# Creating a Circular Economy with Urban Farming

A Self-Sustainable Venice


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# Abstract

This project investigated the financial and social viability of the implementation of two innovative agricultural startups in Venice. We analyzed the FarmBot system in terms of sustainability, user friendliness, and cost to determine the benefits of robotic farming and explore the use of the FarmBot system for urban agriculture. We also determined the product market fit and economic viability of microgreen-centric agriculture, and the feasibility of large-scale organic waste collection for circular-economy use. We concluded that both microgreen-centric agriculture and large-scale organic waste collection are viable. We proposed a method to determine optimal planting methods in the FarmBot, and do not recommend the use of the FarmBot for microgreen agriculture without modifications.

# Executive Summary

City sustainability and space maximization are significant issues, since urban developments have a limited amount of available space. Companies are performing research and development to create startups to resolve these conflicts in Venice. SerenDPT, a company associated with the Venice Project Center, and chaired by Professor Fabio Carrera, has investigated the potential viability of several urban farming projects. These projects, which focus on sustainability and circular economy efforts, take advantage of existing local resources, especially those based on the Adriatic Sea or the Venetian lagoon.

The goal of this project was to investigate the financial and social viability of the implementation of innovative startups in agriculture to create quality employment in Venice. Included in the project is an analysis of applications of urban farming using robotic systems and other innovative and alternative agricultural processes and technologies. The geography of Venice, considering the need for transport by canal, leads to a costly and inefficient transport of goods into the city, which can be detrimental to the environment. One cultural movement dedicated to reducing these emissions is the zero-kilometer farming movement, which dictates that food should be produced, sold, and eaten all within the same kilometer.

SerenDPT (Serenissima Development and Preservation through Technology) is a company of entrepreneurs who aim to create high-paying jobs in Venice which allow employees to reside in Venice even as cost of living increases. SerenDPT has collaborated with the nonprofit organization INN Veneto, which has donated to the ITALIS Grant to create and animate a community that develops content and services to activate ideas. This grant was given to winning teams from the ITALIS Hackathon to allow them to further develop their ideas. During this event, several teams competed to create their best innovative ideas in agricultural fields.

## FarmBot

Today, robotic farming methods are being incorporated into the agricultural field to increase yield, labor efficiency, and other parts of the process. One benefit to robotic farming is that control centers can collect and process data in real time to help farmers make the most effective decisions in terms of planting, fertilizing, and harvesting crops. Robotic farming startups such as FarmBot have been gaining popularity worldwide. Their device, the FarmBot, is an open-source, open-hardware system for semi-automated small-scale farming that is marketed to farmers and consumers with a goal to “create an open and accessible technology aiding everyone to grow food and to grow food for everyone.” Our task was to operate the FarmBot and display its benefits. This was accomplished in parallel with determining the most optimal planting layout.

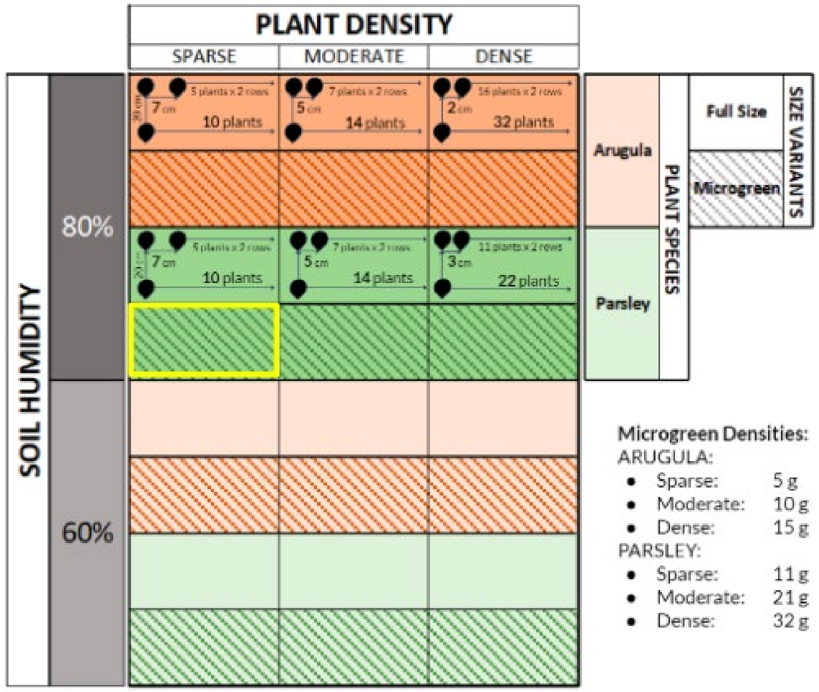


Figure 1. FarmBot experiment layout and results

The most optimal planting method was for the parsley microgreens. Their location is displayed by the highlighted rectangle in Figure 1. This was deemed the most successful method based on its yield ratio of grams planted-to-grams harvested. When kept at a sparse density and at 80% soil humidity, total yield ratio equated to 14 compared to other sectors barely reaching 10. For a whole entire FarmBot bed to be full of these parsley microgreens, profit could potentially reach €7,000 a year including labor costs. On a large scale, the quick press of a button will drastically limit labor costs compared to traditional farming.

Profit could be substantially larger if the FarmBot is capable of harvesting microgreens and improving the efficiency of planting. Majority of microgreen labor is during the planting and harvesting phase. The FarmBot's open source application allows for the design and creation of tools to operate in these phases. Until these tools are designed, we do not recommend that FarmBot for microgreen production.

## Microgreens

This objective focused on analyzing the market for microgreens in Venice. We determined the feasibility for commercial food outlets to utilize microgreens in their respective stores. Using research that supported microgreen usage, the SerenDPT company fabricated a plan to sell these microgreens to commercial food outlets, and is supporting the ITALIS Hackathon winning team ErbaCea. To determine the current consumption of microgreens, we visited several restaurants, bars, and markets within Giudecca. Our goal was to correctly classify each store on the ShopMap App; an app created by SerenDPT software engineer Nicola Musolino, for the purpose of tracking the location and characteristics of each restaurant and shop in Venice. Our group analyzed Giudecca and projected their densities across Venice. Their densities are displayed in Figure 2.

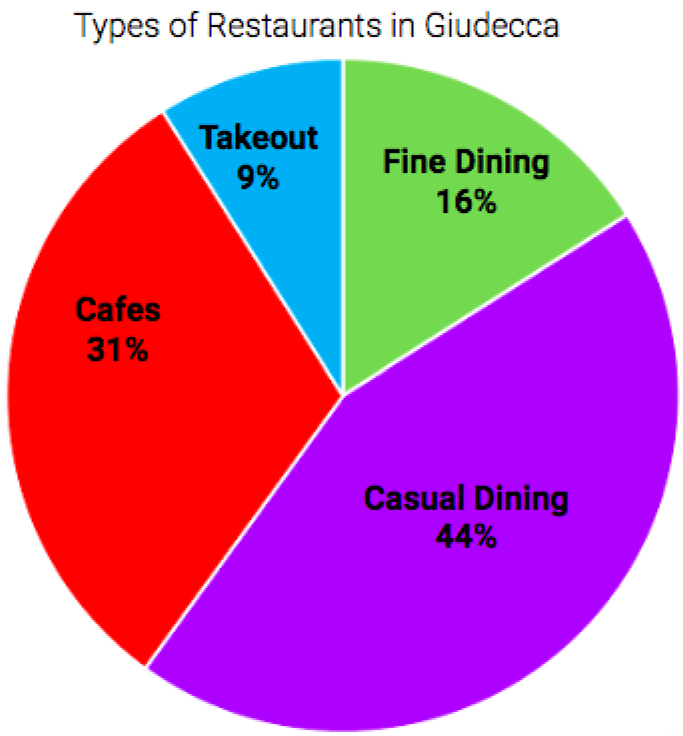


Figure 2. Restaurant density in Giudecca

From this information, we determined which stores were the best candidates for purchasing microgreens. While completing this task, we also determined which places would be most anticipated to purchase microgreens. For the use of microgreens, certain categories of restaurants were omitted from the probability; like take-out, which caters to English-speaking visitors rather than the market where it is necessary to invest. Cafes and bars also do not serve enough food for the utilization of microgreens to be effective. Overall, we determined that fine dining restaurants would definitely make up the microgreen market and that some casual dining restaurants could potentially also be part of the microgreen market. The casual dining restaurants would require further investigation to narrow down our broad category. After determining the microgreen market, we then calculated the potential revenue. All of our calculations were based on a 10% participation of fine dining restaurants (39 restaurants) and information from a retired farmer Michele Savorgnano, who has experience with selling microgreens to restaurants in Giudecca. It was calculated that ErbaCea could earn approximately €3,100 a week, which with just a few employees is definitely a viable market.

## Organic Waste Collection

Smart Fly is a Venetian startup company centered around the application of black soldier flies in organic waste management. Their process is designed to apply circular economy principles, generating usable products such as fertilizer, feed-grade protein supplements and Omega-3 oils from organic waste as shown in Figure 3. The general process involves black soldier flies laying eggs on the organic waste, larvae hatching and eating the organic waste, and then the harvesting of the larvae themselves or their excrement.

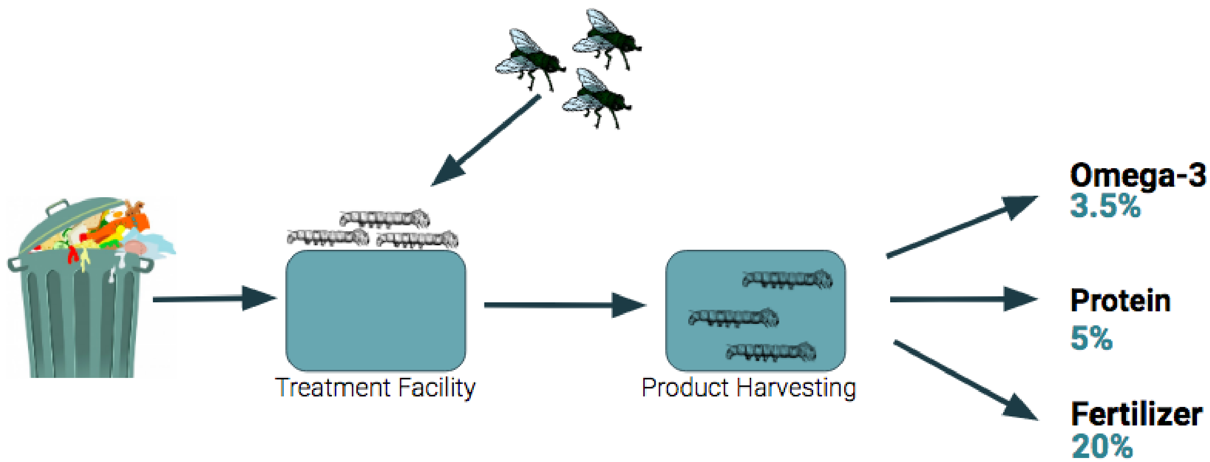


Figure 3. Simplified Black Soldier Flies Procedure

In order to determine the feasibility of implementing a circular economy through the reuse of organic waste, it was first necessary to collect data on the volume of non-commercial and commercial organic waste production in Giudecca as well as obtain general information on the waste collection process in Venice. To measure commercial waste, we contacted a nearby restaurant that already separated organic waste called "La Palanca." They allowed us to weigh a day's organic waste from the kitchen to start our data analysis. Using this data as well as data from the SerenDPT's ShopMap app we were able to calculate the amount of potential commercial waste to be 235 tonnes per year. We also contacted Veritas, the waste collection company in Venice, and they provided us with statistics from the previous two years in Lido. Using Lido and Giudecca population data we were able to calculate the amount of noncommercial (residential) organic waste produced each year in Giudecca to be approximately 1,100 tonnes. After, we calculated the amount of useful byproducts that could be produced from this waste. We completed this by researching current market prices for the main byproducts (Omega-3, animal feed or protein, and fertilizer) and found that from the 1,300 tonnes of organic waste about 400 tonnes of useful byproducts can be produced which can lead to a revenue of €650,000, however if you take labor costs into account then revenue becomes closer to €600,000.

## Recommendations

The FarmBot is a very useful robotic farming tool. Growing parsley microgreens across the whole entire bed with our implemented methodology, we determined that yield profit can reach up to €7,055 per year per FarmBot following the first year. To improve this number, we recommend the FarmBot to include a drainage system to remove access water. In our FarmBot, all this would require is a couple of holes in the bed of the FarmBot and a bucket with tubes. These holes would allow the excess water to drain out and prevent the growth of mold. In addition, a better lighting system should be implemented. These two features will increase mortality rate.

We do not recommend growing microgreens in the FarmBot. We suggest that while the FarmBot is very helpful on a large scale, microgreens should be produced manually. The FarmBot is advertised to reduce manual labor, but since microgreens require such dense planting, the FarmBot is unable to complete this task. In addition, the most labor-intensive aspect of farming microgreens is the harvest. Currently the FarmBot is incapable of harvesting all plants and thus does not relieve any labor efforts in that regard, however the FarmBot would be a suitable system for monitoring and watering if new tools were created to plant and harvest microgreens. After observing ErbaCea's farming practices, we believe microgreens could be grown more efficiently in a hydroponic system with a coconut base. This would provide a minimal amount of expenses, and prove to deliver an average yield of €80 per kilogram of microgreens.

