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Vertical Farming: Creating an Accessible and Sustainable Future

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ABSTRACT

Vertical farming is becoming an increasingly prominent industry in today's world of sustainability. With decreasing land availability, agriculturalists are looking to build farms upward to maximize efficient use of space. However, this industry is expensive and inaccessible to many people due to the dominance of urban lifestyles. This project explores the roles of the engineering and design process in manufacturing more accessible vertical farms in the US through sustainable practices. The vertical farming industry is becoming increasingly advanced through methods such as controlled environment agriculture and technology to optimize growth factors such as lighting through data capture, real-time feedback, and automated farming systems. This paper considers factors that will contribute to reducing the carbon footprint of vertical farms, making them more sustainable and accessible to the public. This experiment uses easily accessible materials to design a practical at-home hydroponic garden for growers, applying sustainable practices and technologies to enhance the farming process. The vertical garden, which will produce lettuce and strawberries, will generate a significantly lower carbon footprint than a conventional farm while still effectively producing edible food. This paper analyzes the cost and resource efficiency of an at-home vertical farm system and how this compares to conventional soil methods.

Keywords: vertical farming, hydroponics, agricultural technology, accessibility, sustainability.

INTRODUCTION

The depletion of available farming land is causing a crisis in the farming industry. With the effects of climate change and the urban sprawl, the amount of available farmland is rapidly declining. Vertical farming is becoming an increasingly prominent solution to this issue today. Building upwards rather than outwards has proven a more effective use of space and resources. However, it can be costly and difficult to start up a vertical farm, making it inaccessible for many growers. This paper explores the role of design in manufacturing accessible and sustainable vertical farms as well as analyzing the process of constructing a practical at-home farm.

Vertical farming, defined as "the practice of growing plants in vertically stacked layers, vertically inclined surfaces and/or integrated other structures," (Bustamante, 2018) has recently emerged as an industry with the effects of climate change on conventional farming practices. With soil depletion and a reduction of available land, agriculturalists have found a space-effective solution: growing crops vertically. Vertical systems will provide solutions to massive population growth and urbanization. Since the world population is expected to reach 9.7 billion in 2050 with 80% of people living in cities (United Nations, 2023), this industry enhance the network of food production and distribution throughout cities (Jürkenbeck et al., 2019). The expansion of this industry to urban settings will play a large role in the future of agriculture and sustainability.

These farms use water-efficient techniques, mainly hydroponic, aquaponic, and aeroponic farming, which are all independent of soil (Sharma et al., 2019). Thus, most vertical farms are located indoors, as this allows for an artificial environment. Through a method called Controlled Environmental Agriculture, plants grow in a controlled environment with regulated temperature, lighting, and humidity to provide optimal conditions (Bustamante, 2018). The regulated environment provides defense from diseases as well as reducing emissions, water usage, and space.

Because this industry is expensive, engineers and agriculturalists are aiming to reduce startup prices while achieving sustainable goals. Engineers have found that the most prominent limiting factors in the adoption of vertical farms are lighting and energy costs. Because large-scale indoor requires an artificial environment, the cost of energy for LED lights and temperature control considerably exceed energy prices generated by traditional farms (Dutia, 2014). Improvements in the efficiency of energy use are the clearest way to increase the implementation of vertical farming.

A major step in developing the vertical farming industry is utilizing more sustainable practices to find less costly energy solutions. Vertical farming could develop jointly with renewable energy, as solar energy and other green power sources can be far less expensive alternatives to electricity. These options should play a role in the designs of future vertical farms, contributing to more affordable and accessible systems.

In this project, an original at-home hydroponic vertical farm is designed using accessible materials and sustainable practices. To help address the issue of the inaccessibility of vertical farming, this paper shares the process of designing and manufacturing a feasible hydroponic farm for anyone to build. It presents an easy design method utilizing easily accessible materials and technology to construct a vertical farm to produce fresh crops for gardeners looking to save space and water. This paper explores the benefits and drawbacks of constructing and implementing an at-home vertical farm as well as comparing the costs to those of a conventional garden.

