Increased Light Efficiency in Vertical Farms - Grant Proposal

iCons I Independent Case Study

Team F

Carly Bell, Emma Cady, Marley Norton, Jacob Tjachman, Maddie Mulkern

PROJECT SUMMARY

Vertical farming is the most innovative form of agriculture seen today, yet it is critically underutilized. One article from NBC News estimates that 50,000 people could be fed from a single self-sustaining building. So why are entrepreneurs not investing? The main issue seems to be cost. Year-round, lower level plants need artificial lighting to grow-- in winter conditions with less sunlight overall, every level of plants requires artificial lighting. The amount of electricity needed to power these buildings leads to expenses that discourage many potential investors. (NBC News, 2013).

Our team believes that by designing architecturally innovative buildings, vertical farming could assimilate into urban areas. Our structures would be designed to optimize the amount of light that reaches bottom levels -- thus, eliminating the extreme cost of artificial lighting that turns many investors away. Our hope is to successfully create models that prove our structure's worth, increasing the amount of light observed at lower levels and decreasing estimated cost accordingly.

Included in our proposal is the history of vertical farming and the issues with horizontal agricultural systems that many farmers currently use. Our team's hope is to create models, both virtual and physical, that prove plants on lower levels of vertical farms can receive similar amounts of sunlight than plants at higher levels. With this even light distribution, we also propose that vertical farming can grow plants just as healthy as those found in traditional farms. The data we collect can be charted into results based on light intensity, and then assessed by our professionals to narrow blueprints to the most plant-efficient, cost-efficient vertical farm since their inception in 600 B.C..

BACKGROUND

While vertical farms have had the most recognition within the past decade, they have technically been around since 600 B.C. The earliest example of a "vertical farm" was in Babylon, built by King Nebuchadnezzar II, known as the "Hanging Gardens." These gardens were irrigated using a chain pump, and towered at 20 meters tall. Fast forward about two thousand years to 1627, and the first concept of hydroponic style agriculture, and growing plants without soil, was hypothesized by Sir Francis Bacon. Nearly 300 years pass, and 1915 brings upon the official term "vertical farming," conceived by geologist Gilbert Ellis Bailey, who wrote a book about farming vertically - underground (Crumpacker).

"Hanging Gardens" in Babylon, 600 B.C.

Progress began to accelerate, and by 1940 8,000 tons of fresh produce was grown hydroponically. It wasn't until 1999, however, that the most modern concept of vertical farming, structures with the sole purpose of growing food, was established by Columbia University, in an attempt to effectively feed New York City. The first indoor vertical farm was built by a company named Nuvege in 2006, and utilized artificial lighting. In 2009, Sky Green Farms in Singapore constructed over 100 towers, each 9 meters tall, designed to grow vegetables using sunlight and rainwater, the first instance of growing vertically without artificial assistance (Crumpacker).

Why, then, for thousands of years, have humans attempted to devise new agricultural practices? What's so bad about traditional farming? Traditional farming is exhausting, and has many limitations. Farms take up a vast amount of space, water, time, and in today's industrialized world, pesticides. Humans have had trouble feeding the rapidly increasing population, and vertical farms might be the answer to efficiently grow, harvest, and distribute generous amounts of produce using considerably less resources. Commercial farming today is detrimental to the environment. It drains the already weakened aquifers, increases carbon emissions from transporting the goods, and creates poisonous run-off from plants over-saturated with pesticides. In order to produce enough food to feed America's insatiable appetite at a low price, farmers feel the immense pressure to grow genetically modified seeds, and use the same-brand pesticides.

