairly flat and there is little surface area for the wind to act on. If all the max options were used, the total weight be square foot would be 340 lbs. These numbers are placed into an excel sheet and will be able to be added together and be changed as the Garden Team

Gives provides more information about growing mediums and densities.

Dead Loads									
Material	Unit Weight lb/ft^2	Total Weight lb							
2 inch polyisocyanurate roof Insilation	0.4	5200							
3/4 inch perlite cover board	0.75	9750							
BUR Ply felts X 3	0.21	2730							
Asphalt layer	3	39000							
Total	4.36	56680					Max Weight	339.83	lb/ft^2
Super-Imposed Dead Load									
Soil Depth (inches)	Soil weight - Dry	Soil weight - Saturated (lb/ft^2)	Number of Hoop Houses	Weight of Hoop Houses	Irrigation	Drainage Tile	lb/ft^2		
2		32.78				GR32	1.93		
4		65.56				GR52	3.79		
6		98.34							
8		131.12							
10		163.9							
12		196.68	Weight of hoop houses is negligable		Weight of Irrigation is negligable				
Live Loads									
Standards									
Snow Load	35	lb/ft^2							
People Load	100	lb/ft^2							
Crops									
Wind Load	Not signifigant								
Givens									
Normal Soil Density	2.65	g/cm^3	165.43	lb/ft^3					
Pore Space	0.5								
Density of Water	1	g/cm^3							
Saturated Soil Density	3.15	g/cm^3	196.68	lb/ft					
Square Footage	13000	ft^2							

Table 2. Spreadsheet of Potential Loads

Hoop House Cost and Weights

We researched different styles of hoop houses made out of different materials and for hoop houses made with metal rods we found the following data

Hoop Houses Weight

Item #	Height	Length	Weight	Width	Framing Type	Price
CF1448	8.25 ft	48 ft	405 lbs	14 ft	Steele	$1197.89
CF1496	8.25 ft	96 ft	745 lbs	14 ft	Steele	$2162.39
CF1648	6.8 ft	48 ft	505 lbs	16 ft	Steele	$1197.89
CF1696	6.8 ft	96 ft	934 lbs	16 ft	Steele	$2162.39
CF2048	10 ft	48 ft	648 lbs	20 ft	Steele	$1864.49
CF2096	10 ft	96 ft	1193 lbs	20 ft	Steele	$3413.79

Table 3. Weights and Prices of Hoop Houses

Conclusion: Out of the hoop-houses made with complete steel structures, according to the data above from A.M. Leonard a Greenhouse supply company, we can calculate that the average pound per square foot for these types of hoop houses is less than 2/3 a pound per square foot. For example: for CF1448: 405lb/ (48ft. * 14ft. Floor area of hoop house) = 0.6lb/sq ft. Some of the other types of structures contain wood and plastic which are both materials that typically have a lower weight than steel.

Roof Access

Three options were considered for the improvement of roof access after comparing our original options through a decision matrix. With our research we believe that the best options are to use a roof mounted winch system, a ground based conveyor belt to the roof, or a ground based moving platform. We considered these three options of roof access in an additional decision matrix were the systems were examined with three different goals in mind. In addition, all of the options have been analyzed for their pros and cons in order for the best decision to be made by the project partner.

1. Winch:

A winch system requires little to no physical effort to get items from ground level to the roof, depending on the system, and it is extremely reliable. Additionally, some models have the capability to lift upwards of 3,000 pounds. However, it can be difficult to orient materials properly to raise them. Also, it adds a ton of weight to one specific spot on the roof, but this can be negated by building the winch system directly into the concrete and steel pillars of the building, helping to spread the weight out over a larger area. The installation of a winch system has the possibility to be more expensive than either of the other two options as the system operates as a permanent structure and therefore eliminates the option of renting for the duration of the construction process. Although the cost is relatively high, having a permanent method for transporting materials to the roof means that the winch system would still have viable applications once construction is complete. If the system is used to transport crops down from the roof, any other method of accessing the roof for individuals would not have to be greatly improved to accommodate the movement of large quantities of produce.