Due to our market calculations the black soldier fly startup, Smart Fly has the potential to be extremely successful. We estimated that the yearly revenue for Smart Fly is approximately €650,000, assuming 10% participation of buyers in the market. However, before continuing with the startup we recommend that a few more calculations are completed to ensure that there is a viable market. When calculating the €650,000 revenue our group had to make a number of assumptions including; that Lido's residents produce the same amount of waste per year as Giudecca residents, that every person generates the same amount of organic waste per meal in a restaurant, that every restaurant in Giudecca produces the same amount of waste, that during low tourist months 65 people eat at Giudecca restaurants per day, during the high tourist months 85 people eat at Giudecca restaurants per day, and that restaurants are only open 6 days a week and take off 12 Italian holidays.

Overall we recommend that a future group complete the same calculations that we did, but over several different trials to gather more accurate data. One way a future group could do this is contact different organizations who have more accurate data, visit and interview more restaurants, or run different experiments like the "bucket" experiment outlined in section 7.5.

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# Authorship Page

**Benjamin Cyran** researched, wrote, and edited the executive summary, background sections 4.1 and 5.1. Cyran also contributed in editing all background and methodology sections with collaboration with his other team members. Following for the methodology, Cyran contributed in writing the Microgreen-centric Agricultural section 5.2. Cyran also wrote the entirely of the data and analysis section 4.3, as well as Appendix E and F. In meetings with groupmates, advisors, and sponsors, Cyran constantly contributed to discussion to lead meetings efficiently and clearly. He provided attention and insightful feedback. Cyran collaborated with Ward on electrical aspects in the project. Cyran created the YouTube channel for the world to view the FarmBot's progress, in addition to having lead management of their website.

**Julia Premo** contributed to editing all sections but primarily assisted in the thorough revisions of sections 2.0 (while writing much of the first portion), 4.2 (while writing most subsections), 5.2 and all subsections, 6.0 and all subsections including writing 6.1.1, as well as Appendix D and G. Julia collected the majority of the ShopMap App data (with Natalie) and assisted Cyran with the reconstruction of the FarmBot. Julia also hand planted all the full-size seeds with assistance from Cyran and Natalie and the sequence organized by Ward. She solely completed information posters about the FarmBot and the project as a whole with minor assistance from Cyran as well as creating an interactive diagram of the FarmBot layout in a Prezi for a detailed reference of the experiment. Throughout the term, she assisted in creating tasks for the week and the agendas for scheduled meetings with advisors. To conclude, Julia contributed to the team blog on the website as well as a large portion of the slideshow for the final presentation.

**Natalie Soens** researched, wrote, and edited background sections 4.1, 5.1 and 6.1 (except for subsections 4.1.1.2, 5.1.2 and 5.1.3. For the methodology Natalie wrote 3.0, 4.2.1.4 and the microgreen part of 4.2.1.5 in the FarmBot sections. Natalie also wrote the entire methodologies and results/analysis sections for the black soldier flies and microgreen objectives (5.2, 5.3, 6.2, 6.3). In addition, Natalie wrote sections 4.3.3.1, 7.3, 7.5, Appendixes A, C, D, G, and H, and organized the works cited. Natalie also collected the majority of the ShopMap App data (with Julia), handled email correspondence with the ErbaCea and Smart Fly, lead Skype calls with Pietro (with Cyran), helped plant the microgreens, and took detailed meeting minutes at IQP/ skype meetings. She also helped edit the entire report and create much of the presentation. Lastly, Natalie helped prioritize tasks and keep the team organized to ensure productivity.

**Benjamin Ward** researched, wrote, and edited the entire abstract, 1.0 introduction, and 2.0 background, as well as sections 4.1.1.2, 5.1.2, and 5.1.3. Ward's primary focus was on the FarmBot sections, including 4.2.3, 4.3.2, and 7.2. Ward also contributed to the editing of the background and methodology sections in collaboration with other team members, as well as the rest of the paper. While leading all software work, electrical work with contributions from Cyran, as well as FarmBot operation, he provided much of the technical knowledge and background required for the project. Ward managed presentations and documents, made substantial contributions to the website, and generally took the lead during meetings with sponsors and advisors along with Cyran. Finally, he conducted most communications and correspondence with project advisors and SerenDPT employees (except for Pietro).

# Acknowledgements

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**Professor**
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# 1.0 Introduction

Societal trends and consumer preferences have driven demand from agricultural systems in close proximity to urban populations. Peri-urban agriculture requires a sufficient amount of land for production, which is difficult to obtain. This dichotomy presents an urgent need for alternative production methods (Knorr, 2017) that allow for increased efficiency of horizontal space and of industrial capacity. This need becomes more prevalent as the population of cities increases with the average, worldwide urban population projected to rise at 1.44-1.84% annually for the next 10 years (United Nations, 2016).

In urbanized countries with a limited amount of conventional space such as Italy, city sustainability and space maximization have been a major area of focus for decades (Gericke, 1940). Supplemented by a local cultural emphasis on “0 km” (zero-kilometer) farming throughout Italian communities (Parla, 2011), and Venice in particular, nonprofits and local governments have emphasized research and development in agricultural fields (European Commission, 2018). This offers increased incentives for more local production to offset high costs associated with the processing and delivery of food to Italian consumers. However, economic factors are in opposition to this movement, and urban farming is cost prohibitive (GTR, 2006). While these costs have driven down the percentage of final food price that farmers were responsible for by 17% in Venetian markets (GTR, 2006), not much farmland is available in or near Venice (WPI, 2018).

Agriculture in the Veneto region, as it currently exists, is extremely mechanized and almost entirely specialized (European Commission, 2018). This market is extremely competitive, and is concentrated in the inland districts of Verona and Rovigo (European Commission, 2018). As such, over 100 km of travel through heavily populated areas is required to supply consumers in the canal city of Venice, followed by a complex distribution through canals for foodstuffs to reach their final destination. Past studies have suggested integration of hydroponic systems for extreme vertical farming in order to take advantage of the extremely minimized amount of land that is available in Venice (WPI, 2018), as well as aquaponic systems which could additionally take advantage of the city’s water area (Università Ca' Foscari, 2017). These studies predict the viability of alternative farming methods for sustainable food growth, but leave open questions about profitability or social success in lieu of a business plan or sophisticated cost and return on investment analysis.

Current research and development efforts have been notably advanced by SerenDPT, a company headquartered in Venice. SerenDPT and associated organizations have indicated the potential viability of several alternative farming projects, with a focus on sustainability and circular economy efforts that take advantage of existing local resources, especially those based on the local ocean or the Venetian lagoon (World Bank, 2017). Ventures being pursued include circular-economy focused projects integrating black soldier flies for organic waste management, exploration of innovative methods of clean, fast and efficient microgreen farming and distribution, and other advancements in food and agriculture technology (SerenDPT, 2019). These projects lack proof of financial viability, and require collection of data to validate their nontechnical premises.

VE19-Farm

The goal of this project is to investigate the financial and social viability of implementation of innovative startups in agriculture to create quality employment in Venice. Included in the project will be analysis of applications of urban farming using robotic agricultural processes and technologies. This will include collection of data to validate projects focused on applications of black soldier flies in composting, and growth of microgreens for zero-kilometer sale in Venice.

# 2.0 Overall Background

Agriculture is an industry that has always shaped the economy. In 2017, 3.9% of Italy's total employment was related to the agricultural sectors (Roser, 2019) and food accounts for an increasingly large 18.8% of monthly family expenditures (Statista, 2019). In agricultural markets, there are six main categories of crops that can be grown and harvested; food crops, feed crops, ornamental crops, oil crops, industrial crops, and secondary crops (Curley, 2019). To serve increasing demand for fresh produce, food crop production has risen significantly; as of 2016, currently 5.1 million hectares of arable land is reserved for food crops (Wirsenius, 2017) of the 4.9 billion hectares reserved for general farming (Food and Agriculture Organization, 2019). The amount of land allocated for food crops is projected to rise at 5.9% annually over the next 10 years (Wirsenius, 2017).

The Veneto Region produces over 10% of Italy's agricultural products while only accounting for 6% of Italy's total area (European Commission, 2019). Out of the twenty geographical regions in Italy, Veneto is the fifth largest and most populated region with a total area of 18,407.4 $km^2$ and a population of approximately 4.9 million inhabitants (European Commission, 2019). It is one of the four provinces of the Po Basin; a very flat plain that extends into the Alps and Apennines (Valkenburg, 1942). Farmland covers about 57% of the region, with the remaining occupied by woodlands (29%), urban areas (8%), and wetlands (6%). The main products grown from this region are cereals (maize and wheat), soybean, and horticulture crops. 80% of all maize grown in Italy is produced in the Veneto Region (Recare, 2018). Orchards and tree plantations also occupy a smaller portion (14%) of the total agricultural land use (Recare, 2018). Most of the farms within this region are smaller, with an average area of 4.5 hectares (11.25 acres) (Clemens, 2004). Given the limited amounts of space, governmental organizations, companies, and nonprofits are exploring new agriculture techniques for efficiency and accessibility. Techniques such as soilless farming and the reuse of organic waste can increase the production of food and feed crops, thus increasing profit for local farmers.

The city of Venice, which is the capital of Veneto, is composed of 118 islands scattered around 145 km in the Venetian lagoon (Cessi, 2019). Despite a reduced permanent population of only 53,799 residents (as of 2017), Venice is extremely crowded with transient visitors (Clemens, 2004). While significant amounts of arable land exist on the surrounding islands in the Venetian lagoon, little to no farmable land is available in the city due to the natural geography of Venice and its high population, an example of which is the central island of Giudecca (Figure 2.1). As such, market owners resort to the importation of sellable produce to acquire products for resale. In 2019, food imports made up 11.7% of all cargo imported into the city (Port of Venice, 2019).

Figure 2.1 Green Spaces on Giudecca from VE17: A Greener Venice

Due to the geography of Venice and resulting lack of roads, transport of goods into the city is particularly inefficient, costly, and detrimental to the environment. Compared to land-based transportation, canal shipping is inefficient and unreliable (Agarwal, 2014). From growth to sale, many agricultural goods must be transported over 100 kilometers to reach the city, which has significant $CO_2$ implications as imported goods account for 22% of the world's $CO_2$ emissions (Hausfather, 2017). One cultural movement dedicated to reducing these emissions is the zero-kilometer farming movement, which is highly popular across Italy. Ideally, food would be produced, sold, and eaten all within the same kilometer (European Commission, 2018). Currently, urban gardens and other forms of alternative agriculture are gaining popularity throughout Italy and are providing farmers with other ways to locally produce food in any environment (Ochoa, 2019).

Urban and peri-urban agriculture (UPA), the cultivation of food and livestock in and immediately around cities, is a prime beneficiary of agricultural innovation. Soilless farming and vertical farming both permit more dense packing and higher yield per area, enabling more efficient urban agriculture. Past studies have suggested integration of hydroponic or other automated systems for large-scale vertical farming as one way to maximize space utilization in the particularly minimized amount of land in Venice (WPI, 2018). These practices compete for resources such as land, water, energy, and labor with other urban necessities. However, urban farming has important benefits to health, sustainability, and the general provision of foodstuffs (Food and Agriculture Organization of the United States, 2019).

A particular focus of UPA advocacy is sustainability, compared to traditional high-volume agriculture, significantly less $CO_2$ emissions are associated with UPA-grown produce due to the heavily reduced transportation and refrigeration costs as well as the decrease in wastage due to these factors. Other notable benefits include easy access to labor, since significantly more people are available in the city locale, and health, since ULA-grown greens are provided significantly fresher and therefore are more nutritious (Gentry, 2019).

## 2.1 SerenDPT and INN Veneto

SerenDPT (Serene Development and Preservation through Technology) is a company of entrepreneurs who aim to create quality work in Venice centered around the city's arising problems in employment. INN Veneto is a nonprofit organization which aims to "attract excellence in order to carry out social innovation projects that will contribute to the development of Venice"

(Todescan, 2018). Through their social innovation program, INN Veneto sponsored the winning teams of the ITALIS Hackathon, and in total funds fourteen projects (ITALIS, 2019). ITALIS, which is an acronym for "Innovation, Land, Water, Work and Social Entrepreneurship" in Italian, is intended to develop startup companies in innovative agricultural fields.

The ITALIS Hackathon was a two-day event occurring July 13th/14th, 2019. The purpose of the ITALIS Hackathon was to simulate ideas for startup companies in the agricultural field, where teams competed to create the best startup idea that would be viable in Venice. Five teams competed and two teams are currently receiving further support, including the winning "Smart Fly" and "ErbaCea," earning €10,000 each. Smart Fly's idea focused on black soldier flies and their ability to feed on organic waste and produce salable byproducts, while ErbaCea focused on growing microgreens in disused spaces for sale to local restaurants. These teams were invited to the H3 Facility to continue the ITALIS program, where SerenDPT is providing them with skills and space needed to develop their business model (ITALIS, 2019).

These teams are collaborating with SerenDPT to create a circular economy in Venice. A circular economy is the ideology of using byproducts that would otherwise be discarded. Wasted materials and energy are used in chemical or biological processes to improve a system's efficiency. Examples of this include eco-conscious design processes, waste minimization, and cleaner production, as well as reuse of byproducts such as heat and waste-water from industrial processes (Yuan, 2006). The lacking agricultural system in Venice requires the import of produce. Venice imported €2,352,108 worth of food in the last year alone (Port of Venice). Worldwide, imported goods accounts for 22% of the world's $CO_2$ emissions (Hausfather, 2017), and a Venetian urban agricultural system would decrease this pollution in Venice, and provide production of fresh foods.