While technology and renewable energy present areas of improvement in the future of large-scale vertical farming, this at-home vertical farm serves as a practical solution for growers looking to save resources. Although the current cost of integrating a vertical farm will likely exceed the cost of buying produce at a grocery store, the cost efficiency will potentially surpass that of grocery shopping as vertical farms develop in the future.

1.2 Hydroponics

One major incentive for the development of vertical farms is to accommodate urban life. These system's ability to be integrated into already existing spaces such as warehouses allows them to be easily incorporated into urban areas (Bustamante, 2018). Providing access to fresh produce in cities contributes to both accessibility and sustainability. The localization of food production drastically reduces the costs of transportation as well as minimizes energy and pollution output (Kalantari et al., 2017). Furthermore, the integration of vertical farms into existing infrastructure combined with the optimization of spacing saves immense amounts of land (Kalantari et al., 2017). This proposes a practical solution to saving land in cities.

This system uses hydroponics, one of the most widespread types of irrigation used in vertical farming (Al-Kodmany, 2018). Hydroponics systems are used to create the perfect artificial micro-climate for plants to grow, as environmental factors such as temperature, humidity, pH, and nutrient solutions that provide the ideal conditions to the plants (Asao, 2012). There are many ways to utilize hydroponics, but this project uses a vertical form of a drip, or substrate, system in which a nutrient-rich solution is pumped to the top of a tower and the solution drips down to individual plants (Sheikh, 2006). An example of a vertical drip system is shown in Figure 1 (Peters, 2023).

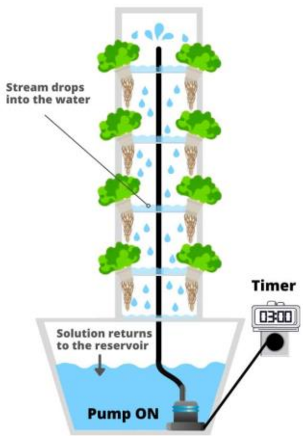

Figure 1: Example of a vertical hydroponic drip system in a grow tower.

Additionally, this experiment uses rockwool cubes, a common medium for plant propagation in drip systems. These are dense cubes made with the fibers of basalt rock and chalk, which retain more water and oxygen than other soil mediums, providing a higher nutrient quality (Sheikh, 2006). Out of the many different types of hydroponic systems, drip systems are one of the more affordable and simple methods. This makes it an optimal choice for this project, as its simplicity makes this method an accessible option for the public.

Hydroponic agriculture serves as one of the most efficient methods of water consumption in farming. A closed-loop hydroponic system can save up to 95% of the water used by traditional agriculture methods because the crops can be spaced out in a way not possible with soil methods (Kalantari et al., 2017).. Additionally, hydroponic farming yields much more crops than soil method yields. For instance, the average yield of lettuce through hydroponics is 21,000 pounds per acre, more than double the 9,000-pound yield for soil methods (Sardare & Admane, 2013). This study compares the amount of water and energy usage of an at-home hydroponic farm to the resource usage by conventional farming methods, analyzing whether these statistics hold true not just for commercial but also for at-home vertical farming.

1.3 Agricultural Technology

Agricultural technology, or AgTech, is making vertical farming smarter and more efficient. The use of sensors and data collectors in indoor farming systems to optimize crop growth will help save costs and resources, reducing waste and the environmental impact of these systems.

Hydroponics can be used in conjunction with AgTech to provide optimal growing conditions for the plants. Vertical systems often integrate forms technology such as sensors that track the growing conditions and automatic heating and cooling systems to maintain an ideal climate. The main types of AgTech observed in vertical farming are precision agriculture, smart farming, and digital agriculture (Siregar et al., 2022). This experiment utilizes smart farming, which applies intelligent technological advancements in agriculture by utilizing modern technologies such as Internet of Things (IoT) platforms to optimize farming systems (Siregar et al., 2022). This method focuses on data collection and analysis to ensure that the system operates in a way to produce the best results. AgTech will enable farms to be more productive, allow for consistent yields, reduce risks and recurrent costs, and make agriculture more environmentally friendly.