2. Conveyor Belt System:

A conveyor belt system would allow for a much quicker, and consistent, delivery of materials to the roof. In addition, as the conveyor belt is based on the ground, there is no weight being added to the roof other than the materials being delivered. However, conveyors are extremely large and bulky, making storage and movement very difficult. Given that the building is around 25 feet tall, the conveyor belt required would have to be a much larger size than normal which does nothing to improve the situation with storage, movement, and cost. The problem with cost could be alleviated at least partially by renting the system from a company as the conveyor belt is not a part of the building and could be easily removed from the premises.

3. Material Lift/Moving Platform:

The use of a moving platform or material lift means that the placement of materials to the roof could be done with pinpoint accuracy. This is a result of the lift's capability to be placed on any side of the building. However, having a mobile lift that has the capability to reach the 25 feet, would result in a dramatic decrease in the amount of material able to be moved at any one time. Due to the large initial and operating costs of owning a material lift, acquiring one for the construction project would have to be done through renting.

Based on up-front costs							
Criteria	Weight	Hand Carry	Winch/Pully	Converyer Belt (purchase)	Conveyer Belt (rent)	Moving Platform (purchase)	Moving Platform (rent)
Ease of setup/storage/operation	1	2	4	3	4	4	5
Number of potential access points	2	1	1	2	2	5	5
Usefulness in the future (investment)	3	1	4	3	1	4	1
Lifting capacity/speed	4	1	5	5	5	3	3
Cost	5	5	2	1	4	2	4
Total:		36	48	41	51	48	50

Based on long-term investment							
Criteria	Weight	Hand Carry	Winch/Pully	Converyer Belt (purchase)	Conveyer Belt (rent)	Moving Platform (purchase)	Moving Platform (rent)
Number of potential access points	1	1	1	2	2	5	5
Ease of setup/storage/operation	2	2	4	3	4	4	5
Cost	3	5	2	1	4	2	4
Lifting capacity/speed	4	1	5	5	5	3	3
Usefulness in the future (investment)	5	1	4	3	1	4	1
Total:		29	55	46	47	51	44

Based on minimal installation time							
Criteria	Weight	Hand Carry	Winch/Pully	Converyer Belt (purchase)	Conveyer Belt (rent)	Moving Platform (purchase)	Moving Platform (rent)
Number of potential access points	1	1	1	2	2	5	5
Usefulness in the future (investment)	2	1	4	3	1	4	1
Ease of setup/storage/operation	3	2	4	3	4	4	5
Cost	5	5	2	1	4	2	4
Lifting capacity/speed	4	1	5	5	5	3	3
Total:		38	51	42	56	47	54

Table 4. Sensitivity Analysis of Roof Access

Building Drawings

Our main problem with building drawings this semester is that we have the wrong building's drawings. The picture below demonstrates that not only is the general shape of the drawing's building wrong, but it's also on the wrong streets.