# 3.0 Methodology

The goal of this project was to investigate the financial and social viability of the implementation of innovative startups in agriculture, to create quality employment in Venice. In order to achieve our team's goal, our objectives were to:

1) Explore the potential of the FarmBot for experimentation and production of microgreens and other produce
2) Determine product market fit for microgreens and economic viability of microgreen-centric agriculture in collaboration with a Venetian startup team
3) Determine the viability of large-scale organic waste collection for circular-economy reuse in collaboration with a Venetian startup team

The temporal scope for all aspects of the project were limited by the seven-week term for our limited time in Venice. In addition, our group determined the social and financial viability of all four of these potential agricultural startups. The social viability is gauged on market interest in the startups, and financial viability will be gauged on a cost analysis. The following sections outline the methods we have adopted to achieve all of the objectives listed above.

Due to the mixed objectives, an outline suited best for cohesive reading was selected. Here each objective has been designated a chapter, containing its own background, methodology and results. This objective focused style clearly describes the initial reasoning behind each objective, proceeding with progress executed to achieve said objective. Separate bibliographies were created to provide the reader with an organized reference to each topic.

The FarmBot's potential is focused on yield and return on labor costs. The product market fit for microgreens is directed to the possible retail food stores that would utilize microgreens. The viability of the organic waste collection is centralized on determining a quantity of available organic waste, so the reuse would be deemed worthy.

# 4.0 Automated Produce Production with a FarmBot

The goal of the FarmBot objective was to determine the most optimal planting formation and procedure. Our experiment tested two different plant species, two different soil humidity, two different harvest times, as well as three different plant densities. This experiment was a base to project the FarmBot's viability in the long run.

## 4.1 Background

In the 1950's 29.6% of the population inhabited urban environments (Krzemińska 2019), and it is currently projected that by 2050, "70% of the world's population will live in urban areas" (Gentry 2019). Today, most food is grown in rural regions and travels on average 2400 km before reaching one's plate (Gentry, 2019). This is not ideal, especially for produce, because vegetables lose approximately 30% of their nutritional value within the first three days of harvest, and are generally treated with various chemical preservatives to prevent ripening during transit (Gentry 2019). In addition, traditional farming methods consume large quantities of freshwater and fossil fuels, resulting in contaminated water sources and an accelerated greenhouse effect (Despommier, 2009). Agronomists and entrepreneurs have proposed many innovative sustainable farming methods, mostly centered around urban farming, including soilless farming, vertical farming, and robotic farming adaptations.

### 4.1.1 Robotic Farming

Today, robotic farming in particular is gaining popularity and is being incorporated into many different innovative urban farming environments improving efficiency and effectiveness. While the concept of automated farming might seem like new technology, it has actually been around for over two hundred years (Gibson, 2019).

In 1767 Richard Arkwright invented the first fully automated waste powered spinning mill, and in 1785 Oliver Evens developed the first completely automated process with an automatic flour mill (Gibson, 2019). Agricultural automation has been labeled the fourth industrial revolution; it is distinguished by "its velocity, scope, and the systems impact." Compared to other industrial revolutions, "the speed of current breakthroughs has no historical precedent." (Gibson, 2019). A recent study in Europe found that European farmers believe that "precision and automation represent the future of industrial agriculture" (Gibson, 2019), and indeed farming in the Veneto region is increasingly mechanized and automated (European Commission, 2018).

One benefit to robotic farming is that control centers can collect and process data in real time to help farmers make the most effective decisions in terms of planting, fertilizing, and harvesting crops. In addition, robotic farming can increase the quality of produce, reduce costs, yield a more consistent product, provide relief from any labor shortages, and help farmers predict future conditions (Gibson, 2019). Potential drawbacks include a large initial cost, learning curve, and that the software often becomes quickly obsolete (Gibson, 2019). Even with these drawbacks, robotic farming or automated farming has become increasingly popular and many new companies have emerged that either sell robotic farming systems or use their own patented system to grow produce at a commercial level.

#### 4.1.1.1 Robotic Farming Examples

While robotic farming startups may all have similar end products, the route or strategy that each company takes to reach the desired product are all unique and cutting-edge technology. These robotic farming startups use patented robots to assist in their agricultural companies where the companies make a profit on selling their produce. Iron Ox is a relatively new company that launched in October 2018 in San Carlos California, and currently as of May 2019, started selling produce in a few Californian grocery stores. Iron Ox utilizes a hydroponic automated farming system that with two main robots is able to produce 30 times more crops per acre of land than traditional farming, all while using 90% less water (Figure 4.1). The company splits a plant’s life cycle into three different parts where each part requires different spacing, lights, and fertilizer. Together, the two main robots (one, a 1,000 pound robot that can move trays of plants, and the second, a smaller robot that can hold individual plants) are able to transport all of the plants around the entire facility to their life cycle designated location. The company also utilizes AI to detect any potential pests and diseases. Lastly, even though the robots tend to the plants while they are growing, Iron Ox still requires human workers to do the planting and packaging (Vincent, 2019).

Figure 4.1 Iron Ox Robot

Another startup robotic farming company is Sky Greens. Sky Greens is a low carbon, hydraulic driven vertical farm in Singapore. The farming system involves rotating tiers of growing troughs that can accommodate both soil farming and hydroponics. The rotating tiers are beneficial because they help ensure that plants receive “uniform sunlight, irrigation, and nutrients as they pass through different points in the structure." The growing structures are highly customizable and scalable, and only 40 watts of energy is needed to power one nine meter tower (Sky Greens, 2014).

#### 4.1.1.2 Robotic Farming Systems

In addition to robotic farming startups, there are also robotic farming systems. These machines are automated systems that one can purchase to grow their own produce. To clarify, a robotic farming start up involves a company using their own patented robots to grow produce in which the consumer then buys that produce and a robotic farming system is when a consumer buys an automated farming machine and uses it to grow whatever produce they desire. Some examples of robotic farming systems are the FarmBot and Zipgrow. Zipgrow is an automated vertical hydroponic system that was recommended by the 2018 IQP Farm for the bell towers in H3 (WPI, 2018).

The FarmBot is an open-source and open-hardware system for semi-automated small-scale farming, marketed toward farmers and consumers. The project aims to "create an open and accessible technology aiding everyone to grow food and to grow food for everyone" (FarmBot, 2019). Hardware and software for various FarmBot models are released to the public and as such anyone can take advantage of these plans to build their own or alter existing hardware. The system has built-in support for over 160 plant variants including common greens, herbs, and vegetables that, using the FarmBot, is grown in a traditional dirt medium. Particular focuses of the FarmBot project include sustainability and accessibility to both businesses and the general consumer. When the system is fully utilized, $CO_2$ emissions are over 26% less (FarmBot, 2019) compared to commercially grown produce in the United States (Carbonfund.org, 2016). Different systems scale based on available space, with the smallest model taking only 3.6 $m^2$ while the largest can handle over 17.1 $m^2$.

In 2018, following the recommendations of a WPI IQP team, SerenDPT purchased a FarmBot with the hopes that the FarmBot will provide a more optimal method for automatic farming. The team strongly encouraged the purchase of the FarmBot. The team provided highlighting key features such as labor reduction, self-maintenance, and great potential due to its open source code and manufacturing. The FarmBot could potentially be operated in parallel with the Zipgrow. The WPI team's intentions were to grow the seedlings for the Zipgrow system. With both these systems running at the same time, it could generate a profit of approximately €4,000 per year (WPI, 2018).

## 4.2 Methodology

This objective focused on the optimal methodology for the use of the FarmBot system in production of microgreens and other produce. We used the FarmBot Genesis 1.4 model in our experimentation, which was the most current model when acquired by SerenDPT in 2018. Topics of investigation included sustainability compared to traditional farming, user friendliness, and cost/benefit analysis. This objective supported the ITALIS Hackathon team "ErbaCea," who is attempting to introduce zero-kilometer microgreens into the local food supply chain (ITALIS, 2019).

All work relating to the FarmBot was confined to the Island of Giudecca, in the H3 headquarters where the FarmBot is located. In addition, the FarmBot was limited by the amount of time it takes to grow our microgreens. Depending on the plant choice, this took anywhere from a two to three week growth time. Through communication with one of our collaborators Pietro Tonini, we determined that we will be growing a microgreens mixture of parsley and arugula. We are defining microgreens as any vegetable greens harvested just after their cotyledon leaves have developed.

### 4.2.1 Setting up the FarmBot

While in Worcester, Pietro provided us with a login to access the FarmBot interface remotely and to have the ability to execute commands if and when necessary. We didn’t need to use it at all, however once we arrived in Venice, the FarmBot proved to be just as compatible with remote control as it was in the United States. Our experimentation with the FarmBot was slow to begin. We disassembled and reassembled the FarmBot into another room because the new location had a more ideal environment for plant growth in terms of light availability. It unfortunately was too large and heavy to fit through the doors so our team deconstructed the top frame from the base and moved the two parts separately before reconstructing it in the other room. We put the FarmBot on a dolly that was built previously by SerenDPT and prepped the base for soil. We caulked the edges as well as lined the base and walls with plastic to prevent leakage. Following the dirt was placed in the FarmBot and watered. After filling it with dirt, we applied water for the dirt to absorb and become optimal for planting. We used a tape measure to divide the soil into the twenty-four planting sections and marked them with string for our own reference. We then calibrated the tools to prepare them for use. Within this time period we also purchased and installed a pump to provide a water source to the FarmBot.

The soil sensor was only partially assembled. With the necessary equipment and guide, the assembling took roughly forty minutes. This is double the expected length of FarmBot’s guide. Necessary adjustments were required to minimize the amount of space taken up by the connecting wires from the sensor to the FarmBot.

#### 4.2.1.1 Choosing Plant Species

Parsley and arugula were chosen to farm based on criteria including grow time, water necessity, grow space and height, and availability in Venice. To determine an optimum solution, a value analysis was conducted using the decision matrix seen in Table 4.1. All categories were on a scale from 1 to 10, with 10 being the best. Weighted factors illustrate the priority of each category. Total was achieved by multiplying the weight factor to the score for the plant. Each category is added up to conclude the decision factor. The winning plants had the highest accumulated score.

| Plant | Availability | Cost | Grow Time | Grow Space | Grow Height | Total (Decision Factor) |
|---|---|---|---|---|---|---|
| | **Weighting Factors** | | | | | |
| | 10 | 10 | 60 | 5 | 15 | |
| Basil | 7 | 9 | 5 | 8 | 9 | 380 |
| Parsley | 9 | 9 | 6 | 9 | 9 | 420 |
| Arugula | 8 | 9 | 9 | 7 | 8 | 410 |
| Tomatoes | 10 | 10 | 5 | 3 | 1 | 290 |
| Cabbage | 6 | 6 | 4 | 4 | 6 | 260 |

Table 4.1 Value Analysis for seeds to grow

Yield was based on weighing each plant after harvest. We weighed each seed on a kitchen scale to determine the quantity for planting. Planting sectors had different densities that required the scale to quantify our data.

#### 4.2.1.2 Establish seed spacing boundaries

For all the full-sized plants, we tested the FarmBot's ability to plant seeds in very sparse and very dense environments. Each full-sized plant is spaced differently in each section. As illustrated in Table 4.2, arugula plants are spaced two centimeters apart in the dense region, five centimeters apart in the moderate region, and seven centimeters apart in the sparse region. Parsley are spaced three centimeters apart in the dense region, five centimeters apart in the moderate region, and eight centimeters apart in the sparse region. The spacing between rows of all full-sized plants is twenty centimeters because we didn't want the roots from the plants in different rows to get intertwined.

The microgreens were hand-planted by weight. Five grams of arugula were planted in the sparse section, ten grams in the moderate section, and fifteen grams in the dense section. Eleven grams of parsley were planted in the sparse section, twenty-one grams in the moderate section, and thirty-two grams in the dense section.

DAP (Table 4.2) stands for Days After Planting and represents how many days the plants will be growing in the FarmBot before we harvest them (thirty for full sized and fourteen for microgreens). The planting densities for both the full sized and microgreen plants were determined based on background research (Carr).

#### 4.2.1.3 Overall FarmBot Plan

To get a better understanding of the FarmBot, figure 4.2 illustrates all the factors in our planting layout. This bed is divided into twenty-four total sections with dimensions of 0.344 meters by 0.477 meters.