However, AgTech is still a developing sector and requires high costs of initial investment as well as further research to reach a substantial level of efficiency and sustainability (Dutia, 2014). These systems can be expensive to implement, and most of the existing AgTech is used by private companies and is inaccessible to the public. As the AgTech sector expands, funds are needed for research and development, primarily financed by private investors (Dutia, 2014). There is much room for improvement in this field, and many companies are starting to invest in AgTech research.

The hydroponic system in this experiment utilizes humidity and pH sensors: simple and affordable technology to track basic environmental factors and create a semi-autonomous system. It applies a process of data collection to automatically control the frequency of delivering water to the plants as well as reading pH levels to alert users when pH adjusters are needed. The electrical components of this vertical farm will be further elaborated on in Section 2.4.

MATERIALS AND METHODS

2.1. Design Overview

This project uses a hands-on approach to addressing the issue of accessibility in vertical farming, experimenting with a grow tower design. This model was designed to maximize efficiency while using affordable and accessible materials, and to fabricate a straightforward design that can be easily replicated while minimizing maintenance costs.

This design takes inspiration from various commercial vertical farm designs. One type of model, a vertical grow tower, appeared to be the best choice because of its space efficiency. An example of this design is the Tower Garden FLEX Growing System by Tower Farms (product number GT350). The dimensions of this tower are 52” in height with the basin width and length 30”, while being able to hold up to 20 plants.

In this experiment, the tower is divided into two sides to allow growers to produce two crops simultaneously while preventing the two nutrient solutions from mixing. The total structure is approximately 45” tall with a length of 12” and a width of 24”. It can hold ten gallons of water, five on each side, and nine plants, divided into five on one side and four on the other. Since hydroponic vertical farming favors leafy greens (Bustamante, 2018), romaine lettuce was chosen as the main output. Hydroponically grown lettuce can be harvested at a much faster rate than conventionally grown lettuce, fully grown after 35 to 40 days of production (Sharma et al., 2019). Additionally, this project will grow seascape strawberries as the second output to test how a non-leafy green will grow hydroponically, and the fruit’s small size will be suitable for the system. These plants were grown in is a warmer climate with moderate humidity, typically with an average of 70-80°F in the summer and 55-65°F in the winter (*NOAA National Centers for Environmental Information*, 2023).

2.2 Materials

The construction of this vertical farm tower is split into two parts: assembling the structure and integrating the technology components, then putting them together. For the tower assembly, the materials can be easily obtained at any home improvement and hardware store, or online. The following materials with in-store unit numbers listed were purchased from Home Depot. The framework for the tower uses four 2-gallon buckets (SKU #150679) with lids (SKU #150679) and two 5-gallon buckets (SKU #672358) with lids (SKU #723222) for the basin, all composed of recycled plastics. To divide each of the bucket layers in half, one 12x24” plexiglass sheet (SKU #241610) was used per layer. An extra sheet was also used to support the base of the tower on top of the basin. A scoring knife (SKU #241610) and a ruler are required to cut these plastic sheets. A reversible electric drill was used to create holes used with the following size drill bits: a 3” circular attachment to hold the plants (SKU #229544), ¾” for the water pipe, and 1/16” for drainage holes.

Super glue and caulk, both obtained from hardware stores, as well as a caulking gun are necessary to secure and waterproof the plexiglass dividers. Lastly, a sharpie and pliers are needed to mark appropriate places to drill and to remove the bucket handles, respectively.

This system harnesses a very simple understanding of agricultural technology and uses basic electronics. Inside the vertical tower, two 12V submersible pumps (Vansuna, Item Number 40Q-1206) were used, one on each side. The main software was an Arduino Uno R3, used to perform the simple functions necessary to maintain the vertical farm. The AgTech components used to create a self-sufficient system were a DHT11 humidity and temperature sensor (BOJACK, Amazon ASIN: B09TKTZMSL) and a pH electrode probe (KETOTEK, Amazon ASIN: B07RRTZ8LF). To control the voltage running to the Arduino and the pumps, an AC110V relay (HiLetgo, Model Number 3-01-0341) is used with a wire connector. Additionally, a breadboard and jumper wires are necessary to connect the system as well as a power supply to generate power for the system.

