IPRO 336: Planning the 21st Century Urban Farm

PROJECT PLAN

1. Executive Summary

Ten years into the 21st century the world's population is still increasing, and most of the growth is happening in dense urban areas. A lot of farmland is used to support the inhabitants of cities, fruits and vegetables are even brought over from the other side of the world. Vertical farming offers many benefits to not only the city where the farm is located but also to relieve some of pressure on the farmland previously used to support the city. Vertical Farming is a radical new idea that involves growing food inside a large building in the city.

Since the idea is new and hasn't been put into practice yet, our IPRO was charged with designing a vertical farm operation on two floors of an existing building on Chicago's west side at 1819 W Pershing. Dubbed "The Plant", this building also houses leasable workshop spaces, the Delta Institute, art space, a restaurant, and more. Our IPRO was also charged with coming up with a plan to rehabilitate the inside spaces of the 600,000 square foot building.

2. Purpose and Objectives

Our sponsor for the project is John Edel, who is in the process of acquiring the PLANT building. He has experience in sustainable building construction and rehabilitation from his company is called Bubbly Dynamics and his office is currently located in the first building he rehabilitated located on South 37th street and Morgan which is called The Chicago Sustainable Manufacturing Center.

Our purpose is to provide John with solutions to the layout of the inside spaces, present ideas on fixing the building envelope from air leaks, propose an agricultural system to use in the farming operations, and to give estimates on how much revenue can be made from the plants grown. These problems were best dealt within four subgroups:

Agriculture- Research and determine best growing methods for different agricultural systems. Systems included are hydroponics, aeroponics, and aquaponics. Research ways to control humidity, lighting, temperature, and recycling of energy. Create closed-loop systems where insects, plants, and animals all benefit from each other's waste. To conduct this research, the agriculture team has designed and built an aquaponics prototype in order to learn more about the delicate balance of growing vegetables using water from a fish tank.

Computer System Software- Create a software application capable to control the temperature in the farm areas as well as the conditioned spaces in the rest of the building. Research and determine the best software architecture for our Control System Software. Generate a project plan to develop the software application. Determine what kind of electronic equipment can be used to monitor and control the temperature, humidity, light, CO_2 level and air flow.

Design- Create schematic plans based on program spaces given by John. Recognize possible waste heat energy loops and calculate the average heat loss of the building. Utilize waste heat into passive energy systems that offset the heat loss, resulting in less use of electricity and gas while conditioning the program spaces at comfortable levels.

Marketing- Determine the best vegetables to plant in an aquaponic system, taking into consideration factors such as temperature required for germination, harvests per year, value per square foot of plantings and the demand in retail and specialized markets. As the agriculture group progresses in construction of the prototype, the marketing team will adjust plant recommendations according to the successes and failures of our particular system.

3. Organization and Approach

Agriculture- Research was conducted by visiting Growing Power in Milwaukee, a farm that is growing food aquaponically. We also got our hands on a DVD from a man in Australia doing the same thing, but slightly closer to the scale of our prototype. Since our agricultural system is going to be indoors we will be using artificial lighting, research had to be done on the available technology and how it could be applied to our project; such as the distance of the light to the plant, the amount of heat given off, the color spectrum, and the energy used by the different lights. Research was also conducted on the kinds of plants we want to grow, how they can be grown, and the type of fish we want to use. All these depended on the space available to us, the growing medium used for the plants, and the temperature of the water.

Our main research method, however, is the maintaining and monitoring of the prototype which is soon to become operational. The information we are hoping to get from the aquaponics prototype is as follows:

-Best growing medium (hydroton, gravel, soil)

-Cost vs production

-Best lighting techniques (Fluorescent T8's or T12's, metal halide, high pressure sodium)

-Initial cost + running cost vs. production

-Environmental Conditions (Temperature, humidity, water quality)

-Cost of maintaining environmental quality vs. production

-Energy needed to maintain the system.

Computer System Software- The requirements for the Control System are defined as follows:

- The system must be capable to control the temperature, humidity, light, CO_2 level in the farm area and the temperature of the full building, monitoring the temperature in each room and in each floor of the building. We will use the basement (the concrete walls) as a temperature battery.