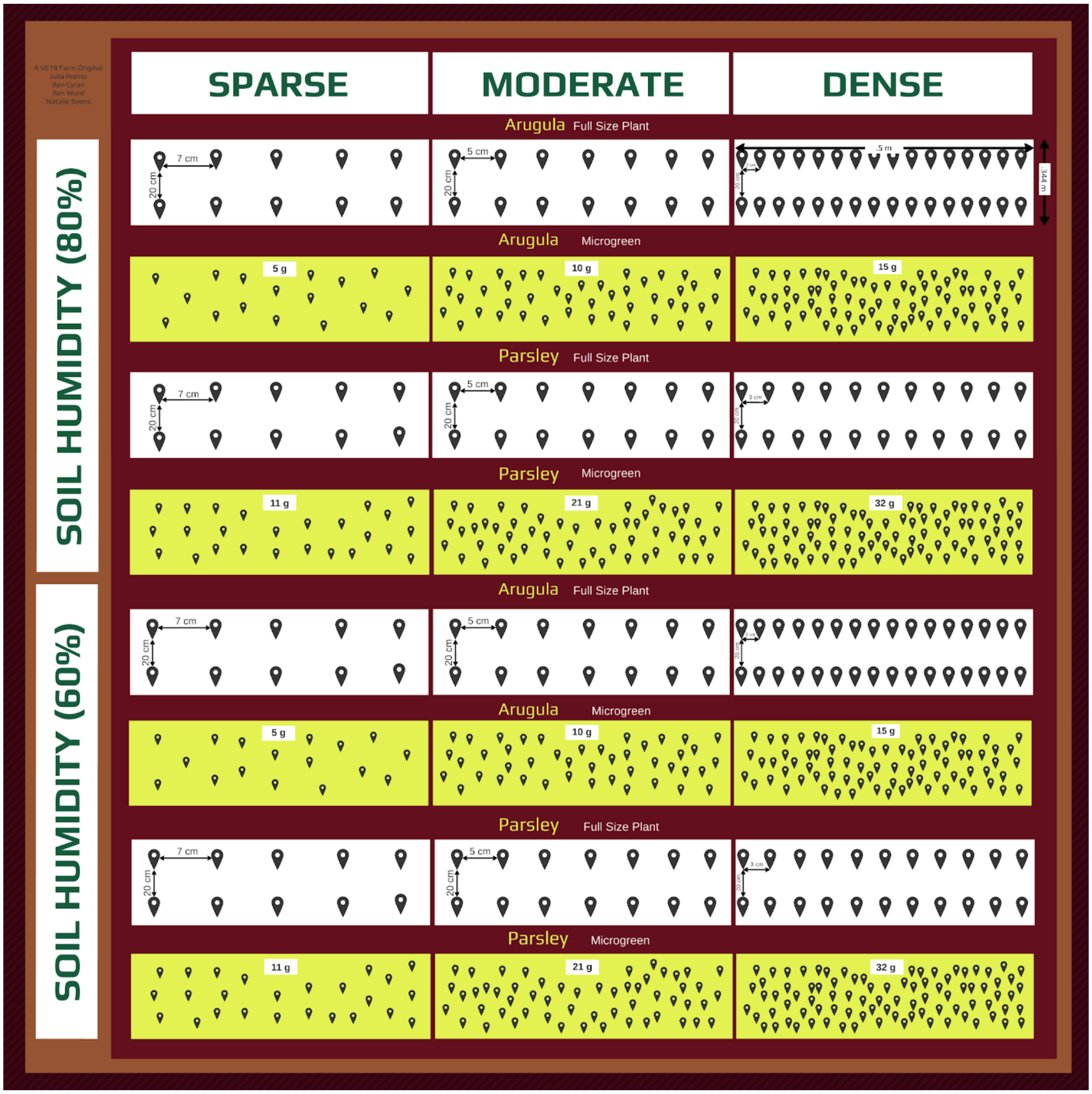



Figure 4.2 Overall FarmBot Layout

In Figure 4.2, the top four rows have a soil humidity of 80%, while the bottom four rows have a soil humidity of 60%. All eight rows alternated between microgreen and full-sized plants, starting with a full-sized plant and ending with microgreens. The species were grouped in alternating rows of two, so the first two rows have arugula, the second two have parsley, third two have arugula, and last two parsley. The densities of the plants are organized horizontally in three different columns. The leftmost column has the least dense planting, middle column moderately dense, and the rightmost column has the most dense planting. More detail about planting densities is illustrated in Table 4.2.

| | | Normal Size Cultivation | | | | Microgreen Cultivation | | | |
|---|---|---|---|---|---|---|---|---|---|
| Type of Plant | | Spacing (cm) | | | DAP (day) | Grams of Seeds (per section) | | | DAP (day) |
| | | A | B | C | ABC | D | E | F | DEF |
| Arugula | In row | 2 | 5 | 7 | 30 | 1x (5 g) | 2x (10 g) | 3x (15 g) | 14 |
| | Between row | 20 | 20 | 20 | 30 | | | | 14 |
| Parsley | In row | 3 | 5 | 7 | 30 | 1x (11 g) | 2x (21 g) | 3x (32 g) | 14 |
| | Between row | 20 | 20 | 20 | 30 | | | | 14 |

Table 4.2 FarmBot Planting Densities

#### 4.2.1.4 Planting the Seeds

All of the microgreen sections in the FarmBot had to be planted completely by hand because the FarmBot was unable to plant seeds as dense as microgreens require. In order to plant the microgreen seeds, we first used a tape measure to correctly divide each section. Five cm were measured in from each side of the original sections (the ones divided by string), so instead of 0.47 m x 0.344 m sections they were actually approximately 0.4 m x 0.244 m sections. Divots in the dirt were made to outline these updated sections that way when we planted the seeds we would know where the divisions were. In order to plant the seeds, we used a kitchen scale to measure the exact weight of seeds per section, specific weights are documented in Table 4.2, and then after measuring we poured the seeds out onto the dirt (by hand) as evenly as possible. Lastly, we covered the seeds with a thin layer of dirt and lightly watered the seeds with a spray bottle.

The layout of the planted microgreens closely following our original FarmBot planting plan (Figure 4.2). On November 11th, 2019 all but one row of microgreens was planted. After planting the 80% humidity arugula microgreens, it became apparent that due to some math errors, we did not have enough seeds to plant the 60% humidity arugula microgreens. Our plan was to return to the seed shop the next day to purchase more seeds, but because of many large acqua altas the seed shop shut down for an entire week. Our group then tried to order more arugula seeds online which were originally projected to arrive on November 25th, 2019, but then got pushed back to the end of that week. Since our group had time off from November 27th to December 1st due to Thanksgiving break, we wouldn't be able to plant those arugula seeds until December 2nd, which would only give them one week to grow. Our solution to this issue was to plant just one square of arugula microgreens (the most sparse 60% humidity section) and then to plant other seeds we had on hand in the moderately and most dense sections. We are aware that these two sections will not provide us with any useful data, however we figured we should plant something since we did have extra seeds and we didn't want to have empty space in the FarmBot. These seeds were planted on November 25th, 2019. In the moderately dense 60% humidity arugula microgreen section there is parsley and in the most dense section there is Rossa di Verona.

To plant the full-sized plant species, the FarmBot has a built-in vacuum that is designed to work in conjunction with the seeder tool. This seeder tool applies pressure to the seed bucket or tray to pick up the seeds. At the time of planting, we did not have access to the correct sized seeder needle. The one we had available was too large and would have simply inhaled the seed without being able to deposit it into the soil. With time as a restriction, we simulated the usage of the seeder for labor costs. To plant the seeds, we had the FarmBot follow the same sequence of planting except we manually planted the seeds after the FarmBot marked the location of where the seed should be in the soil with the needle. The FarmBot application then recognized these plants in its software. All of the full-sized seeds were planted on November 11th, 2019 and followed our original planting plan as illustrated in figure 4.2.

#### 4.2.1.5 Harvesting the plants

In order to harvest the microgreens our team first delicately pulled the microgreens out of the soil (roots and all) and put them on a plate. We only harvested one section of microgreens at a time in order to avoid confusion. After the microgreens from one section were all harvested we then, to the best of our abilities, attempted to remove as much dirt as possible from the plants. This was the most difficult part of the process and took a large amount of time. Since the parsley was larger when harvested, we were able to dip the entire plant into a bucket of water to wash off the dirt, however since the arugula was significantly smaller we had to go in and remove dirt by hand. After we removed the dirt we weighed the total amount of all the microgreens per section with a kitchen scale and then recorded the data online. We are aware that our values were not 100% accurate because there was still some dirt left on the plants as well as the plants being very dense due to being soaked in water but it was the best we could do without dedicating too much time to the harvesting of the microgreens.


Figure 4.3 Harvesting of microgreens - arugula

After 30 days, the full-size plants should have been ready for harvest. Unfortunately, all the arugula plants were dead, and the parsley plants were not fully grown. We dealt with our situation and harvested regardless, putting our sprouts in separate plates based on the section they were removed from. Unlike when we harvested microgreens, we cut the plants at the base with scissors instead of ripping them out of the soil. This made it a lot easier in terms of cleaning as we didn't need to pull the soil out of the roots. Instead of the kitchen scale, we used the digital scale from ErbaCea to get more accurate measurements. All in all, the measurements aren't completely accurate since there was still some soil in the roots, but the plants themselves were also a bit wet making them more dense. We ended up weighing the parsley, wrote the measurements and took the profit calculations for our presentation.

### 4.2.2 User Friendliness of FarmBot Software

The FarmBot operates its software on a website called *my.farm.bot*. The user is able to create an account username and password to connect their FarmBot. Upon login, the application provides multiple useful windows. The Farm Designer already is designed with over 30 different types of plant species, and the user can add additional plants through the creator tab. Figure 4.4 illustrates the Farm Designer window.

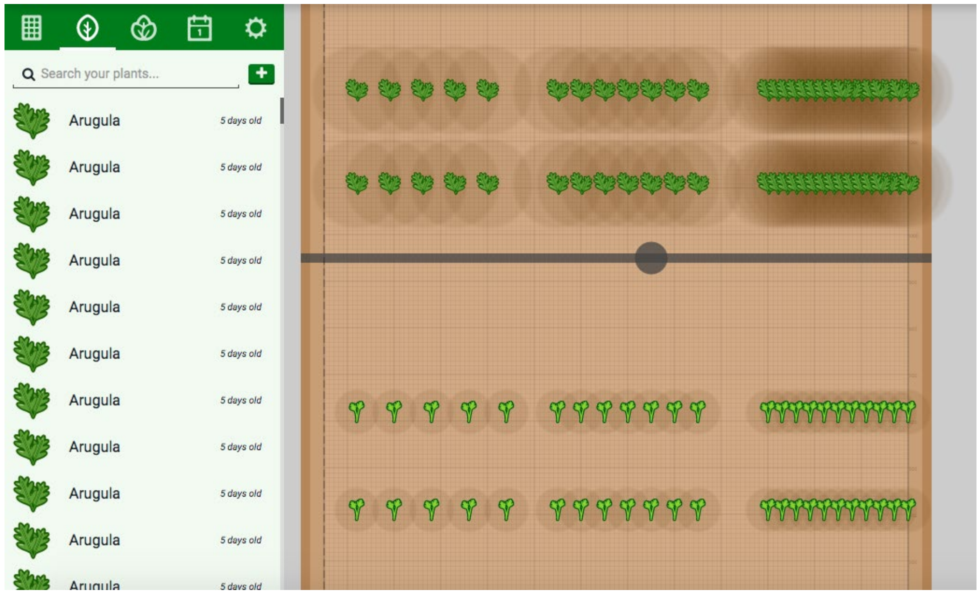



Figure 4.4 my.farm.bot Farm Designer window

The grey line and circle in the middle of Figure 4.4 illustrates the FarmBot's current position in the structure, with the grey circle symbolizing the gantry. This grid has adjustable dimensions to declare the length and width of the FarmBot's structure, so the FarmBot can travel across the entire plot.

In the controls window, the user is able to move the FarmBot a particular length or to a specific coordinate. This window also contains the peripherals of the FarmBot and their respective pin numbers. The FarmBot is designed with three preset pins: vacuum, water, and light. Note that the preset light refers to the light on the FarmBot's camera. There are two extra peripherals that can be used by a third-party light, or even a webcam to observe the FarmBot constantly.

In the sequences tab, you can design operations for the FarmBot to automatically follow. This is arguably the most important tab as it controls the automatic commands of the FarmBot. Sequences are simple to setup due to the FarmBot's outstanding software. Figure 4.4 shows the window for the operation of a water sequence.

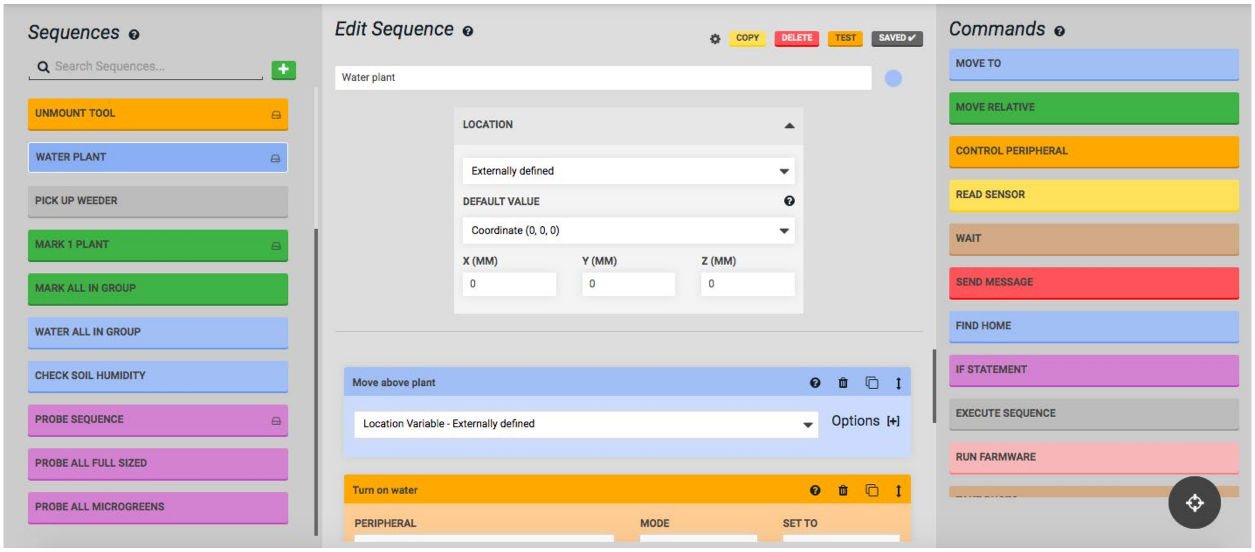


Figure 4.5 Water Sequence operations

To add a sequence, click on the green plus in the sequence portion. Commands are dragged into the edit sequence portion to add that operation. Each command has additional options that make the command simpler to use.