In addition, to maintain the hydroponic solution, a general A&B hydroponic nutrient solution is necessary as well as hydroponic pH acid and base adjusters to support a stable pH. This nutrient solution provides an adequate foundation nitrogen, calcium, and iron for the plants. The plants are grown in 3” hydroponic cups (xGarden, Amazon ASIN: B07W9H8ZRH).

The lettuce and strawberries in this experiment were bought as seedlings and transplanted into the hydroponic system rather than germinated on their own, which tests the plants' main growth after undergoing germination. The plants were purchased during construction of the system, and their growth was maintained until the system was functioning and able to support the plants.

2.3 Tower Construction

The initial step in constructing this vertical farm design is to fabricate the structure of the tower itself. First, the handles of the buckets were removed using pliers. With a sharpie, a line was marked on the 2-gallon buckets to indicate the divider placement. The locations of the divider and the drainage holes in the bucket were marked following the pattern shown in Figure 2. Then, using the 3" diameter circular drill attachment, three holes were drilled into the sides of each 2-gallon bucket, halfway up the bucket placed above where the three drainage spots are. These holes will serve to hold the plants in the system. Using a ¾" and a ⅛" drill bit, a pattern of holes was drilled into the bottom of each bucket as shown in Figure 2. The ¾" holes are for the water pump tubes to reach the top of the tower, while the ⅛" holes allow water to drain on the plants below. The ⅛" holes are a good size because they do not drain too fast nor too slow.

For the bucket lids, the 3" circular drill bit was used to drill three holes into a shape that allows for water to drain from the bottom of the bucket on top regardless of what side it is on. The appropriate shape is pictured in a more detailed modeling of the holes and dimensions of each layer shown in Figure 3, and the arrangement of the drainage holes for the bucket lids in Figure 2.

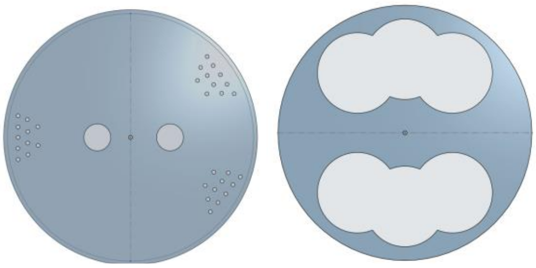

Figure 2: CAD model in Onshape depicting placement of holes in each 2-gallon bucket for draining. The left shows the bottom view of the bucket with the ¾" and ⅛" holes, while the right shows the top view of the 3" holes in the lid.

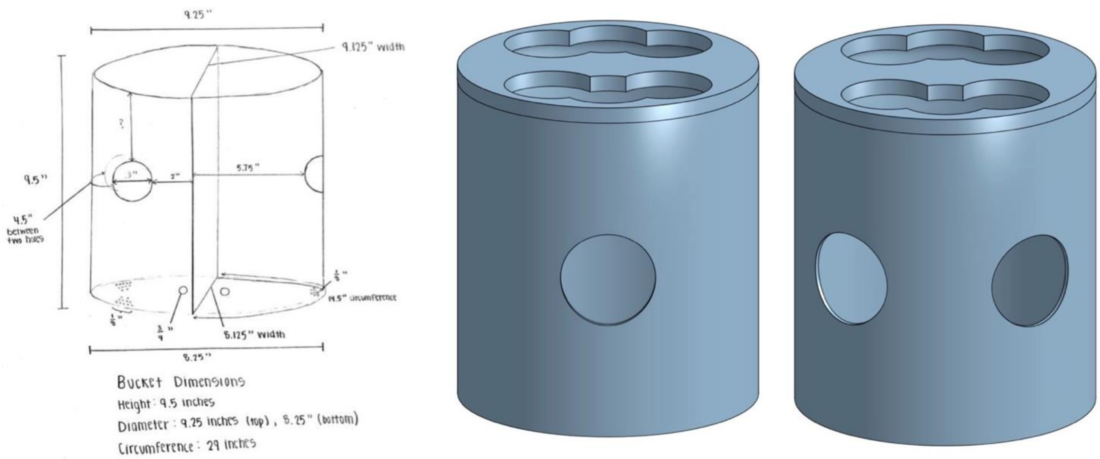

Figure 3: The left image shows a sketch of the dimensions for each of the three 2-gallon bucket layers as well as the placement of holes to hold plants and for drainage. The two right images show a 3D CAD model in Onshape of two views, one from each side, of the layers with the 3" holes.