What many Americans still see as something to be proud of; huge, vivacious, "family-owned" farms, are destroying ecosystems by killing or debilitating countless species, including pollinators. Currently, 800 million hectares are devoted to farming, which consumes 38% of the world's land. In another 50 years, the predicted population is said to be 8.3 billion and growing. In order to feed that many people, 109 hectares of farmland would be needed (Dispommier). If we continue farming traditionally, this will not happen, because that space simply is not available. Vertical farming would maximize the amount of crops grown in a smaller space, without limitations on growing seasons. It can decrease the amount of water usage from 250 liters down to 20 liters, because all the water being used is by the plant, and not lost through evaporation. Crop yield can increase from 3.9 kg to 41 kg. The ways in which vertical farming is superior to traditional farming is nearly countless. If there is any hope of feeding the sky-rocketing population without destroying the planet irreparably, our habits must be changed. Vertical farming might be the answer.

Vertical farms that are capable of growing immense amounts of produce have already been designed, so why are they not widely used for commercial farming? It turns out, growing massive amounts of produce can be incredibly expensive. Artificial lighting is typically used because of variabilities in weather, season, and location, which can create quite an expensive electricity bill. It takes about 250 kWh of energy every year for every square meter of growing area (The Conversation). However, artificial light may not be necessary. The Earth receives more energy from the sun in an hour than humans use in an entire year (Harrington). If we can utilize this energy, we can create incredibly efficient agricultural systems, and successfully feed the growing population, while simultaneously creating space for them to live and leaving the damaged ecosystems to heal.

By using powerful software to carefully design structures with different materials and orientations, we can create an optimized vertical farm that would require significantly less artificial light. What little amount of artificial light is still needed for off seasons can be produced from solar power.

METHODS

Overview of Study Design

In the beginning of our study our team will brainstorm preliminary models. These models will consider shape, materials, and dimensions. Selecting which models we believe will work best technically, our team will begin developing virtual models using Autodesk 2020 CAD Software. Creating spotlights in CAD, quantitative data can be collected for light intensity. The spotlight will be altered in relation to the structure to mimic sun movement, the angle of depression parallel to the base of the structure will be altered to imitate the angle of sunlight seasonally, and the intensity of the light will be changed to represent differences in overall sunlight over the year. These alterations will hopefully mimic the sun’s changes in the sky over the course of the day, as well as seasonal conditions.

Finally, we will construct physical models with 6 ft diameter bases from the CAD models that performed best. Using actual plant beds, evenly spaced light sensors, and quickly germinating plants, light intensity and plant growth at each level will be measured quantitatively. Because growing plants can introduce a lot of variability, we plan to monitor the details of our experiment to limit the amount of assumptions. Soil pH, controlled air humidity and composition, consistent volume of water over consistent increments of time, equal amount of seeds for germination, extra germinated plants in case some do not germinate, consistent temperature using insulation, and the same volume of soil are all factors that we will control.

MODEL	DESCRIPTION
1 (Control)	A structure with a rectangular base. The structure has multiple shelves on which plants are plotted.
2	A spiraling conical structure. Plants are plotted in shelves that spiral around the cone to the point -- a “spiral staircase” appearance.
3	A cylindrical structure. The structure has multiple shelves on which plants are plotted. This model would make use of solar fiber optic lighting.
4	A cylindrical structure. The structure has multiple shelves on which plants are plotted. This model would contain reflective material on the outside to focus light onto the plants.
5	A cylindrical structure. The structure has multiple shelves on which plants are plotted. This model would make use of both fiber optics and reflective materials.

Data Collection Procedure

The constructed models will be set up in an open field or space on the University of Massachusetts Amherst campus to allow the maximum light with minimal obstructions possible. Assuming an average of twelve hours of sunlight in a day, and the sun moving across about 180° from one horizon to the next, and because our structures are all a circular base, we can place sensors around the structure at every 30° to receive light readings at every hour. That's equivalent to six light sensors on one level of the structure.

Assuming our sensors can automatically record this data, the numerical values from this data will then be transferred to Excel spreadsheets for organization purposes, since there will be data taken continuously for at least two months, or the average growing period for the seeds being grown. This will minimize the amount of operator errors made. This may seem like an excessive amount of data considering the vast time period, but this will give a more precise representation of how plants can grow with only solar power, given the unpredictable weather patterns and obstructions in a designated area.