To properly track the progress of plants, the FarmBot provides a camera to view plants as the grow. This camera has the ability to be harmonized with the weeder tool to automatically remove weeds from the bed. The camera recognizes weeds and marks the location. We did not use this feature in our experiment, as the FarmBot would end up destroying all of the microgreens.

### 4.2.3 User Friendliness of FarmBot Electronics

The FarmBot had problems moving once we transported it to a new room at the beginning of the term - it stuttered during short-distance movement on the X axis. In an effort to solve this problem we decided to look at the Farmduino, which is a custom-built Arduino-compatible microcontroller purpose-built for the FarmBot. This microcontroller features hardware, similar to an Arduino MEGA 2560, that interfaces with a connected Raspberry Pi which handles communications with the web interface and user controls. To fix the stuttering of the FarmBot, we implemented a technique recommended on online FarmBot forums which suggested that we swap stepper drivers to see if the issue was with the motors or the drivers. When we swapped the stepper drivers, there was a human error in replacing the stepper driver in the X1 location on the Farmduino. The stepper driver was placed upside down and power was connected directly to ground. This caused the stepper driver to burn out and damaged one of the general-purpose input/output pins of the Farmduino; the driver location, X1, that is highlighted in Figure 4.6.

Figure 4.6 FarmBot electronics enclosure, damaged driver highlighted

The FarmBot's hardware proved to be very adaptable in this dire situation. The Farmduino is built to have an additional location for a stepper driver called "AUX." We modified the firmware code for the FarmBot and redirected all logic from X1 to AUX on the Farmduino. The FarmBot began working, but still retained the stuttering problem. After this, we suspected that the current stepper driver in use was already damaged before we arrived in Venice. We tried replacing it with the spare stepper driver, but that one proved to be damaged before our arrival as well. Replacing the stepper drivers with new ANYCUBIC A4988 Driver units corrected the errors and provided a fully functionable FarmBot. The FarmBot was now much more smooth in moving in both short and long distances.

The FarmBot allows the user to create whatever tools are deemed necessary. Due to the product being open source, the user is easily able to view diagrams of tools and project those needed adjustments to implement their own. The universal tool mount can attach an unlimited amount of tools with the correct attachments. All the necessary files are on the variety of their websites. To view their software visit software.farm.bot/docs. While their electrical components are on gensis.farm.bot. These websites may be merged and changed in the near future, as the company is expanding rapidly. They produced a brand new FarmBot while we were here- the FarmBot Genesis MAX v1.5, which is more than twice the length of any previous version.

Finally, we looked into the user friendliness of extending the functionality FarmBot electronics. According to the FarmBot documentation, auxiliary connections are available within the electronics enclosure, using headers compatible with Molex 151048-1206 connectors, as well as via the FarmBot-custom universal tool mount headers.

Considering the need for lighting, we investigated the possibility of controlling high-power 120VAC/230VAC frequency-adjustable lighting. Due to the complexity of frequency-controlled lighting, we chose to experiment using simple red-blue grow lights which are common in indoor farming operations. We developed a few simple circuit options which could be implemented to enable this feature.

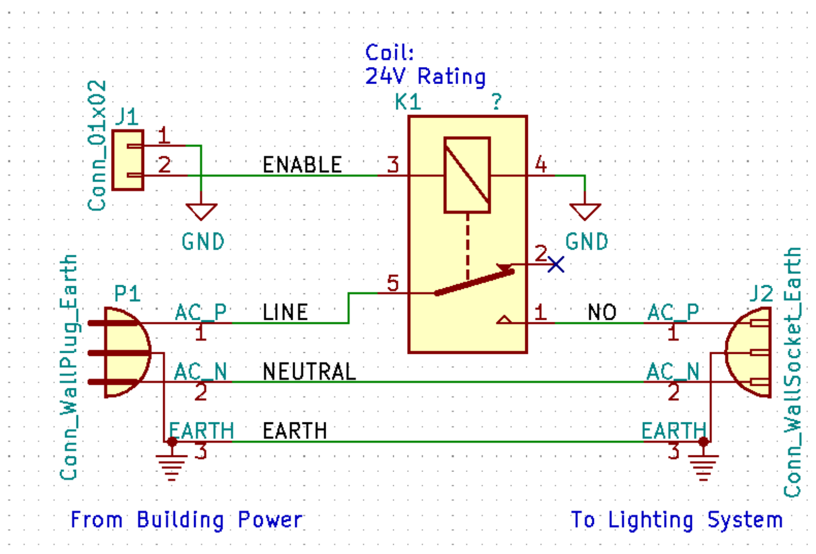



Figure 4.7 FarmBot lighting control circuit schematic (option 1)

This circuit, seen in Figure 4.7, allows the FarmBot to control a 24V-rated relay from a high-current 24VDC output pin on the Farmduino. Only three of these headers are available: P12/D7, P15/D10, and P16/D12. The ENABLE signal switches on the relay to connect LINE to the normally-open output NO. No freewheeling diode is present since it is integrated into the FarmDuino. In fact, the FarmDuino 24VDC outputs use much the same architecture as the circuit in Figure 4.8, including a low-side MOSFET device that performs switching functionality rather than the BJT.

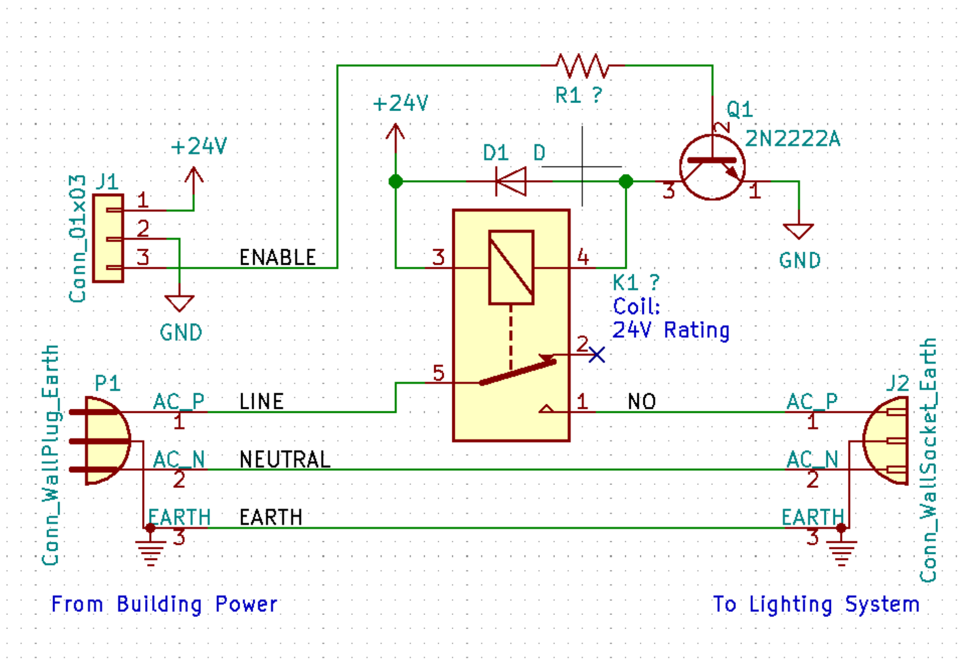



Figure 4.8 FarmBot lighting control circuit schematic (option 2)

An alternative circuit, seen in Figure 4.8, allows the FarmBot to control a 24V-rated relay from a low-current GPIO pin on the Farmduino. Many of these pins are free, compared to only three available 24VDC outputs which could be utilized for the circuit in Figure 4.7. The ENABLE signal switches on bipolar junction transistor Q1, for example a 2N2222A device, which acts as a low-side switch since the FarmBot GPIO pin cannot supply enough current to switch and hold the relay coil. Resistor R1 must be rated to consider the transistor β and the relay coil resistance. When switched on, the transistor sinks current to ground through the transistor coil, which closes the normally-open relay circuit and connects LINE (120VAC/230VAC relative to NEUTRAL) to the output socket. Freewheeling diode D1 prevents voltage spikes, created from coil inductance when the relay is opened, from damaging components.

### 4.2.4 FarmBot Performance Assessment

Our goal for this task was to determine how the FarmBot can execute different planting techniques and to determine the most ideal planting methodology and environment for different plant species in the FarmBot. We chose to grow arugula and parsley at three different plant densities while additionally testing two different soil humidity levels. We tested both full-sized and microgreen sized for each plant species. All variables were chosen to supply SerenDPT with the most optimal planting formation. The plant bed was divided into twenty-four total sections (8x3) with three columns to separate seed densities and each row separating seed species and soil humidity. The dimensions of each section was 0.344 meters by 0.5 meters.

#### 4.2.4.1 Collect growth data based on soil humidity

As well as varying planting density, soil humidity was another variable tested with the FarmBot. To do this the FarmBot was split up into two sections (the top half and bottom half), where one section (top half) had plants growing in a soil humidity of 80%, and the other (bottom half) in a soil humidity of 60%. The FarmBot is capable of using a sensor to determine the soil humidity of the different sections in the FarmBot and then watering accordingly. The values of 60% and 80% soil humidity were determined based a range of recommendations for planting, considering each option and deciding on two similar to the average of 70% (Carr).

#### 4.2.4.2 FarmBot Performance Indicators

To properly prove the FarmBot performance, yield and labor costs must be compared to traditional farming methods. Once the growth cycle for a given plant was completed, the total fresh yield was measured in terms of $g/m^2$. An economic comparison was analyzed to determine how expensive it would be to continue growing plants.

## 4.3 Results & Analysis

Aligning the tracks and belts for the FarmBot to move laterally (x-axis) initially proved to be difficult. The belts couldn't be too tight, nor too loose, otherwise the FarmBot would mechanically bind and prevent the gantry from moving. Once we understood the construction of the FarmBot, realigning the belt became simplistic through trial and error.

With the FarmBot structure was already assembled, it wasn't until later on that we noticed a drainage issue. Drainage became a problem as the water continued to pool in the FarmBot. Its construction should have contained a drainage system to prevent water from creating mold. This issue was more prevalent before the seeds were planted because the only outlet for water at that time was evaporation.

Additionally, the FarmBot was marketed to have a growing area of around 1.4 meters by about 2.9 meters. The length of the FarmBot track is 3 meters but when constructed, the two tracks were not completely even, so on one side the gantry was unable to travel the entire allotted distance. This was due to the geometry of the planting box as it was constructed before we arrived.

### 4.3.1 Yield

These crops were successfully harvested and provided a substantial amount of flavor. The microgreens and full-sized plants require different harvesting procedures as mentioned. Pulling the microgreen roots out and cleaning the dirt off versus cutting the full-size bases with scissors significantly changed the labor times. Labor hours were cut from 30 seconds per plant to 5 seconds per plant after using scissors. These times included harvesting, removing all dirt, and restructuring the FarmBot to be ready for the following cycle.

#### 4.3.1.1 Microgreens

For all microgreens variants, we harvested the plants 14 days after seeding. This is the required time for them to grow as microgreens are harvested after the cotyledon leaves develop. We planted all but one row of microgreens on November 11th, 2019. Due to many large acqua altas and stores in Venice shutting down, the Arugula microgreens with 60% humidity and sparse density were planted on November 25th, 2019. The seeds for the moderately and most dense 60% humidity arugula sections were not able to be obtained in time to run the experiment. The sparse arugula microgreens with 60% humidity were harvested on December 9th while all other microgreens were harvested on November 26th. All microgreens were planted by hand since the FarmBot would have taken several days to plant every seed individually, even after software changes to allow spacing this closely. This could be mitigated with a custom seeding tool designed using the standard FarmBot attachment system. Table 4.3 portrays all of our harvested plants' weights.

| Plant | Sparse (60%) | Sparse (80%) | Moderate (60%) | Moderate (80%) | Dense (60%) | Dense (80%) |
|---|---|---|---|---|---|---|
| Comune (Parsley) | 154.2g | 112.1g | 212.3g | 109.5g | 192.5g | 151.0g |
| A Seme Calibrato (Arugula) | 14.4g | N/A | 7.5g | N/A | 2.8g | N/A |

Table 4.3 Harvested weights of microgreens

For microgreens, the area that grew the most microgreens was the dense parsley. While this area grew the most, it was not the most efficient. As shown in Appendix E, the sparse parsley grew more efficiently per gram. The planted-to-harvested ratio for the sparse microgreens was twice that of the dense area. In Appendix E, we calculated out parsley microgreens to create €7,055 of profit per year. These calculations were based off FarmBot results and the microgreen market analysis.

The arugula weight measurements in the more humid section are not available because they died before harvest. Their death was due to a lack of light available in our growing facility as well as mold growth in the soil. While this negatively affected yield, this was not a major loss. We were experimenting with the methodology, and failure in yield will prove more accurate results in the future after learning from our mistakes.