With a sharpie, each plexiglass sheet was marked into a specific trapezoidal shape with bases 8.125” and 9.125”, and a height of 9.5”. This specific size was necessary for the sides of the plastic sheet to perfectly line up with the inside of the bucket and prevent leaking. Using a scoring knife on a ruler, this shape was scored on both sides until flexible enough to snap. Then, each divider was super glued into the bucket, then left to dry for 24 hours. Once the superglue was dried, the edges of the dividers were caulked using a caulking gun to waterproof the divider. Again, this was left to dry for 24 hours and then tested to ensure that the dividers prevented leaking. With the last plastic sheet, an 8 x 12” rectangle was scored and snapped out of the middle, leaving a border to support the base of the tower while leaving space for the water to drain from the bottom layer into the basins. The drainage holes of the 5-gallon buckets were cut in the same way as the 2-gallon bucket lids, using the 3” circular saw attachment and drilling holes to line up with the drainage holes. The final layout should look roughly like the model shown in Figure 4.

To prepare the tower to support growing the plants, the 3” hydroponic cups were used. Slits were cut into the sides to make sure that they would fit inside the 3” holes at an angle to let the plants grow both out of the tower and upward, and these were then super glued into the holes. Duct tape was placed under each hydroponic cup to prevent water from spilling out of the system through the slits in the bottom of the cups. Once the individual layers were ready, each bucket was stacked on top of each other on top of the two basin buckets as shown in the figure above. Then, hot glue was used to attach all these buckets in place, carefully lining up the layers so that it would drain properly. An image of the final construction is shown in Section 2.5.

2.4 Electrical Components

Once the main structure was fabricated, the electrical components of the system were prepared. The main objective of the electrical setup was to record the temperature, humidity, and pH of the system and control water given to the plants while monitoring the pH. The principal electric component was the Arduino R3 board, which uses C++ code to control the water pump and sensors. A setup of all the connections was initially drawn up, shown in Figure 5.

Then, the sensors and relay were tested to ensure compatibility with the Arduino. As shown in Figure 6, the DHT11 sensors were connected to the Arduino, as was the control from the pump. The 5 volts and the ground on the Arduino were both connected to a breadboard to allow for multiple connections with these inputs. The power supply transformed the 120V AC from the wall to 12V DC for the pumps to use.

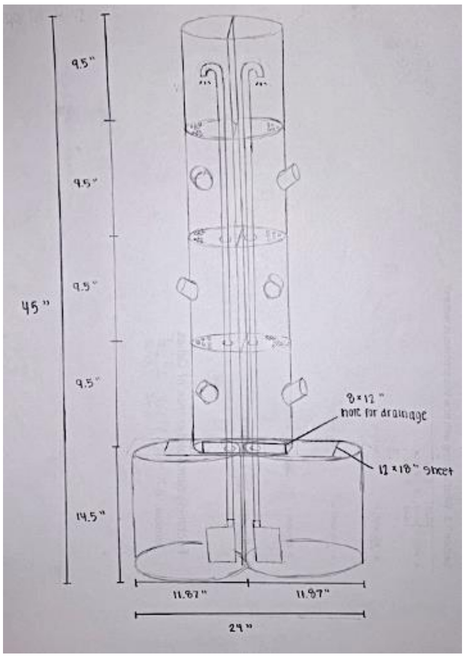

Figure 4: Sketch of a basic model of the vertical farm structure.

While programming the functions for the Arduino, it was important to download the DHT Sensor Library from the Arduino IDE application to be compatible with the DHT11 sensors. The basic functions of the code were to read the temperature and humidity values from the DHT sensor, and automatically water the plants if the humidity drops below a certain number. 60% humidity was found to be an adequate value for the environment that the plants were being grown. If the humidity falls below 60%, the pump will turn on and water the plants for 60 seconds before turning off. The code also ensures that the plants will receive water even if the humidity sensors become flawed. To ensure daily watering, the code includes a daily counter in which the pump will turn on for 60 seconds every 24 hours. The Arduino code can be provided upon request from the author.