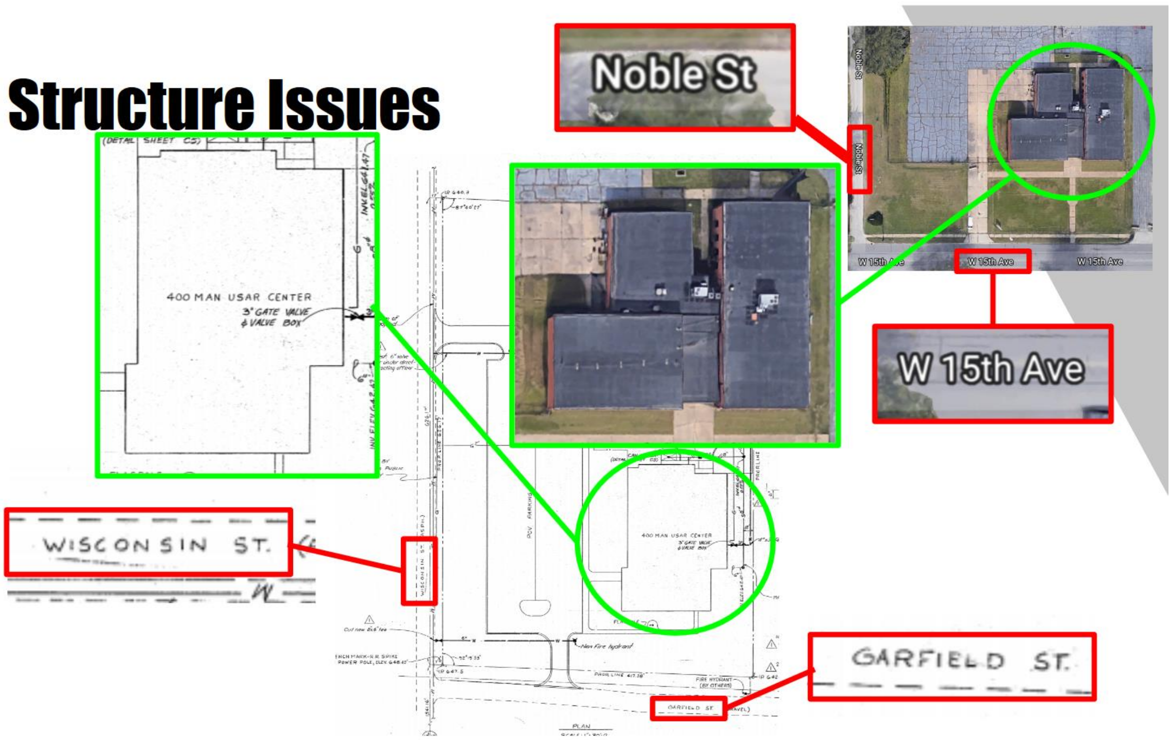

Figure 7. Issues with drawings

It also turns out that we will have to submit a Freedom of Information Act request and wait up to a year to receive the correct documents from the United States Corp of Engineers Archives. In the meantime, we have four accurate drawings, but they are nowhere near enough to substitute for the full set of drawings.

Structural Engineering Firm Research

Since the project will require a professional engineer to sign off on any changes that will need to be made to the building and to ensure that the building has a sufficient safety factor to hold the load, we started to research different structural engineering companies. We reached out to them in order to gain an idea if they did the type of work that we would need done and what information that they would need from us to get a proposal in order to get a cost estimate on inspecting the building first. Unfortunately, after speaking with the firms listed in the table below we were not able to get all of our answers as the firms either requested the building documents that we do not have or the information they need from us is information that we would get off of the drawings. A few companies even went so far to say that we would have a hard time getting a firm to take on our project. This is because our project partner, Peace Gardens and Farms, would be a new client so there is no established rapport, and the project would be a timely and costly endeavor. Not only did these firms view this project as a risk for our project partner but they were concerned about the risk the firm would have to make participating in such a grand project. However, if the scope of the project was limited to a single roof then it would be easier to find a firm willing to take on the project. Limiting the scope to a single roof diminishes costs, labor, and time required, while also setting up the framework to complete other roofs if the first roof works out well.

Inspector 1	Inspector 2
Thomas Engineers	SilverCreek
Enspect Engineering Consultants	Building Department of Gary
Superior Engineering	MECA Engineering
DLZ Engineering	RJ Mycka Inc

Table 5. List of structural engineering companies

Irrigation

The irrigation system for the rooftop garden will be critical to its success and will help to improve the overall efficiency. Each team member of the irrigation sub group was assigned a specific type of irrigation, with which we all conducted our corresponding research. The information gathered was put into a chart and will eventually be moved to a decision matrix. While a final decision is yet to be made, the team has determined that the best method for irrigation would be the drip irrigation system. While the startup cost is decently large, the majority of the weight is centered in one water circulation system, and the tubes can extend greatly beyond that. Having almost all of the weight centered in one place makes it much easier to work into the design in such a way that we can maintain the structural integrity of the building. In addition, the tubing that is used for the distribution of water has almost negligible weight and a very low cost. The tubes are placed above ground so the maintenance of them is much cheaper and easier than any irrigation systems placed below ground. The efficiency of drip irrigation is also one of the highest as a result of the positioning of the tubes leaving little room for water to evaporate, meaning the majority of it goes right into the soil.