Quantitative data about the success of the crop growth can be measured using leaf and/or fruit weight and root length. Leaf and/or fruit weight will determine how productive the produce is in the perspective of consumers, and root length will be a good determinate of how healthy the plant is.

Potential Sources of Error

Growing produce can have an immense amount of variability, but if this is controlled and accounted for appropriately error can be minimized. Changes in weather or other obstructions cannot be controlled, but the frequency can be approximated to determine the amount of error.

Some errors occur from operator errors. This can include equipment maintenance neglect. If sensors are damaged, that would be detrimental to the data we collect, even if it is only one days worth. The plants must also be watered very regularly with equal volumes of water manually, because automation is much more expensive and requires electricity.

Procedure error can occur from variability in water, temperature, air composition and humidity, and seed germination. Water can have greatly varying pH levels, amount of minerals, and temperature. Some seeds will not germinate successfully, so error will most likely occur, but this is actually an accurate representation of what can occur in reality.

Optimal conditions for the model would have full sun each day, so when full sun is not achieved, it can be assumed that there is some degree of error that needs to be considered. In an attempt to account for the sun's movement throughout the day, light sensors are placed around the models as discussed. However, some amount of error can occur if sensors do not recognize all the light accurately.

Assumptions

When creating our models assumptions should be as minimized as possible. That being said, it is crucial to address the assumptions made to recognize areas that can be improved.

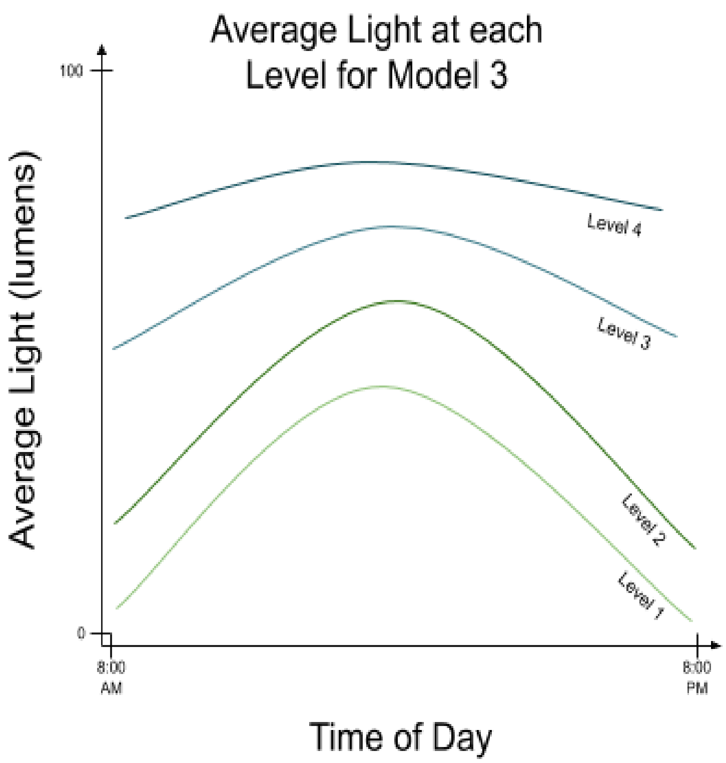
In this case study, we assume that there will be no outside interference or contamination with the plants via fungi, insects, or other pests. We also assume that weather will not be severe enough to cause structural damage or damage to the plant through frost or other means.

Data Analysis & Interpretation

Our data will come in two parts. Part one consists of measurements of light level, in lumens, at many locations on each structure throughout the course of each day for an entire growing season. This data will tell us qualitatively how much light is reaching the plants over time. We will graph the average light level of each floor for every hour between 8:00 AM and 8:00 PM, averaged across all days of the study period. This will tell us how much light each floor is receiving, which is important in determining success of plant growth. If the light level is insufficient, that means that we either have to alter the structure or compensate with artificial light to increase productivity.