The placement of each electrical component in the system is subjective and can be altered. For this experiment, the humidity and temperature sensors were placed in the top bucket with plants because this layer is the driest and those plants will need water the most. However, this placement requires longer wires for the sensors to reach the top of the tower. An alternative option is to keep the sensors in the lowest layer to minimize the length of wire needed and decrease threshold of humidity from 60% because this layer is more humid. The pH sensors are located in the basin where most of the water is stored, indicating when to change the pH of the water in the system.

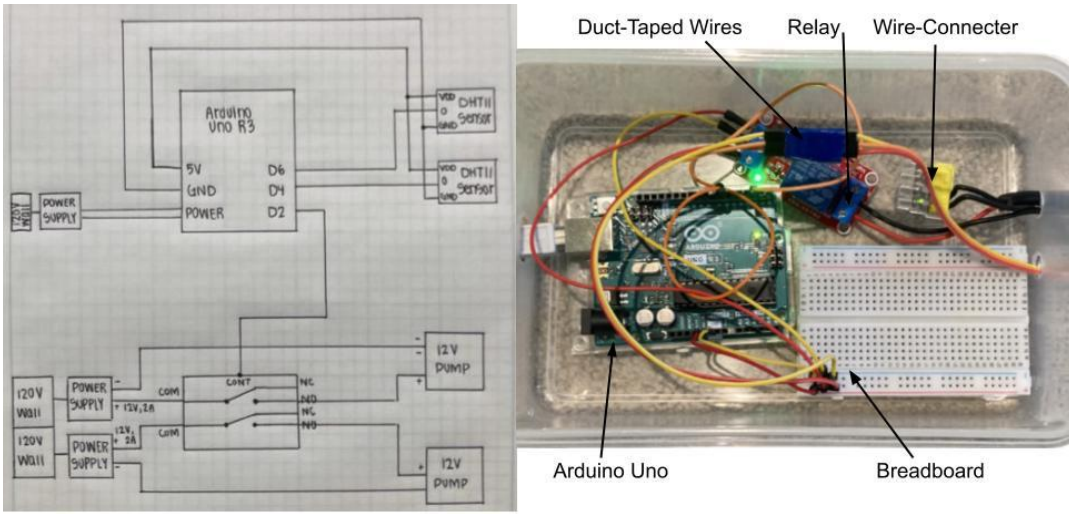

Figure 5: Model of all the electrical connections comprising the technology used in this system.

Figure 6: Final construction of the vertical grow tower; system with lettuce shown on right.

Figure 7: Process of lettuce being placed into rockwool cubes.

2.5 Final Construction

Once both the tower construction and the setup of the electrical components and code were complete, these two elements were integrated together into the final product. To make sure that the structure was stable and would not fall because of wind, multiple large rocks, weighing a total of about 10 pounds on each side, were placed into the basin buckets to weigh the tower down. Then, the ½" tubing was attached to the pumps and placed in the basin while fitting through the holes in each layer to reach the top bucket to pump water. The DHT11 humidity sensors were placed in the highest bucket with plants and attached to the inside lining of the bucket with tape. Both the wires from the humidity sensors and the pumps connected to the Arduino through holes in a plastic box to keep the Arduino, breadboard, and relay safe from water and natural occurrences. The setup of this electrical box is shown in Figure 5, and the final construction is depicted in Figure 6.

2.6 Integrating the Plants

Once the structure is built, the plants can be transplanted into the system. To transfer the lettuce and strawberries from soil to hydroponics, they were first taken out of their soil and their roots were soaked in water to prevent contamination of the nutrient solution. Once this process was complete, the roots of the plants were placed into the rockwool cubes as shown in Figure 7. When the plants were securely positioned into the rockwool, they were placed into the hydroponic cups in the tower, making sure that the strawberries and lettuce were either side. The plants were placed into the cups at an upward angle, and extra rockwool was used to maintain their position and restrict movement. The vertical farm after the implementation of the lettuce is shown in Figure 6.