Delivery method	Advantages	Disadvantages
Microspray	Low cost, visible, easy to install, reliable	Uneven distribution (plant interception), high water loss (wind, evaporation), foliage wetting (increased disease potential)
Surface drippers/perforated pipes	Low cost, visible, even delivery of water	Moderate water loss
Sub-surface drippers/perforated pipes	Low cost, moderate efficiency (water delivery to root zone)	Non visible (difficult for maintenance), higher potential for damage by people digging
Sub-surface capillary	High efficiency	High cost, maintenance and repair is difficult because not visible, 'capillary rise' of substrate needed or water will not reach plants
Wicking associated with irrigation in drainage layer	High efficiency, ease of installation	Linked to proprietary systems, 'capillary rise' of substrate needed, this may be unsuitable for plant establishment if the water is applied too deep for the plant roots to reach
Hose	Good for domestic application for easily accessed areas, not so good for other areas. Allows monitoring to occur at the same time	Cost (requires someone to be present on-site), low water efficiency, foliage wetting, uneven distribution

Table 6. Table about Pros and Cons of different types of Irrigations (Growing)

Building Drawings

A subsection of the team has spent the last few weeks going through all of the building drawings that were provided by our project partner Marty, in order to gain a better understanding of the building and what we are working with. Through the process of separating the drawings into different groups based on their subject and usefulness were able to more easily filter out any unnecessary information that may have been included. The team has also begun to identify points of concern in the structure of the building to help us plan for the future construction of the rooftop garden.

Roof Safety

The options for Green Roofs – Fall Protection safety are:

- Guardrail Systems
- Personal Fall Arrest Systems
- Safety Net Systems

These are mainly for construction workers who are building a green roof, OSHA says that if construction workers that are involved in the installation of green roofs and exposed to a fall distance of 6 feet or more has to be protected by one of those three things, but even though they are meant for construction workers, I think they could be a good starting place

OSHA Requirements for Guardrails:

- The top edge height of the top rails are 42 inches plus or minus 3 inches above the walking-working surface
- The guardrail system can exceed 45 inches in height only if it meets all of the other criteria
- Midrails are installed at a height midway between top of rail and walking-working surface
- Screens/mesh extend from surface to top of rail and extend along the entire opening
- Guardrail systems should be capable of withstanding at least a force of 200 lbs. (890 N) applied either downwards or outwards (within 2 inches of the top edge)
- When the 200 lb. Test load is applied, the system should not bend to a height less than 39 inches
- Must be smooth surfaced to prevent injury to workers
- Top of rails and midrails should not overhang unless it poses no danger to workers
- Top and mid rails are at least 0.25 in in diameter
- When guardrail systems are installed near holes, they must be installed on all unprotected sides and edges
- For guardrails installed around a hold used to pass materials
    - When materials are being passed, no more than 2 sides of the system should be removed
    - When materials are not being passed, the hold must be guarded by a guardrail system or closed with a cover
- When guardrail systems are used around holes that serve as points of access
    - Should have a self-closing gate that slides/swings away from the hole and has top and mid rail and meets above requirements for that or
    - Is offset to prevent someone from walking or falling into the hole
- Systems installed on ramps and runways are installed along each unprotected side/edge

KeeGuard Rooftop Railing for Fall Protection

- OSHA Compliant
- Non-penetrating railing system, preventing leaks and allowing you to maintain your roof warranty
- Flexible solution meaning that the design of it allows it to work around obstacles and elevation changes
- Long lasting: expected to last decades due to it being corrosion resistant

Railing Systems
Considerations:

- Choosing a railing that offers code-compliant fascia mount options: A side mount system of posts, rails, and balusters is the ideal way to install a railing on the roof. Some systems only offer fascia mounted balusters, but for a rooftop setup, you want to go with all fascia mounted components, including the posts.
- Choosing a railing that is compatible with LED lighting accessories: Using lighting components that work with your railing system is a great way to improve safety while also eliminating the need for a lot of additional light fixtures. Also, as the cords are hidden in the posts, you don’t have to worry about guests tripping over them. LED railing lighting uses small, low energy-emitting devices that don’t become overheated and are able to be held in place by your post system. Some, like surface mount lights, can also be recessed into your floor to light up a pathway or to illuminate your railings from below.
- Iron and aluminum railings are great options for the roof. A rooftop takes the full brunt of bad weather. Railings should be powder coated as a safeguard against rust and UV damage. Systems that use pre-galvanized steel and a zinc phosphate pre-coat are particularly weather resistant, and the heft of steel stands up well to wind, rain, and everything in between.
- Using pre-welded panel systems makes installing the fence easier.

Recommendation:
Iron and aluminum railings are the sturdiest railing solutions, and coating them with pre-galvanized steel and zinc phosphate pre-coats will allow the railing to be weather resistant.

Alternative Ideas

After talking with a number of structural engineers about our desired rooftop garden and the type of building we are working with we received numerous unofficial notices that this project could potentially cost a lot of money. Potentially in the hundreds of thousands. Now of course these are estimates simply made based on the little information we know about the building and based on the cost of most roof top garden projects, so there is a possibility that the building's roof may not need to be reinforced and in that case the project would cost a lot less but even so it may be beneficial to be aware of some alternative ideas for using the roof space.

Some alternatives could be creating an indoor vertical garden. This garden could be placed inside the community center on the first floor, so there would not have to be any reinforcements. The vertical garden could be used all year, producing safe, leafy greens with LEDS and water. The roof could be used to collect water via rain barrels or rain basins that could be filtered and used elsewhere on the farm or for the vertical farm. Solar panels could be placed on top of the roof to help power the LEDs for the vertical farms. Another alternative is adding more hoop houses to the ground to help produce more crops.

Recommendations

1. Do some research on rooftop gardens themselves and last semesters documentation to get an overall understanding of what rooftop garden project usually pertain, and where the team currently is.
2. Meet with civil engineering staff member Sue Khalifa for guidance on figuring out the team direction you all will want to go this semester. She has experience in the field and had some great insight and understanding on knowing what needs to be done for a project like this. This is Sue’s email: skhalif@purdue.edu
3. With that said, create a semester plan right away. Include what you want to accomplish long term this semester and what will need to be done on a day to day basis. Sue will be able to help you with that.
4. **Consider designing for 1 roof.** We found that designing for the whole building (all 3 roofs) may be over the top and expensive. During the mid-semester design review, one of the reviewers explained that it may be a good idea to design a prototype rooftop garden for one of the roofs, and if in the future you end up having to create a design for the rest of the roof, you will already have a design to modify. Designing for one roof may end up being more affordable in the long run and we recommend you all look into the pros and cons and consider if you agree this is a better solution our client.

Conclusions

At the end of the semester, the team has finished doing background research on the project, and specification development that will be necessary to consider going forward. We learned that the drawings we were given for the project were not the correct drawings for our building, so we are currently undergoing the waiting process with the United States Army Corps of Civil Engineers to receive the correct drawings for our building from them. Once we receive these drawings, we will be able to contact one of the structural engineers of whom we have initiated contact with and who have expressed interest in doing work with us for our project. To prepare for designing and for the structural inspections we hope to have in the future we have analyzed the potential roof weight loads. These weight loads estimates will help the team determine if the building will have to be reinforced to hold this rooftop garden or if it will be okay how it is. Along with this we have done research on other factors of the project that will need to be considered when designing this rooftop garden such as potential irrigation systems, drainage solutions, solutions for making accessing the roof easier, guardrails and other ways to make the roof safe for pedestrians, Indiana building codes and what the typical design process is like for rooftop gardens. With this in mind we are hoping that this will be enough information on both the project goals and the needs of our building so that the team next semester will be able to use this information to start creating a design for this rooftop garden.

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Appendix

Picture 1. Google Maps

Picture 2: Masonry exterior walls and concrete interior walls

Picture 3: Steel beams in the gym

Picture 4: Steel beam supported roof

Picture 5 Asphalt Roof