#### 4.3.1.2 Full sized Plants

For the fully sized plants, we waited 30 days to harvest after planting. This was the required harvest time for the purchased plants. We planted all species on November 11th, 2019 and harvested December 9th. Table 4.4 displays their average weights.

| Plant | Sparse (60%) | Sparse (80%) | Moderate (60%) | Moderate (80%) | Dense (60%) | Dense (80%) |
|---|---|---|---|---|---|---|
| Comune (Parsley) | 2.6g | 4.5g | 4.7g | 4.4g | 6.0g | 4.6g |
| A Seme Calibrato (Arugula) | 13.6g | N/A | 11.5g | N/A | 10g | N/A |

Table 4.4 Harvested weights of full size plants

Once again, the unavailable data for the arugula was due to their death. Parsley was slow to being its growing, where we did not see green until November 24th. In our time lapses, you may notice the few sprouts in the parsley areas. This is because ErbaCea placed their remainder of used microgreen soil in our FarmBot. We weeded these plants using the weeder tool due to their irrelevance in our project.

Unlike parsley, arugula was faster to begin growing. The microgreens section with more water sprouted above the dirt in only three days. Other arugula sections also quickly followed, including the other microgreen section as well as the full sized sections. While they initially grew faster, the arugula provided lower yield. This is because of their density and lack of available light.

### 4.3.2 User Operation (Hardware & Software)

The FarmBot open source compatibility proved very useful when troubleshooting. Following a human error which destroyed a stepper driver, we modified Arduino code to solve our problem. We modified the FarmBot to use the AUX input on the FarmDuino as the X1 input had been damaged from the destroyed stepper driver. The ability to perform this is rather user friendly. Most ordinary devices don't have the ability of open source compatibility. In our situation, the Farmduino provided a painless recovery. Here the connection from the stepper driver to the motor was fixed.

*My.farm.bot* provided very useful for multiple users to access the FarmBot. The application functions remotely, so the farmer can move the FarmBot without being in the same room. All that is needed is the FarmBot to be online and for the farmer to have internet access.

### 4.3.3 Experimental Analysis

While we investigated the yield and interface of the FarmBot, our experimental procedure supplied fruitful information from results as well as mistakes.

#### 4.3.3.1 Lighting

Within a couple of days of planting the seeds, our team noticed that all of the plants that had sprouted were growing sideways toward the only window in the room and later, after about a week, some of our sections had large sections of dead plants (Figure 4.9). The dead plants are shown as the bottom row, with the healthy plants shown in the top as well as the middle. To combat this issue we tried leaving the overhead lights on in the room as well as ordering some large lights online. On November 25th, Michele Savorgnano visited our room to assess our plant situation and he concluded that because our plants were not receiving adequate light from the start, that all but one row of plants were compromised and won't give us accurate data. The only row of plants that are unaffected are the full sized arugula microgreens in the 60% soil humidity section because they still hadn't grown that much. Overall, Michele recommended that we should restart our experiment.

Considering our group only had two more weeks of growing time when Michele visited, we decided that we would continue our experiment and to switch our focus more to developing a methodology for using the FarmBot rather than collecting accurate data.

Figure 4.9 Microgreen plots with large sections of dead plants due to lack of light

With these remaining two weeks, we repeated our experimented for the microgreens. This time however, we had detachable lights that were clipped on the FarmBot. This neighboring light made a substantial difference. The arugula microgreens grew and survived on our second attempt.

#### 4.3.3.2 Planting Method

Based on our farming experiment, we determined that the most optimal planting method for the FarmBot would be to plant the entire bed with parsley microgreens. These crops should be at 80% humidity and planted sparsely (11g worth). While the moderate planting procedure had a higher yield, their ratio of planted-to-harvested was less efficient. A FarmBot fully planted can produce €7,055 in profit per year. With a drainage system and improved lighting system, this profit can be even greater.

# 5.0 Microgreen-centric Agriculture

The goal of this objective was to assess the economic viability of selling microgreens to restaurants in order to assist ErbaCea, a startup centered around growing microgreens using an indoor hydroponic system. We completed this objective by calculating the potential microgreen market within the main islands of Venice. This involved updating SerenDPT's ShopMap App, reaching out to a number of restaurants in Giudecca, communicating with a retired microgreen farmer Michele Savorgnano, and conducting research to have a good understanding of the microgreen farming process.

## 5.1 Background

Microgreens, a special crop defined as "tender immature greens produced from the seeds of vegetables, herbs, or grains," are an ideal candidate for commercial-scale urban farming (Kyriacou, 2016). These greens are appealing for their nutrient content, where they contain concentrated amounts of vitamins including A/B/C/E/K and minerals including iron, magnesium, phosphorus, potassium, and zinc compared to their larger cousins (Petre, 2018), and can be grown easily in populated areas due to their compact growing area.

Microgreens are generally harvested at soil level (at the base of the hypocotyls) as soon as the cotyledons are fully expanded and turgid, which takes on average between 7 and 21 days. The most exploited species belong to the *Brassicaceae, Asteraceae, Chenopodiaceae, Lamiaceae Apiaceae, Amaryllidaceae, Amaranthaceae,* and *Cucurbitaceae* families. Due to their high price market and short production schedule, growing microgreens can be very appealing to some consumers, however microgreens also tend to have smaller yields and short shelf-life so growing microgreens on a commercial scale can prove difficult (Kyriacou, 2016).

The idea of microgreens originated in the late 80's in San Francisco California and they have gained popularity in high end stores and restaurants due to their vivid colors, delicate textures, unique flavor enhancing properties, and nutrients (Kyriacou, 2016).

### 5.1.1 Microgreens and Hydroponics

Soilless farming is highly popular in urban environments and is a prime tool for efficiently growing crops like microgreens due to its production of healthy, clean, grit-free seedlings (Bulgari, 2017). Soilless farming is a broad term that encompasses all farming techniques that grow produce without the use of soil. Instead of soil, nutrient solutions and various growing mediums like sand, gravel, peat moss, rockwool, coconut fiber, perlite, and sawdust are utilized (Jensen, 1997). Foods grown in soilless environments can be grown completely indoors and in controlled environments. This method of agriculture uses limited to no pesticides, thus reducing poison consumption and producing healthier foods, as well as reducing water usage by 90% (compared to soil based methods) (French, 2019).

Hydroponics is the most highly favored type of soilless farming where plants are grown using a water based, nutrient rich solution and sometimes a growing medium. It is an appealing technique because it's systems are clean, lightweight, and can be easily mechanized (Jones, 2016). In addition, compared to soil based systems, hydroponic systems use 90% less water (Patterson, 2009). Hydroponics has 6 primary variations and applications: wick system, water culture, ebb and flow (flood and drain), drip systems, nutrient film technique (NFT), and aeroponics (Simply Hydroponics and Organics, 2008). This may function as either an open or closed system; open being the nutrients are discarded after passing through the roots and closed being the nutrients are recovered for later reuse (Jones, 2016). Of the six main methods, nutrient film technique is the most common among hydroponics (Simply Hydroponics and Organics, 2008).

Coconut fiber, also known as coir, is quickly gaining popularity in the hydroponic world because it is a completely "organic" growing medium, has large oxygen capacity, good water holding ability, and is high in root stimulating hormones (Simply Hydro, 2019). In addition, using coconut fibers promotes circular economy, because the coconut fibers are a waste product from the coconut industry and would have probably been thrown out otherwise (Simply Hydro, 2019).

### 5.1.2 Microgreen Market

Microgreens have become a recent trend but have yet to obtain a specific market worldwide. They're not very easy to resell to the commercial market since they have to be sold almost immediately upon harvest, so the business would have to manage direct sales to customers. It is important for one to complete an analysis to determine if growing microgreens is viable in their situation. A cost-benefit analysis is a comparison of cost and benefits from projects to determine if efforts are worthy to be taken upon (Saez, 2007). This economic value can be estimated in determination by comparing the absence of the project to the implementation of the project. This economic value is referred to as net benefit over total cost. Net benefit is chosen over total benefit to eliminate the option of breaking-even, because the line is omitted to avoid uncertainties. The opportunity cost, an economic term simplified as the next best option, is what is referred to when not implementing the project. Correct economic analysis requires a large ratio to account for the discounting that occurs over time. Discounting in the economic context refers to the prospective change in price over time due to inflation. The larger the ratio, the lesser of an impact inflation will have on the net benefit. Using this method, students at Michigan State University weighed the cost for urban agriculture against the benefits of the vegetables produced (Buckley, 2015). In project-level costs the group considered start-up, input, labor, and management costs. As an individual producer labor, seeds, and equipment are to be considered.

### 5.1.3 Microgreen Hackathon Team

Due to the cultural emphasis on local farming and sustainable agriculture through circular economy, processes like soilless vertical farming, automated farming, sustainable waste management systems, and microgreen production are highly relevant. SerenDPT and INN Veneto are organizations working to create/sponsor startups in these industries that will further push Venice to become a more sustainable city while also creating advanced employment options.

ErbaCea, an agricultural startup, is centered around commercial applications of microgreens sales through coir (coconut fiber) hydroponic systems. The growth of microgreens in Venice has the potential to impact sustainability by dramatically lowering $CO_2$ emissions from transportation: preliminary estimates suggest this may be by a factor of 25% or more (Hausfather, 2018).

## 5.2 Methodology

This objective was focused primarily on assisting ErbaCea with their microgreen startup. In order to assist ErbaCea our group completed a preliminary microgreen market analysis in Giudecca and researched the potential of using an automated pH probe in a hydroponic system. The microgreen market was assessed through the collection of data on all stores in Giudecca and additionally through communication with a retired farmer (Michele Savorgnano) and restaurants. Overall, the market analysis provided our team with enough information to determine if there is a large enough demand for microgreens that ErbaCea could be a successful startup.

### 5.2.1 Assess Microgreen Market

Our group assessed the microgreen market by first categorizing all restaurants in Giudecca through SerenDPT's Input App, visiting restaurants, talking with a retired farmer (Michele Savorgnano), and performing a few calculations to estimate potential revenue.

#### 5.2.1.1 Record store data in Giudecca through SerenDPT app

SerenDPT has an online database containing information about all the shops and their products throughout the main islands of Venice. In order to properly assess the microgreen market in Giudecca our group needed to know how many restaurants are currently in Giudecca, what type of food they sell, and if they could potentially utilize microgreens. To do this, our team updated SerenDPT's online shop database (ShopMap) through an application called InputApp. In order to update the app, our group went to every store in Giudecca and recorded its name, geolocation, store type and picture. If the shop was a restaurant then our group recorded the specific type of restaurant (Take Away, Fine Dining, Cafe, Casual Dining, and "Other." - Appendix F), the general food cost (1 to 4 euro signs), and if there were microgreens on the menu.

Before starting to update the database, several adjustments needed to be made to the InputApp. Nicola, an employee at SerenDPT who created the app, assisted us with this task. Nicola was able to fix a bug in the software, create a drop down menu feature for specific restaurant types (Appendix F), allow us to properly create and submit new entries, as well as merge data from the InputApp with another database that had details about shop information in Venice from a prior project.

During the time that Nicola was fixing the InputApp, our team utilized another app called Epicollect5 to collect the data. Through Epicollect5, our team made a short survey that could be easily filled out on our phones that allowed us to input the same data that we would have through the InputApp. Once all the data was collected through Epicollect5 we input the data into a google excel sheet and then Nicola helped us transfer it back into the Input App.

#### 5.2.1.2 Determine plausibility of microgreen usage in new food outlets

Our team visited two restaurants in Giudecca called La Palanca and Trattoria Ai Cacciatori and asked a few employees about their microgreen usage. Initially we were under the impression, due to hearsay from our sponsor, that these restaurants would be using microgreens, but upon asking a few questions we discovered that they do not. This was unfortunate because we were planning on gathering information about the current market price of microgreens as well as the average amount of microgreens a restaurant purchases each week. Instead we used the information to help us determine what category of restaurants (casual, fine dining, cafe, takeout) would most likely utilize microgreens and form the target market.

#### 5.2.1.3 Estimate potential microgreen market in Giudecca

The last aspect of determining the microgreen market in Giudecca involved our group conducting some small calculations and estimates. We were able to obtain some information about the quantity, frequency, and price of microgreens that restaurants purchase from a retired Giudecca farmer, Michele Savorgnano. Using this information as well as our target microgreen market as determined in 5.2.1.2, our group calculated the amount of microgreens needed per week as well as the amount of potential revenue per week. Lastly, from our calculations we concluded if we thought ErbaCea had a viable market for their startup.

### 5.2.2 pH Probe Exploration

After meeting with ErbaCea, our group was specifically asked to look into the potential of using a pH probe in a hydroponic system to constantly monitor the pH of the water circulating through the system. When it detects an abnormal pH, the sensor should automatically adjust the pH back to the desired value. This section is purely research based as we did not have the time or budget to try to purchase or create any of these devices.

## 5.3 Results & Analysis

This section highlights the specific data collected from the ShopMap App, more detail about our microgreen market choices, and our calculations to estimate the potential microgreen revenue.

### 5.3.1 ShopMap App

Our group was able to successfully update the ShopMap App with Giudecca shop information. Using a combination of EpiCollect5, SerenDPT's InputApp, and last year's IQP's data we were able to compile details about 67 shops in Giudecca (Appendix G). This included information about the shop's name, address, type, exact geolocation, and picture. Out of the 67 shops we recorded the majority are located along the main Giudecca strip. In addition, 48% of the total stores are restaurants and among those 44% are casual dining, 16% are fine dining, 31% are cafes, and 9% are takeout. Figure 5.1 illustrates what our data points look like on the Input App.