-The control system must be intelligent enough to detect when we have an excess of heat in one of the spaces of the building, and move that heat to another space that requires heat.

-If all spaces meet the heating requirements, the system will move excess heat to the basement. In case that a room require heat, the system must check if the building has some amount of heat storage in the basement, in case that the basement has some heat, the system must move that heat to the room that require it. If the basement doesn't have heat, the control system will turn on the heater.

There will be little electronics boards (embedded systems) across the building to receive the signals from the sensor and send this information to the main computer, the main computer will take the control decision and will send the instructions (turn on/off air conditioner, heaters, open/close pipe gates) to the embedded systems. John Edel expressed his desire to develop the Control System under the philosophy of Open Source and also use Open Source tools. To accomplish this objective we started to analyze the different open source operating systems and compared 6 different operating systems (Debian, Fedora, OpenSuse, Ubuntu, Mandriva, OpenSolaris, and PCLinuxOS) based in Linux and Unix technologies. We also researched about electronic boards (embedded system) completely designed under this philosophy. Based on this research we will have the schematics of the boards and we will have access to free tool to operate these boards.

Taking in consideration the software requirement, we started to develop our software process plan. Following the standards set in software engineering we divided our process in six phases: (I) Requirements Capture (II) Analysis (III) Design (IV) Code (V) Test (VI) Implementation

Design- Parameters were developed based on the needs of the client and the limitations of the building. John expressed his interest in passive energy systems for the vertical farm, which by itself will primarily occupy two of the six floors of the building. Residential and commercial spaces are also part of the program, and the desire is to provide heating and cooling into these conditioned spaces from the farm. Given these parameters, the following were created:

- Schematic drawings for the program of the entire building that incorporates the farm, the residential and the commercial spaces, as well as a productive greenhouse on the roof
- Passive energy system proposal that includes straw bale insulation of the exterior walls, reuse of the waste heat from the equipment and plants in the farm, and the possibility of geothermal systems.

Marketing- Choosing the right vegetables to plant requires balancing many overlapping factors.

To begin the process, we surveyed our sponsor, our IPRO professor, online resources for farmers, and local farmers. This resulted in a list of 10-15 vegetables with a general idea of their relative value. From there, the team took the following steps to confirm and establish a case for each vegetable:

Use the online database of the USDA to gather the sale price per pound at the terminal market for each vegetable for every week starting with the current week and reaching back ten years.

Graph and analyze the above data to derive trends of the past years and use them to predict the financial success of the chosen vegetables, as well as demand for them in the terminal market.

Find the yield in pounds per square foot per harvest of each vegetable in traditional growing conditions(on a field in the open air). Utilize the number of harvests in a year to calculate value per square foot per year.

Use the yield in pounds per square foot per harvest and the retail price per pound to calculate the base level of dollars per square foot the vegetables could generate if grown traditionally.

Study the optimization an aquaponic system could provide using the prototype and try to build on the base price to arrive at a figure that more accurately represents the profit this project could generate. This figure takes into consideration that organic produce free of pesticides, especially those grown in close proximity to the consumer can be priced higher than their non-organic counterparts grown in grocery stores.

4. Analysis and Findings

Agriculture- From building the prototype we found out that a lot of money is needed to build such a system. We also discovered that a lot of money can be saved by putting the plant beds above the fish tank to minimize piping and pumping, but unfortunately the space where we are building the prototype was too small to do this. We learned that using a siphon filter in the plant beds was the best method to fill and drain the plant beds and giving the proper nutrients to the roots, and is requires no electricity. We learned that watercress has the best water filtering properties, that sprouting plants is easier in soil than in moist paper towels, the fish in the fish tank cannot exceed one fish per gallon, and the ratio of water to volume of plants needs to be around 1 : 1.

Computer Data System- Based in several benchmarks about the performance and security of different Linux/Unix systems and the variety of applications available for each system, we decided to use Debian because it is the most stable platform and has the best performance as well as the wider variety of applications.