Part two will consist of measurements of plant growth. As light intensity increases, the crop productivity can be expected to increase. Productivity can be quantitatively measured using root weight. We will be growing radishes, a root vegetable, so this is an effective metric as the root is the part consumers are most interested in. We will harvest the radishes at the end of the growing season and weigh them after washing and drying them off. We will average the weight of all the radishes from one model to ascertain how efficient each model is at allowing sunlight to reach plants and support them.

Anticipated Results



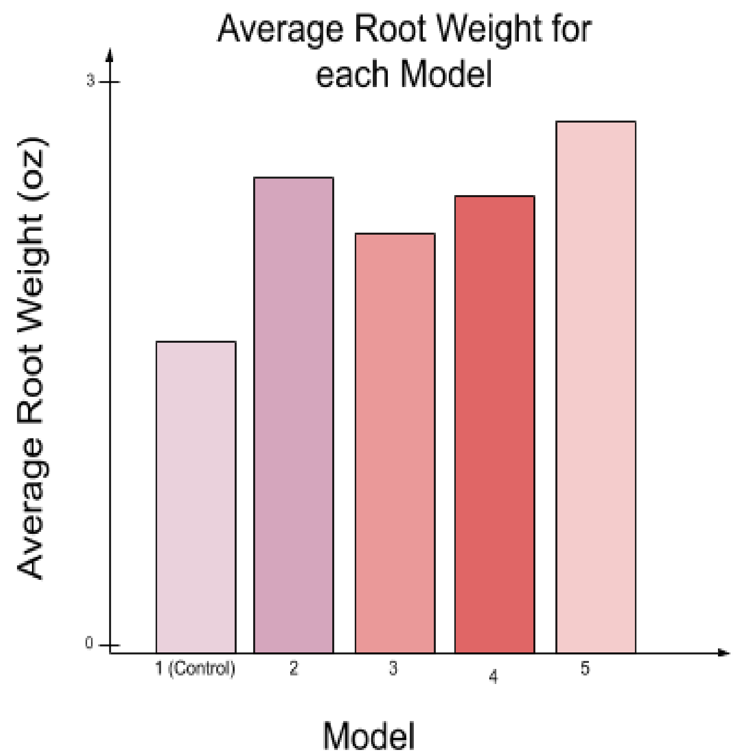


Figure 1 (left) : Average Light at each Level for Model 3Figure 2 (right): Average Root Weight for each Model

Our graphs predict the anticipated results from our study. For Figure 1, the data graphed is the average light at each structure level for any given day, only for model 3. Each model would have similar looking graphs -- time of day along the x-axis, light in lumens along the y-axis, and 4 curves to represent each structure level. Curve flatness correlates with the evenness of light distribution on the model throughout the day. The more parabolic the data for a structure level, then the less even the distribution of light is throughout a given day. The most sun hitting the lower levels when the sun is directly above them and the least sun hitting the lower levels when the sun is rising or setting. The model that does the best job distributing light would be a model whose graph has four, relatively flat curves, that all exist near each other on the y-axis.

Figure 2 represents the average root weight from each model at the end of the growing season when the roots are harvested. This does not take into account how many radishes can fit in each model. For example, model 1 may have small average root weight, but can fit many more radishes than model 2, the cone. Model 2, however, would have fewer, but larger radishes. Our team decided larger radishes would be more desirable to customers, thus we decided to graph average root weight rather than total root weight.