For each of the shops that we recorded we also went through and added in their respective NACE codes. The NACE codes are a necessary addition needed for the ShopMap database because they are used to describe the types of shops. Some examples for NACE codes are; 55.4.0.2 = cafe, 52.3.1 = pharmacy, 52.1.1 = grocery store. Our group used last year's IQP (Evaluating Changes in the Venetian Retail Sector and Managing the Use of Public Space 2018) for all information related to NACE codes.

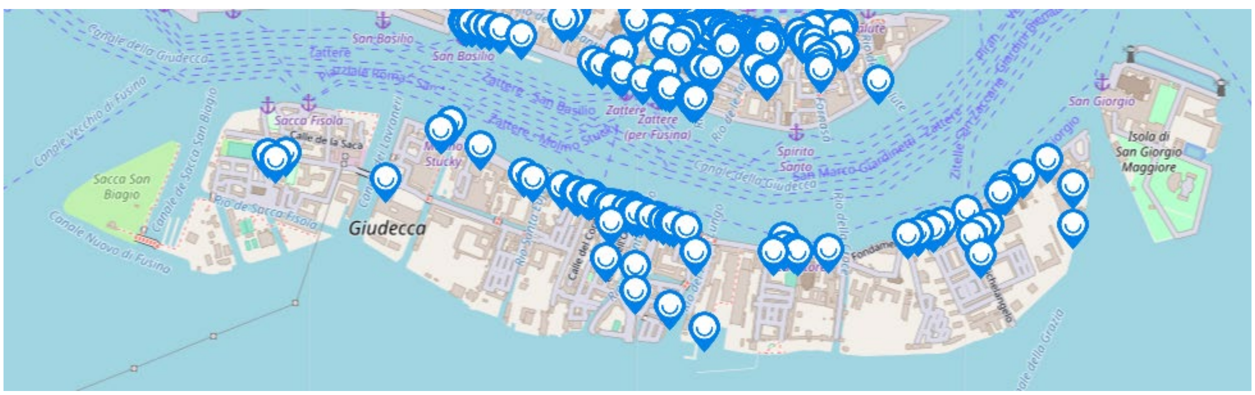



Figure 5.1 Input App with our updated data points

### 5.3.2 Microgreen Market Analysis Estimates

Our group performed a series of calculations in order to estimate the potential microgreen market in terms of weekly revenue. Then using these estimates, we ultimately decided if the microgreen startup, ErbaCea, has a viable market to sell their microgreens.

#### 5.3.2.1. Microgreen Market Determination

Our group ultimately decided that our "fine dining" category would be the ideal microgreen market for ErbaCea. This is because as we visited other restaurants who fell into our "casual dining" restaurant category, all of the restaurants did not use microgreens and many did not even know what microgreens were. When we visited these restaurants, we were accompanied by a fluent Italian so there weren't any language barrier issues influencing our data. We ultimately determined that fine dining restaurants would be more likely to know what microgreens were and how to properly utilize them in their food.

We find that some restaurants from our "casual dining" restaurant category would also be part of the microgreen market due to the wide range of menu items, but because casual dining is such a broad category we can't recommend the entire section. We would recommend further investigation into these restaurants.

#### 5.3.2.2 Microgreen Market Calculations

All of our market calculations were assuming the microgreen market is only made up of "fine dining" restaurants (from all of Venice) and that there was 10% participation. First we calculated how many fine dining restaurants were in the main islands of Venice. To do this we used the same restaurant proportions that we concluded from our Giudecca ShopMap App data. According to the ShopMap there are 4,969 stores in the main islands of Venice, and according to our data 48% of the stores should be restaurants with 16% of the restaurants fine dining. This leads to a total of approximately 382 fine dining restaurants.

Our recorded 5 fine dining restaurants in Giudecca equated to about 390 fine dining restaurants total in Venice assuming the same density. Assuming 10% participation of buyers, we completed the rest of our calculations in terms of 39 restaurants.

To calculate potential market, we first calculated the quantity of potential microgreens needed per week and how much revenue that would bring in every week. The rest of our calculations were based on information provided to us by a former Venetian microgreen farmer, Michele Savorgnano, who said that on average restaurants buy about one kilogram of microgreens a week for €80. Since our 10% market is from 39 restaurants, 39 kilos of microgreens every week will equate to approximately €3,100 revenue a week.

#### 5.3.2.3 Microgreen Market Viability

Based on our previous calculations that ErbaCea can bring in a potential revenue of €3,100 a week, our group determined that this is a viable market and ErbaCea could be a successful startup. Even though €3,100 isn't an extremely large amount of weekly revenue, our group concludes that since microgreens don't require a large amount of labor, only two or three workers would be needed to run the startup and €3,100 a week is enough to support three employees.

### 5.3.3 pH Probe Information

After conducting some research about the current status of automated pH controllers with constant rather than intermittent monitoring, our group concluded that while there are a small amount of pH controllers available commercially, these products are new, not established, and not completely reliable. All of the products that our team found were expensive, had no reviews, and contained vague descriptions of their capabilities. We are not able to guarantee the usefulness of any of these systems, so our team doesn't recommend ErbaCea to try to purchase any of these systems.

Our team was able to find many academic and research articles depicting different groups efforts to create and test their own automated pH controllers with constant monitoring for hydroponics systems (Domingues, 2012) (Saaid, 2015) which is encouraging and will hopefully lead to new pH products being available in the near future.

If ErbaCea is still really committed to an automated pH system with constant monitoring, they will currently have to make one themselves, which would require extensive background research and lots of trial and error (more time and work that our group could dedicate to this portion of our project).

# 6.0 Organic Waste Management

The goal of the organic waste objective was to determine the economic viability of using black soldier flies to compost food waste in order to assist Smart Fly, a black soldier fly centered startup in Giudecca. We accomplished this by determining the viability of the organic waste market within Giudecca. This involved obtaining information from Veritas, a waste management company, visiting and measuring waste from a restaurant, La Palanca, utilizing our ShopMap App data and having a thorough understanding of the black soldier fly farming process and the amount of byproducts it produces.

## 6.1 Background

Black soldier flies have a six-week long lifecycle that can be used to process organic waste (Donahue, 2017). In this process, mature fly stock are introduced into the waste, where they lay their eggs. After the eggs hatch, the larvae will spend about a week or more consuming the decomposing organic waste, after which the larvae are harvested (Figure 6.1). Revenue can be generated through the selling of the useful byproducts created as a result of this process. The byproducts are fat (Omega-3) which is commonly used in cosmetics, protein or meal which is commonly used in animal feed, and frass or fertilizer.

This process requires large volumes of waste. Traditionally, this is obtained from pre-consumer waste however, large volumes can also be required through commercial and noncommercial (residential) waste collection programs. By turning organic residues into valuable feedstock and other products, this black soldier fly "farming" process helps promote a circular economy (Riera, 2019). While some companies use huge treatment facilities in order to process hundreds of tonnes of organic waste, it is also possible to run a "farm" on a much smaller scale with only small composting boxes.

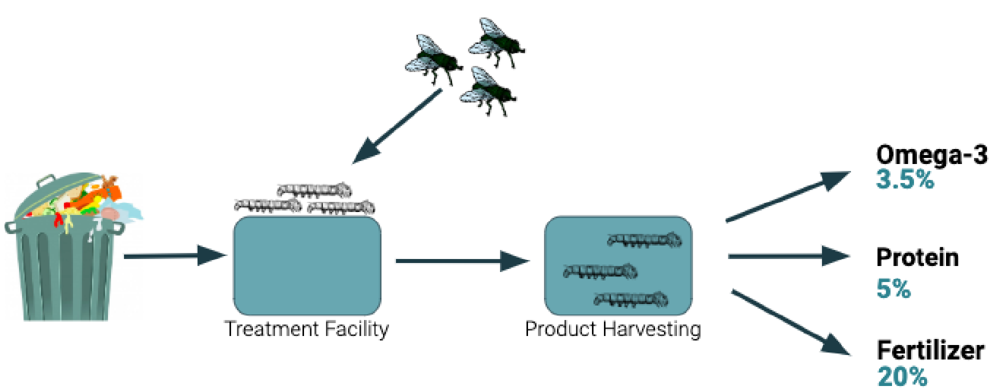



Figure 6.1 Simplified Diagram of Black Soldier Fly Process

### 6.1.1 Real World Applications of Black Soldier Fly Farming

Using black soldier flies to produce compost, oils, and protein is a relatively new concept that is gaining attention worldwide. In Scotland, black soldier flies were found to be more productive then their current waste management system, anaerobic digestion, because the black soldier fly treatment can generate larger economic value and jobs (Riera, 2019). In addition, compared to anaerobic digestion, black soldier fly farming also produces 10% less carbon dioxide per waste input (Riera, 2019).

In the United Kingdom, there is also a growing support for black soldier flies because of the production of protein for animal feed. Research has predicted that black soldier flies have the potential to "establish a new sustainable and 'clean' industry with total annual revenues approaching £1.0 billion within 5 years and substantial additional growth from the export of new, internationally traded, commodities." (Fera Science, 2019). The use of black soldier flies was also projected to bring significant environmental and circular economy benefits as well as the creation of an estimated 4,040 employees (see table 6.1) from just 40 insect farm sites (Fera Science, 2019).

| Job Type | No. Roles | Comments |
|---|---|---|
| Site roles | 2,200 | 55 Jobs @ 40 sites |
| Building jobs | 400 | Based on previous projects, build is estimated |
| Supply chain | 770 | Assumed at 35% of site roles |
| Indirect jobs created | 670 | Assumed at 20% of direct jobs created |
| **Total** | **4,040** | |

Table 6.1 UK job production as a result of insect farms

### 6.1.2 Smart Fly Hackathon Team

Smart Fly is a Venetian startup company centered around the application of black soldier flies in organic waste management. Their process is designed to apply circular economy principles, generating usable products such as protein powder and Omega-3 oils from organic waste. Organic waste is currently not managed separately from inorganic waste in Venice so Smart Fly's primary objective is to determine if they have a viable market to support their startup.

## 6.2 Methodology

In order to determine the feasibility of implementing a circular economy through the reuse of organic waste, our group collaborated with the Smart Flyers Hackathon team (Smart Fly). We collected data on the volume of commercial and non-commercial organic waste production in Giudecca and obtained information on the waste collection process in Venice to give us an understanding of how general waste and organic waste is collected throughout the city.

Work related to organic waste management was assessed primarily at H3, so the team was able to properly calculate the amount of organic waste being produced per household as well as understand the current organic waste disposal methods. Information related to current waste disposal methods were obtained through communication with Veritas, a waste management company located on the mainland (since there are no waste management companies in Venice). We define organic waste as a collection of materials that are biodegradable.

### 6.2.1 Estimate non-commercial organic waste generated in Giudecca

The quantity of non-commercial organic waste was estimated using detailed infographics provided to our team by Veritas. Veritas was able to supply our team with two infographics, one from 2017 and one from 2018, that contain data about the quantity of organic waste they collect (Appendix B). While Veritas does not collect separated organic waste from Giudecca, it does collect separated organic waste from Lido. Our team used Lido's waste and current population data as well as Giudecca's current population data, to calculate a rough estimation of the total non-commercial organic waste in Giudecca (Appendix C).

### 6.2.2 Estimate commercial organic waste generated in Giudecca

In order to assess the commercial organic waste in Giudecca, our group visited one restaurant; "La Palanca" which is located on Giudecca. We visited "La Palanca" at the end of a typical work day (Tuesday evening) and after having a short discussion about the typical amount of customers they serve each day, we weighed out all of their organic waste. "La Palanca" separates their trash by waste from the bar, waste from breakfast and lunch, and waste from dinner. We weighed these bags separately and then added the total weight together for calculations. The calculations we completed were the amount of organic waste per meal, per restaurant over one year, and for all the restaurants in Giudecca. Data from the ShopMap App was also used to complete these calculations.

### 6.2.3 Understand current state of waste management system

For our group to make accurate assumptions and calculations, we needed a general understanding of the current waste management situation. To do this, our group established contact through email, with Veritas, a waste management company, in order to obtain information on the quantity of organic waste they collect.

Smart Fly helped us edit and translate our email and once Veritas responded with helpful infographics which not only provided us with helpful organic waste data (as explained in 6.2.1), but also depicted their current waste management process. This included information about what other companies assist Veritas in the waste collection, where the collection sites are located, where the waste goes, and how much compost is produced.

## 6.3 Results & Analysis

In our results section, our team calculated the quantity of commercial and noncommercial waste that could be collected within Giudecca. After that, we estimated the amount of useful byproducts that can be produced with the black soldier flies and then the potential revenue from these products. Lastly, we ultimately determined whether or not we think Smart Fly will be able to viably collect organic waste in Venice.

### 6.3.1 Quantity of Non-Commercial Organic Waste in Giudecca

Veritas was able to supply us with two infographics (one from 2017 and one from 2018) that provided us with useful information about the amount of organic waste they collected each year and how they dispose of it (Appendix B).

In 2017, Veritas and two other companies, Alisea and ASVO, collected a total of 83,843.52 tonnes of biodegradable waste from eight different collection sites (pictured in Appendix B), 2,318.24 tonnes of the biodegradable waste was collected from Lido which is about 115.9 kg (255.5 pounds) of waste per person per year or 2.22 kg (4.9 pounds) per person per week (Appendix C).