RESULTS AND DISCUSSIONS

3.1 Functionality

This system is autonomous apart from having to replace the water and nutrient solution every two to three weeks. The program continuously recording the humidity of the top layer every minute, and If the humidity reaches a level below 60% relative humidity, the pump will run for a minute. However, since the water is pumped quicker than it drains, the pump is programmed to run in twenty-second increments and then wait for thirty seconds to let the water drain, then repeat until it has run for a total of a minute. This prevents overflowing of the top layer and reduces the pressure in the top bucket to minimize the chances of the divider detaching. Additionally, the code has a daily timer to run the pump every 24 hours, making sure the plants still receive water even if the sensor doesn't work properly. The pH sensors measure the pH of the water in the basin. Although they do not automatically re-adjust the pH, they indicate when the water requires pH adjusters. The automation of pH maintenance is an opportunity for improvement, but since there is little interaction between the water and outside factors, adjusting pH should be an infrequent occurrence.

3.2 Cost Analysis

The final fixed costs associated with the materials are shown in Table 1 all listed as of 2023.

Overall, the fixed costs of this at-home vertical farm are similar to those of commercial farms sold online. Although most large-scale vertical farming companies have complex indoor systems and don't sell small scale designs, some companies will sell grow tower systems like the one in this experiment for anywhere between $200 and $700. For instance, the FLEX Growing System by Tower Garden referenced in Section 2.1 sells for $670, while another commercial tower, HydroBuilder's EXOTower 3-Tier Hydroponic Garden Tower (SKU # 11-300), is marked at $219. These costs vary due to obvious factors like size but also because of differing levels of autonomy and resource efficiency. Since the less costly ones likely do not use the level of agriculture technology explored in this paper, this experiment proves to be a relatively efficient and cheap way of producing your own vertical farming system.

The additional variable costs only include electricity and water. Even so, this design does not use LED lights and instead utilizes natural lighting, which cuts down much of the energy cost. The cost of electricity comes solely from that used by the power supply, which takes about 10 W of electricity per hour. The final electricity cost as well as other variable costs (Table 2.).

In a study produced by the University of Nevada, Reno, Chenin Treftz and Stanley Omaye conducted an experiment comparing the fixed and variable costs of growing strawberries through hydroponics versus soil. In their study, the costs of hydroponically grown

Table 1 : Approximate fixed cost of materials to construct the vertical grow tower.

Item	Amount	Total Cost
2-gallon Paint Bucket	4	$20.00
2-gallon Paint Bucket Lid	4	$10.00
5-gallon Bucket	2	$10.00
5-gallon Bucket Lid	2	$6.00
Plexiglass Sheet 12 x 18”	5	$60.00
3” Circular Drill Attachment	1	$23.00
¾” Drill Bit	1	$12.00
Superglue	1	$8.00
Caulk	1	$13.00
Arduino Uno R3	1	$37.00
12V Submersible Pump	2	$51.00
DHT 11 Humidity & Temperature Sensor	2	$6.00
110V Relay	1	$7.00
Jumper Wires + Breadboard	1	$13.00
Hydroponics pH Sensor	1	$20.00
3” Hydroponic Cups (50 pack)	1	$13.00
Total Items	**42**	**$309.00**

Table 2 : Variable Costs Associated with Strawberry and Lettuce Growth for One Year

Item	Amount (frequency per year)	Cost
Romaine Lettuce Seedlings (6 seedlings)	4	$36.00
Seascape Strawberry Seedlings (25 seedlings)	2	$32.00
A&B General Hydroponic Nutrient Solution	3	$54.00
1” Rockwool Cubes (200 count)	1	$14.00
Electricity	87.6 kW	$22.00
Total	10	**$168.00**

strawberries more than doubled the costs of soil methods (Treftz & Omaye, 2016). Similarly, the expenses of hydroponics for the system explored here also exceeded the cost of soil-grown strawberries found in Treftz and Omaye’s study as well. However, the one-year costs were much closer to the cost of soil farming found in their study. Regardless, the hydroponic method saved more resources and proved to be the more sustainable option. Continued research in optimizing the cost efficiency in vertical hydroponic farming will make it a cheaper alternative to conventional methods in the future.