During the analysis of the requirements for the development of our system, we notice that it would be problematic if we only let the main computer make all decisions concerning the environmental control of the entire building, because if there is a failure in the main computer, we lose all environmental control of the entire building. Instead of letting the main computer do all the work, we changed the architecture of the system to utilize individual electronics boards to make the decisions concerning temperature control of smaller areas. These boards will send progress reports back to the main computer; in this way the main computer will be informed of the actual status of the building via the electronic boards. With this architecture, if we have a failure in the main computer we will not lose all environmental control of the entire building.

Design- The schematic plans were drawn in accordance with John's program, and helped recognize which areas of the building would be high traffic areas, thus making all but three of the freight elevator shafts obsolete. Unused elevator shafts are useful in air movement because the ducts can run the height of the building from within the shafts, thus providing conditioned air into the residential and commercial spaces. The primary input of the energy system would be waste heat from the farm, but more information is needed regarding the lighting options of the farm in order to provide more accurate numbers for determining and sizing equipment.

Marketing- The data-mining and calculations described in the Organization and Approach section yielded results such as the following:

Vegetable	Value per Sq Ft per Year
Swiss Chard	$18.78
Kale	$6.06
Shiitake Mushrooms	$ 12.96 (per log instead of per sq ft)
Chives	$11.04
Arugula	$23.50
Bell Peppers	$1.99
Button Mushrooms	$27.36

Total Profit Report-

1) Total Profits = (profits from the crop) – (expenses to grow the crops)

The profits from the crop are being compiled by the marketing team, and expenses to grow the crops are being compiled by the architecture team and the agriculture team.

Lighting has many aspects to it which will affect the growth such as wattage of the bulb, intensity of the light, light spectrum in which the lights have a natural tendency to produce, and the pattern at which we will expose the plant.

According to Brew & Grow (B&G):

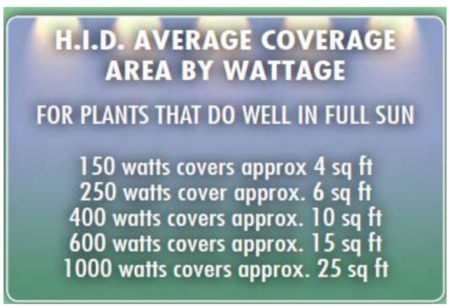


Chart 1, coverage area by wattage

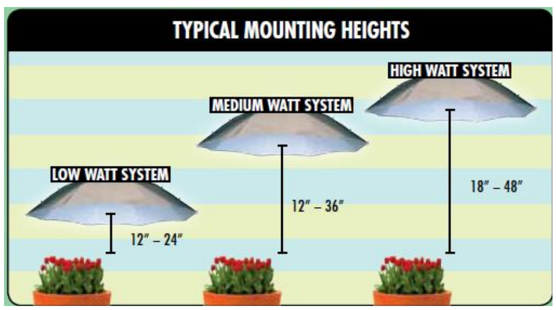


Chart 2, typical mounting heights

Using the data from chart 1, the ratio can be found that describes which has the best coverage with the least amount of watts.

Watts	Coverage(ft^2)	coverage/watt ratio
150	4	0.026666667
250	6	0.024
400	10	0.025
600	15	0.025
1000	25	0.025

Chart 3, Coverage/Watt ratio

The data concludes that the 150 watt lights would be optimal for costs. This may not be the best method however, due to replacement costs for each individual system.

Using Data from Chart 1 and the prices of replacements and systems, a graph of the total maintenance cost for a single square foot was constructed.