TIMELINE

MONTH	PHASE OF COMPLETION	DESCRIPTION
May	Design Models	As a team, research different structures currently used for vertical farming. Make a list of the pros and cons to each structure. Come together as a team to brainstorm new structures, or modifications to existing structures, that could maximize their efficiency while minimizing current issues.
June	Software Modeling	Download and familiarize the team with CAD software modeling. Create the models chosen from Phase 1. Add a light source to the model and measure (qualitatively) the amount of light hitting each level. Collect the data for each model with the light source in different positions (to mimic the position of the sun throughout a given day). Collect a second set of data where the light source is to mimic winter versus summer conditions.
July	Comparing Results	For each model, determine the average light intensity of each level throughout the simulated "day." Overlay these averages on a single graph for each model -- light intensity on the y-axis and time on the x-axis with multiple series representing the model's levels. Make multiple graphs for the different structures. Do the same from the simulated seasonal data.
August	Report & Proposal	Using the curated graphs, the team will decide which models were the most efficient. Estimate costs, resources, and work necessary to build a larger-scale model (6ft diameter). Create a proposal for funds from the previous phases.
TBD	Physical Modeling	This phase will require a physical model which more efficiently tests the structures' actual ability to hold and grow plants. This portion of the project requires a longer time commitment -- over the required growing

		seasons -- and multiple trials -- plant growth can be variable. Hopefully, the data and proposal can secure the funds necessary to further pursue this project.

MATERIALS AND BUDGET

As this is a sustainability project, it makes sense to have the models themselves be built sustainably and from sustainable or reclaimed materials.

ITEM	DESCRIPTION	COST (USD)	BREAKDOWN
CAD Software	Autodesk 2020	0$	Licensing through UMass gives access to this software for free.
Building materials	Reclaimed wood, Nails, Screws	$90	Hardware store - $3 per 2x4 $10 for nails/screws
Technology	Solar Panels, Light Sensors, Fiber Optics, Mylar, CAD Modeling (Materials that are elevating the models)	$190	Hardware store - $10 per light sensor kit x12 Lighthouseleds.com - $1 per fiber optic 10 ft cord Tapplastics.com - $9 per roll
Plants/ planting materials	Radishes, Soil	$25	Hardware store - $9 per bag of pot soil Amazon - $7 Radish Seeds

Watering Supplies	Hose, Watering Can, Water itself	$265	Hardware store- $10.99 15 ft Utility Hose $6.99 2 gal Watering Can Rest of cost is based on ½ of the average annual water bill for an Amherst household
Tools/ Building equipment	Gloves, Safety Glasses, Drills, Hammers, Saws	$0	All of these materials will either be borrowed from others or taken as donations
Manpower	To perform the assembly and to check on the sensors	$0	Volunteers/ our own staff working for free
TOTAL COST		$570	

KEY PERSONNEL

Our team is composed of intelligent and highly motivated people with unique skills that serve our study's goals. All of us have experience working in groups, and have the communication skills necessary for strong collaboration.

Marley Norton, our project coordinator, is a creative and driven leader who completed a senior internship on grant writing. With this experience they are best suited to guide the team throughout this process. Their contribution ensures that our team meets frequently to discuss the latest innovations in current vertical farms, as well as helping other team members bring out the best of their skills throughout the entire research process.

Carly Bell has past experience modeling with CAD software. She and Jacob Tajchman, who studies computer science, both have the tech skills necessary to design easily-exportable virtual models that will be used in the rest of our study. Tajchman has formal experience with experimental design, and will ensure that our hypothesis is testable and our procedures are replicable.

When it comes to looking at this data and comparing it to determine the most efficient model, Emma Cady's critical thinking skills make her the forefront analyst of our team. In addition, her experience in leading presentations means we will have professional and easy to understand designs for charts and public presentations.

Maddie Mulkern, who received honors for their senior capstone, has the writing prowess necessary for a formal report detailing the results of the study. If our study is fully funded to allow for the physical demonstration of our models, Mulkern's employment at a garden center lends them experience needed to carefully tend to the plants we will grow.