3.3 Resource Comparison

Evidently, this system can save a great deal of space compared to traditional farming methods. Although the implementation of this system exceeds the cost of planting crops in soil, this vertical growth tower exponentially saves space, which poses a garden alternative in an urban world where living space is decreasing. While most types of lettuce and strawberries grown traditionally in soil need to be spaced 12-18 inches apart, this system can grow nine plants in a horizontal space of two square feet. Thus, this hydroponic system is around 1.5x more space efficient than conventional methods, as soil production would only support six plants in this amount of space.

Additionally, this system uses significantly less water compared to traditional soil farming methods. Treftz and Stanley’s experiment showed the soil system to use 30% more water than the hydroponic system for strawberries (Treftz & Omaye, 2016). This experiment’s system holds 16 L, or about 4.2 gallons of water total. Assuming this water is replaced every three weeks, a total of 72 gallons of water are used in a year to grow both lettuce and strawberries, which is about 14% of the water used for soil-grown strawberries in Treftz and Stanley’s experiment. Compared to the statement that hydroponic systems can save up to 95% of the water used through conventional methods, the 86% of water saved in this experiment does not quite match the efficiency but still saves a tremendous amount. Without the benefits of a large corporation and indoor facilities to achieve the perfect isolated environment, this system does an adequate job of minimizing water use.

CONCLUSION

These results show that it is possible to make vertical farming more accessible, but this specific design has yet to prove that fabricating an at-home vertical farm is cost-efficient compared to utilizing soil methods. However, this study proves that implementing this device into a home can greatly save resources compared to soil farming. Domestically, this system can contribute to solving problems related to water usage generated by conventional farming. If more agriculturalists shift in the direction of hydroponic farming, these methods can help reduce the crisis of decreasing freshwater supply as well as help areas in droughts recover by reducing water usage.

Additionally, this study supports investment in the growing industry of agricultural technology, since the sensors used in this system help to minimize water usage by tracking humidity. Although the technology applied in here is affordable compared to the more costly technology used commercially, this design takes steps towards implementing technology that is accessible to the public. As more people invest in the advancement of AgTech, this industry should see higher usage and profits. The development of AgTech will increase efficiency in the vertical farming sector and save an even greater number of resources. Furthermore, the increasing use of renewable energy sources could help vertical farming reach a higher level of sustainability.

This project could have been completed differently with other objectives. For example, if this project did not aim to maximize affordability and feasibility, more electronic elements could be incorporated, and an indoor system could be utilized to create an artificial environment. LED lights were not used because of the extra cost of energy, but this addition could potentially improve plant quality. The number of plants being grown also could have been altered. With more space available, larger buckets could have been used to construct the tower, or another layer could have been added to the top of the tower to maximize space efficiency in comparison to the amount of land used. On the other hand, the experiment could have focused on the cultivation of just one type of plant. This change would have saved a considerable amount of time and resources, because dividing the buckets into two sides was both time-consuming and labor-intensive. Overall, this design was a compromise between affordable and easy-to-use materials as well as automation.

If someone were to replicate this experiment, designating one tower to a specific type of plant and using two different towers with their own water reservoirs would be advised for growing multiple plants. This would eliminate contamination between the two systems without the extra effort of dividing the layers, as well as being more cost-effective. A further step would be to automatically maintain both the humidity and the pH of the system by connecting the pH meter to the Arduino and programming it to release pH adjusters into the system as needed. The level of automation used in this structure could be enhanced in multiple ways, and the accessibility of future technology will allow for more complexity in agricultural technology for everyday growers.

In essence, the vertical farming industry is constantly becoming more accessible as the need for space and resource-efficient systems become more apparent. As problems such as soil depletion and decreasing land availability worsen, people will turn to more efficient methods of farming. The vertical farming industry is continuously developing to be more accessible to the public, and this experiment's goal to design structures that prioritize accessibility and sustainability will be one of many to come. Further experimentation is necessary to find a design that maximizes sustainability and output compared to initial costs.

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Conflicts of Interest

None of the authors have any conflicts of interest to disclose.

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