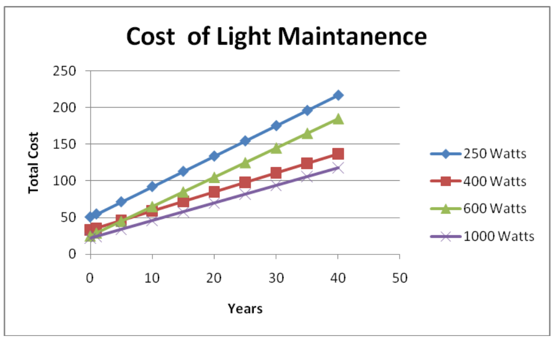


Figure 1, Cost of maintaining a square foot with a hps HID light

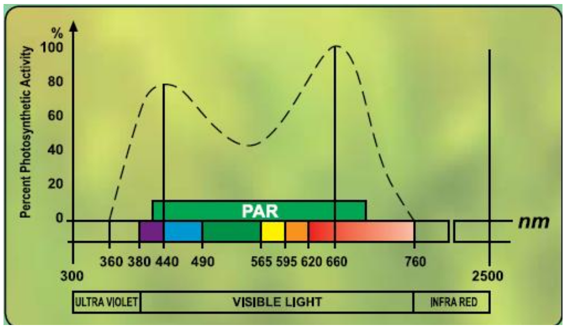
According to Figure 1, we can conclude that the 1000 watt would be the most cost-effective. 150 watts was not listed on the B&G price list, so this graph is not completely unbiased. The prices used were for the HPS universal replacement and the Lumatek Ballistic System listed in B&G's price list. We are assuming that these lights will not be used for a period longer than 50 years, since more efficient lights will be constructed by then.

An idea to optimize space was to stack plants on each other. This is impossible with the larger plants, since they require larger distances. The larger lights require more distance due to the heat produced from the process of constructing the light. This heat may scorch the plants at low distances.

<u>Different types of Bulbs</u>

There are Incandescents, Fluorescents, LED, and High Intensity Discharge lamps. There are also plasma lights being researched, but are far too expensive to be considered in this research, but may be a possible source of light in the future.

Photosynthesis works using the principal that the photons from light ionize the plants and produce electrons that enable the electron transfer chain to occur. Using this idea, we come to the conclusion that increase in photons, or intensity, will increase the growth of the plant. We also know from research that growth is also affected by the frequency of the oscillations of the photon. They tend to respond well to the blue and red frequencies of the visible light spectrum. However, the blue light has a tendency to encourage growth, while the red encourages fruiting.



Using information from B&G, we find that each type of bulb creates a different intensity recorded in chart 4. B&G also provides a chart that gives equivalence of different bulbs.

Type	Lumens/Watt
Incandescent	15
LED	60
T8 & T12 flourescent	30
T5 flourescent	92.6
MH	110
HPS	150

Chart 4, Lumens per Watt of different bulbs

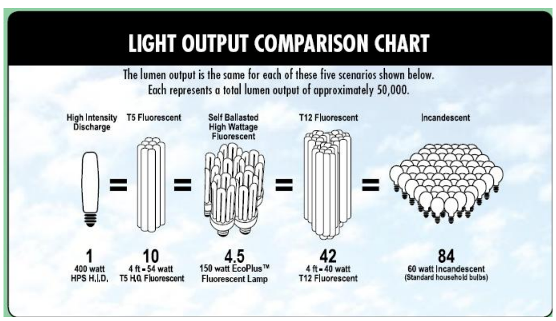


Chart 5, B&G provided light comparison

Electricity Costs

The electric companies charge costs in the form of kilowatt hours (kW/h). They can charge a flat fee or a fee that is determined by the demand for electricity. In the chart below, the number of systems is the amount of systems required to be equivalent to the high pressure sodium system. Data from chart 5 fills the watts and number of systems for all except for metal halide which was found by taking the HPS 150 lumens per watt and dividing it by the lumens per watt of MH, 110. Assuming the photon theory, we can assume that all the light systems have the same coverage, since they produce the same light intensity.

	# of systems	Watts/hour	Coverage (ft^2)	kW/h per ft^2
HPS	1	400	10	0.040
MH	1.363636364	400	10	0.055
Fluorescent T5	10	54	10	0.054
Fluorescent T8 & T12	42	40	10	0.168
Incandescent	84	60	10	0.504

Chart 5

Using the 6l Large service time of day cost estimator, Rate_6l_Large_General_Service_Time-of-day.mht, the following chart was created with the estimated costs for a ft^2 of a plant exposed for 16 hours a day. The cost on peak was created using the following equation.