RELEVANCE OF PROPOSED STUDY AND BROADER IMPACTS

We expect our work to inform the designs and applications of commercial vertical farms to be used in urban areas. Understanding how to design a more efficient model provides the opportunity for engineers to improve the current agricultural state. Dispersing our designs to a broader audience can educate the public about sustainable agriculture. This should make vertical gardens appealing and more welcoming to consumers and farmers. which lays down the framework for policies supporting the construction of vertical gardens with greater production capacities.

People who are looking to cut the costs and increase the efficiency of vertical gardens. For example, farmers and consumers will benefit from decreases in transportation costs. Since vertical gardens don't sprawl in the way traditional farms do, they free up space that architects and city planners can take advantage of. With this, populations can benefit from more open areas coupled with the efficiency of growing crops closer to large population centers (NBC News, 2013).

Humans are highly visual creatures, and the aesthetic appeal of a lush vertical garden could attract people to live in the neighborhoods around it. Vertical gardens, towers of green, beautify the area around them and clear hazy smog through plant respiration. In crowded, stress-filled cities this is especially valuable, considering greenery promotes positive mental health (Poplett, 2018). Mental health isn't the only thing that vertical gardens benefit: they offer fresh produce to urban areas, a frequent home to 'food deserts' that lack healthy goods (Mead, 2008), which promotes good nutrition. and their lower transportation costs and decrease smog through plant respiration, and increase land available for other projects. However, as of this proposal the full extent of these benefits has yet to be implemented on a truly effective level. Our virtual models are the perfect tool to share information about the boons of vertical farming, as they can be converted into image files that we can easily export to other web-platforms. Our current plan is to create a professional website with our data and background research displayed in shareable articles. This website will serve as our 'hub' to update our communities on the latest findings regarding vertical gardens. In addition, we plan to use a QR code to link to the website, and paste these stickers onto public boards in urban areas. so creating a website to exhibit them and their associated light data is the most efficient way to communicate our findings. Links to this website can be posted on Facebook, or distributed on QR codes posted in densely populated areas. To truly cause a broader impact, the general public should be able to access our study. Utilizing the internet and the ease one has spreading information through it, we predict that we will grow the future of urban vertical farming to new heights.

REFERENCES

"Could Vertical Farming be the Future?". *Frontiers: NBC News*, 2013. http://www.nbcnews.com/id/21154137#.Xq3i2y_Myu5. Accessed 2 May 2020.

Crumpacker, Mark. "A Look at the History of Vertical Farming." *Medium*, Medium, 19 Oct. 2018, medium.com/@MarkCrumpacker/a-look-at-the-history-of-vertical-farming-f4338df5d0f.

Despommier, Dickinson D. "The Vertical Farm: The Sky-Scraper as a Vehicle for a Sustainable Urban Agriculture." *Mailman School of Public Health, Columbia University*, January 2008. https://www.researchgate.net/publication/241325575. Accessed 4 May 2020.

Harrington, Rebecca. "This Incredible Fact Should Get You Psyched about Solar Power." *Business Insider*, Business Insider, 29 Sept. 2015, www.businessinsider.com/this-is-the-potential-of-solar-power-2015-9.

"Is Vertical Farming Really Sustainable?" *EIT Food*, www.eitfood.eu/blog/post/is-vertical-farming-really-sustainable.

Jenkins, Andrew. "Food Security: Vertical Farming Sounds Fantastic until You Consider Its Energy Use." *The Conversation*, 20 Jan. 2020, theconversation.com/food-security-vertical-farming-sounds-fantastic-until-you-consider-its-energy-use-102657.

Mead, Nathaniel M. "Urban Issues: The Sprawl of Food Deserts". *Environmental Health Perspectives, 116(8),* A335. 1 August 2008. https://doi.org/10.1289/ehp.116-a335a

Poplett, Emilie. "Horticultural Healing: Plants and Mental Health". *Association of American Universities*, 27 November 2018. aau.edu/research-scholarship/featured-research-topics/horticultural-healing-plants-and-mental-health.