Cost on peak = kW/h per ft^2 x Time on peak x Cost of 1 kW/h for on peak

According to the cost estimator on peak hours cost .05, and off peak hours cost .02. There were other specifications such as summer hours and winter hours ignored, since a month period wasn't given for those seasons, nor did the calculate button work on the estimator. There was also a $246.39 monthly base charge ignored since it is impossible to acquire the cost per square foot due to the unknown amount of total space to be used in the farm complex.

type of bulb	Time on peak (hours/day)	Time off peak(hours/day)	cost on peak	cost off peak	Cost/day	Cost/year
HPS	3.00	13	0.01	0.03	$ 0.03	$ 11.68
MH	3.00	13	0.01	0.04	$ 0.04	$ 15.93
Fluorescent T5	3.00	13	0.01	0.04	$ 0.04	$ 15.77
Fluorescent T8 & T12	3.00	13	0.03	0.11	$ 0.13	$ 49.06
Incandescent	3.00	13	0.08	0.33	$ 0.40	$147.17

Chart 4, cost to provide electricity for each type of bulb for one square foot

Arugula	$ 23.5
Bell Peppers	$ 1.99
Chard	$ 18.78
Chives	$ 11.04
Kale	$ 6.06
Button Mushrooms	$ 27.36
Shitake Mushrooms	$ 12.96

Chart 5, Profits of each plant in a square foot in a year

Mushrooms do not require as much light, about 12-16 hours of light, so a new chart can be formed for them as seen in chart 6. This data below is used with the full sun specifications in the previous charts, but most mushrooms require shaded to partial lighting, so the cost would be even less, since there would not be as many fluorescent systems applied to the system as there are in the following data.

mushroom lighting	off peak hours	cost/day	cost/year
Fluorescent T5	12.00	0.01	$ 3.07
Fluorescent T8 & T12	12.00	0.03	$ 9.57
Incandescent	12.00	0.08	$ 28.70

Chart 6, mushroom light requirements with full sun

Heating

Waste heat from the lights can be redirected to other parts of the building, including the fish tanks.

Growing Methods

Agriculture is a business experiencing growth in all aspects. There are multiple methods of growing crops in the coming future. We have methods such as the classic dirt, aeroponics, hydroponics, and aquaponics. Each method has their pros and cons. Dirt is a method that has been used and improved before the dawn of many empires and is continued to be used in modern times. Compost piles can be constructed using waste material, worms, and the proper environment, to make cheap and environmentally friendly nutrients for the plants to use to grow.

However, people have attempted other methods such as growing plants downward with a light source beneath the plant. This method allows for more growth due to gravity assisting the plant's growth instead of hindering it. Methods such as hydroponics, aquaponics, and aeroponics remove the necessity to purchase dirt and aeration of the soil. These methods require a special solution to provide the nutrients, but aquaponic systems can contain animals, such as fish to produce waste which can be processed into nutrients for the plants.

Animals

Animals can play an integral role in our environments. Animals have natural abilities that would allow for less work to be done manually by individuals or robotics. Some of these characteristics are to produce waste, pollination, and efficiently produce proteins within them.

Fishes are able to live within the aquaponic systems and do not require much excess light or heat depending on the type of fish. Fish need protein to survive which can come from bugs harvested in the farm, store-bought fish food, or plants growing in the tank such as duckweed. They can also feed on plant clippings as some fish are omnivores. Fish produce ammonia, which is broken down by bacteria in the system into nitrites and nitrates. Plants convert the nitrates into nutrients which act as fertilizer.

Bugs such as bees and butterflies naturally pollinate plants and can be essential to a plants fruiting. The crops grown can only be sold when they are fully matured and bear fruit. These fruit are the only purpose of growing the plants and so vast an area would be foolish to attempt via manpower. Another addition to honeybees are that they produce honey, which can be sold in the market adding to their worth.

Compost heap is a natural system of constructing nutrients, such as nitrogen which is vital in the growth of plants. These heaps can be construct using waste materials found in nearby companies that have biodegradable materials such as food and plants. Shipping companies must trash tons of waste in cases of mechanical failures such as refrigeration failures. This waste can either cheaply be purchased, or possibly be donated and processed into food for the crops that would require a couple months to process. Animals such as worms can expedite this process and casings of these worms are quite valuable to gardeners. These can either be used in our own farms, or sold to individuals who would choose to purchase it from the company to use in their own garden. The requirements would be only to purchase the first group of worms and ensure the proper temperature, humidity, and lighting for keeping a compost heap.

Growing power has constructed a simple system of stacking boxes of waste on top of each other and having worms travel upwards, consuming and breaking down all the waste material into compost. This can easily be replicated indoors.

The fishes that produce the waste will not consume the plants in the aquaponic systems, but will require some other form of food. These foods will contain protein and other nutrients to ensure proper growth so that they will grow large and receive large prices in the market. An economically friendly method may be to grow other animals that are efficient in converting food into proteins. Some animals discussed were roaches, worms, and rabbits. Each of these animals reproduces at high rates, so loss of numbers will not be a problem. They also do not require much room to grow.

Final Computations

In an ideal situation, we would have a completely aquaponic system using the eco-friendly method of receiving donations of waste material to be used in compost heaps. This compost heap would produce worms which can be ground into food for the fishes and the fishes can produce adequate waste material for the crops to grow. The plants will constantly continue to grow, since there are no seasons within the building through consistent lighting and heating. This would allow us to negate all cost for necessities except for that of heat and lighting.

In the ideal case, the following chart would produce the profits per year per square foot of each plant.

	yield profit for a square foot	electricity costs	heating costs	total
Arugula	$23.50	$11.68		$11.82
Bell Peppers	$1.99	$11.68		-$9.69
Chard	$18.78	$11.68		$7.10
Chives	$11.04	$11.68		-$0.64
Kale	$6.06	$11.68		-$5.62
Button Mushrooms	$27.36	$3.07		$24.29
Shitake Mushrooms	$12.96	$3.07		$9.89

Chart 7, Estimated yearly profits using a completely environmentally friendly non-waste system.

This however is ignoring the initial costs to start and implement a system of this caliber. The lighting is using a High pressure sodium lighting and full sun intensity. Some plants do not require such a high intensity such as the mushrooms. Temperature is also constant and plants require more heat when germinating. This also does not take into account the profits made by possible excess compost, fish, or honey sales.

5. Conclusions and Recommendations

Agriculture- We believe that aquaponics will be the best growing method for the farm, as it provides a closed loop system between the fish and the plants, minimizing inputs and maximizing outputs. Lights...

Computer Data System- Three of the six steps in the development software process have been accomplish (Requirements Capture, Analysis and Design). These steps are platform independent, which means that they do not depend on the programming language. We can also utilize this information to start writing the code. Further information about Distributes Computer Systems is required to be able to create a better work synchronization between the main computer and the electronics boards.

Design- Half of the design of the building is in the plans, but the other half lies in the energy system that caters to the comfort of the building's occupants. Given the limited budget of our client and physical state of our atmosphere, we cannot depend on conventional heating and cooling systems as the primary source of comfort for the occupants. By reusing as much of the waste heat and waste material as possible, we aim to create a successful example for buildings of similar type, so future enthusiasts like John can have a point of reference when they set forth to change the world for the better.

Marketing- We established the retail value of each vegetable on our list. These values in time will likely change with the market, and therefore will need to be re-evaluated in the future. The next progression should be to choose the ideal vegetables in a way that allows the parties involved the most appropriate vegetables that fit their resources and needs. An example of what could be considered and questioned in this stage can be; when is the vegetable in a higher demand due to limited geographical resources that are able to grow that vegetable? If the growth and harvest period of this vegetable are planned to coexist with a demand than this in return can supply the demand and yield a potential higher profit.

6. Appendix

Prototype Budget:

Subgroup	Amount	Note
Agricultural Systems	$380	Prototype (paid by IPRO)
	$120	Prototype (paid by Edel)
Design	$0	Team Building Exercises
	$0	Printing Materials
	$0	Modelmaking Materials
Marketing	$0	Printing Materials
	$0	Reference Logging
Total:	**$500.00**	

List of team members:

Subgroup	**Team Leaders**	**Team Members**
Agriculture	Adrien Binet Richard Gulling	Talha Bhatti
		Gaurav Gaonkar
		Michael Kagehiro
		Zachary Phillips
		Jake Skaggs
Computer Data System	Fernando Guerrero	
Design	Emily Chen	Jason Bredau
		Jacob Davis
		Raul Garcia
		Jose Maria Nunez-Gimeno
		Isaac Plumb
		Konrad Sobon
Marketing	Emily Ryan	Preston Andrews
		Elnaz Moshfeghian
		Travis Valmores