In 2018, Veritas and ASVO collected a total of  86,274.46 tonnes of biodegradable waste from the same eight collection sites and 2,318.24 tonnes of that waste collected was from Lido. This means that about 136.5 kg (300.92 pounds) of waste was collected per person per year or 2.62 kg (5.77 pounds) per person per week (Appendix C), a 118% increase from 2017.

Since Lido is roughly 2.6 times larger than Giudecca in terms of population (Appendix C), based on the 2018 data, around 1,066.38 tonnes of organic waste could potentially be collected for the Smart Fly startup.

### 6.3.2 Quantity of Commercial Organic Waste in Giudecca

All of our commercial organic waste calculations were based on data we collected from La Palanca on December 3rd 2019. Our group went to La Palanca and measured the weight of their organic waste which they separated into waste from the bar (3.37 kg), kitchen waste from the morning (9.02 kg), and kitchen waste from the evening (7.74 kg). The total amount of organic waste was 20.13 kg. La Palanca also informed us that that day they had somewhere between 60 and 70 customers and on average throughout the year they have anywhere between 60 and 90 customers. Using this information, we first calculated the amount of organic waste generated per meal: 0.31 kg / 300 grams (Appendix H). From there we calculated the amount of organic waste generated per year.

To do this we separated the year into high tourist months and low tourist months. During high tourist months (April - October + February due to the carnival) we assumed that 85 people ate at La Palanca each day and during the low tourist months (November - March) we assumed that 65 people ate at La Palanca each day. We also assumed that La Palanca was only open 6 days a week and that they closed on 12 Italian holidays. From this we were able to estimate that about 5,300 kg of organic waste is generated total during the high tourist months and 2,000 is generated during low tourist months, leading to a total of around 7,300 kg of organic waste per year for La Palanca (Appendix H).

From data, we then assumed that all of the restaurants in Giudecca were of similar size and had the same amount of customers. This is a large assumption and given more time we would have further investigated the differences amongst restaurant size and customer popularity in order to make our calculations more accurate. For our final estimation we multiplied the 7,300 kg of organic waste per year by the number of restaurants in Giudecca (32) and were able to calculate that around 235 tonnes of organic waste is generated commercially in Giudecca each year (Appendix H).

### 6.3.3 Quantity/Potential Revenue of Byproducts Produced

After calculating the total amount of commercial (restaurant) and noncommercial (residential) waste that could potentially be collected within Giudecca the next step was to calculate the amount of useful by products that could potentially be produced. Smart Fly was able to provide us with some useful data: 3.5% of organic waste is converted into fats, 5% into protein, and 20% into fertilizer. Using that information from the 1,300 kg of potential organic waste, using black soldier flies approximately 370 tonnes of useful byproducts are produced (45 tonnes fat, 65 tonnes protein, 260 tonnes fertilizer - Appendix H).

After calculating the amount of products, we then estimated the potential revenue. With help from Professor Michalson we were able to find the market prices for all of the products. For fat we found the price of fish oil and for protein we found the price of animal feed. Using these values, we were then able to calculate the potential revenue of black soldier flies using one year of Giudecca organic food waste, assuming 10% participation, to be approximately €650,000 (Appendix H).

This calculation does not take into account labor costs due to the lack of resources and available literature on this subject. We do not believe labor costs should be substantial, as the procedure should not require a high-skill worker and products are quick to collect.

### 6.3.4 Black soldier fly Production Factors

Another aspect of the black soldier fly process that is important to take into account is production: labor, space, smell, etc. Black soldier fly composting can be completed on a variety of levels from small buckets to large indoor facilities. By just using a small 40 x 60 x 15 cm plastic box it is possible to process 15 kg of waste every 13 days (Mertent, 2019), or with a large 424$m^2$ facility it is possible to process 2 tons of waste per day (Donahue, 2017). Due to our estimate, assuming 10% participation, only 130 tonnes of waste would need to be processed each year. This means that a large 424 $m^2$ facility is definitely not needed (Appendix H).

If Smart Fly were to run their startup using the small 0.24$m^2$ plastic boxes, assuming a 10% participation rate, the startup would need to have approximately 300 plastic boxes of black soldier flies processing waste throughout the entire year. This number is deceptive, as the 300 boxes only take up about 74$m^2$ of space which, if stacked, translates to about 3 bell towers the same size as the bell tower at the H3 facility. Considering the amount of unused bell towers in Venice, using bell towers for black soldier flies is definitely something to consider. However, like any waste facility, there will be some unpleasant odors, so finding a bell tower away from busy tourist traffic would be prudent (Appendix H).

Labor costs would require a part-time worker to commit full eight hour work days on Monday, Wednesday, and Friday. If the facility was spread across three bell towers, three workers would be required. Their wage would range from €11 to €15 hourly. One worker would be fully capable of running the facility if everything was in the same location (Donahue, 2017), which could reduce labor costs. One part time worker would make a yearly salary of approximately €16,000 a year, which is a total of around €47,700 in annual labor costs (Appendix H).

### 6.3.5 Veritas Waste Management General Process

Veritas was able to supply us with information about the entire organic waste management process. Of the eight total collection sites, Veritas collects waste at six (2017) or seven (2018); ASVO and Alisea were contracted to collect at one site each in 2017, while only Alisea collected in 2018. Once all of the waste is collected it is brought to one of the five transfer stations (depends on the location of waste pickup); Jesolo, Portogruaro, Chioggia, Mirano, and Fusina. From the transfer stations, the waste is either brought to one of the two treatment facilities, Bioman and S.E.S.A, or to a recovery facility, Agrilux. In 2018 from the 86,274.46 tonnes of waste collected, 17,233.2 tonnes of compost was produced.

### 6.3.6 Assessment of total organic waste

Using a combination of data from restaurants in Giudecca, Veritas, our ShopMap App, and various online databases, we were able to estimate an annual potential revenue for waste generated in Giudecca to be approximately €600,000 - assuming 10% participation. This revenue accounts for three part-time workers. Using one larger facility, revenue can be upwards of €632,000. This is definitely a viable market for Smart Flyers and our group recommends Smart Fly as a potential successful start up.

# 7.0 Future Recommendations

We recommend the following tasks be completed as a continuation to this project:

## 7.1 Sustainability Comparison

The FarmBot can be placed in urban centers to extremely reduce the distance required to import food. This would lower both costs and $CO_2$ emissions. We recommend a sustainability experiment should be conducted and compared to traditional farming, including the use of electricity, water, and other consumables. This should consider emissions generated from producing the product, as well as the emissions generated from using the product. The FarmBot company conducted a $CO_2$ emission test of their own; they claim that the FarmBot grows vegetables using 25-30% less $CO_2$ than those purchased from a store in the United States (FarmBot, 2019). While their data appears reliable, a third party should conduct the experiment for unbiased results and adjust for Venice-specific factors such as the unique transportation limitations.

## 7.2 FarmBot controlled Lights

Our test environment contained little available light. The only consistent light available for plant growth was sunlight through a small window in the room. During working hours, the ceiling light provided some additional temporary light. The FarmBot does allow a third party to control lights. A lights peripheral is labeled as pin 7, which can be used as an output to control 24VDC lights directly. This option can be usually controlled on and off. This peripheral specifically, controls the light on the gantry. The FarmBot does include two additional peripherals that can be setup and controlled by the user. This allows for the user to include lights to be operational by the *my.farm.bot* web application. To include controlled lights, the FarmBot web application includes sequences. A sequence could perform actions including watering when a button was pressed, or even an "if statement" to operate if certain conditions apply. This would be the best method to implement controllable lights on the FarmBot.

Another possible option for FarmBot-controlled lighting would be to apply the above method through the FarmBot web interface, but instead of connecting the lights directly to the FarmBot they would be connected through an intermediate system. One example of this would be the proposed system in section 4.2.3, which suggests several options for applying mechanical relays to control high-power AC or DC systems. An additional option would be to create a simple one-way communications protocol between the FarmBot an external microcontroller. This can be accomplished by using one FarmBot output as a clock signal and modulating another output as a data line. Another method would be further modifying the FarmBot software or firmware to support more advanced communication methods. The external microcontroller would then be able to configure more complex lighting environments, such as a frequency-controlled system or a more complex lighting array, based on the FarmBot output.

One popular method for lighting is to have third party lights outside the FarmBot surrounding it. These lights are angled acutely with the ground, causing light to shine diagonally instead of perpendicularly. This method is not optimal for the FarmBot, as multiple users commented that this light pattern causes plants to grow at an angle of the light. This growth defection hinders its growing method. We recommend building an exterior structure to apply lights from above. This structure must be tall, as the FarmBot must have enough room to operate without colliding with the lights. This method is more attractive than a dome enclosure due to its pricing: a dome enclosure of lights would require a massive budget, especially if these lights are going to alternate frequencies to benefit growth stages. A strong light from above is cheaper, more attractive, and more efficient.

## 7.3 Vertical Farming in Bell Tower

Due to logistical challenges as well as time constraints from the other objectives in our project, our group was unable to tangibly complete our fourth objective which was to assess the bell towers for their viability in vertical farming. While this objective is important and could provide useful insight into repurposing old bell towers, our sponsors and group members agreed that the three other objectives had higher priority. In addition, more research than previously thought needs to be completed in order to run the "grow tent experiment" which was the main aspect of this objective. We believe that that a future IQP team whose focus is based solely on vertical farming in bell towers will have a larger success with this objective. Please see Appendix D for more details.

## 7.4 FarmBot Drainage

In our experiment, our FarmBot had no drainage included. This caused a large amount of water to accumulate inside the bed. Over time, the waterlogged soil began to grow mold in various areas around the bed, including around our crops. A drainage system is necessary for the FarmBot's long term success. Our recommendation would to drill several holes in the sides of the FarmBot's bed. These holes should be about a 6 mm in diameter, a size where soil would rarely escape but water will be allowed to flow relatively freely. This could be supplemented with a layer of gravel about 25mm thick to allow for better drainage for the center of the bed. Several holes should be in place to allow for optimal locations for drainage. A slope inside the bed could be added to transfer the water from locations away where there is a lack of drainage. A tube should be attached to the bed to transfer the water to FarmBot's water bucket. This recycled water will prove to be efficient.

## 7.5 Non-commercial Organic Waste Estimation

To calculate the volume of non-commercial organic waste our team used Veritas' organic waste collection data from Lido. Combined with Lido's population data, we were able to calculate an estimate of 1,066.38 tonnes of organic waste to be projected in Giudecca per year. Our team would recommend another IQP group to further refine this estimation by conducting a small scale organic waste collection experiment in Giudecca.

Our team originally planned to run this "bucket" experiment during our time in Venice, but due to time constraints from other aspects of our project, as well as communication issues between our group and Smart Fly, we unfortunately ran out of time. The "bucket" experiment would entail a bucket placed inside of our facility or some other chosen location. Then, over a specific amount of time pre chosen families would come and drop off their organic waste into the bucket. Before the experiment starts, Chart B from Appendix A would be filled out. Each time a family member drops off their waste they would fill out Chart A from Appendix A. These charts would be printed out and posted on a clipboard near the bucket. Every day a member of the IQP group would weigh and record the weight of organic waste collected. Using information from the charts, including number of people in the family and how long it took to accumulate the waste, the IQP group would calculate an estimate on non-commercial organic waste per capita.

# 8.0 Works Cited

## Overall Background Works Cited:

Agarwal, R. C. (2014, September 18). Water Transport: Kinds, Advantages and Disadvantages of Water Transport. Retrieved October 5, 2019, from http://www.yourarticlelibrary.com/geography/transportation/water-transport-kinds-advantages-and-disadvantages-of-water-transport/42133.

Clemens, Roxanne. (2004). Keeping Farmers on the Land: Adding Value in Agriculture in the Veneto Region of Italy (MATRIC Briefing Papers. Retrieved from Iowa State University Digital Projects: https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1007&context=matric_briefingpaper

Curley, R. (2019, August 15). Crop. Retrieved from https://www.britannica.com/topic/crop-agriculture

European Commission. (2019, November 9). Retrieved from Veneto website: https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/veneto

Food and Agriculture Organization. (2012). Livestock and Landscapes. Retrieved from http://www.fao.org/3/ar591e/ar591e.pdf

Food and Agriculture Organization. (2019). Agricultural land (sq. km). Retrieved October 4, 2019, from https://data.worldbank.org/indicator/AG.LND.AGRI.K2?end=2016&start=2016&view=bar.

Gentry, M. (2019). Local heat, local food: Integrating vertical hydroponic farming with district heating in Sweden.
Science Direct, pp. 191-197. Retrieved from Science Direct database.

Hausfather, Z. (2018, April 27). Mapped: The world's largest CO2 importers and exporters. Retrieved from https://www.carbonbrief.org/mapped-worlds-largest-co2-importers-exporters

Ochoa et. al. (2019, July). *Sustainable Community Gardens Require Social Engagement and Training: A Users' Needs Analysis in Europe*.

Port of Venice. (2019). *Port of Venice*. Retrieved from https://www.port.venice.it/files/page/190705portofvenice1-2019_0.pdf

Recare. (2018). Veneto, Region Italy. Retrieved from

VE19-Farm

https://www.recare-hub.eu/case-studies/Veneto-region-italy

Roser, M. (2019, April 26). Employment in Agriculture. Retrieved October 2, 2019, from https://ourworldindata.org/employment-in-agriculture.

Statista. (2019, September 16). Household average monthly expenditure 2018 Italy. Retrieved From https://www.statista.com/statistics/881144/household-average-monthly-expenditure-italy/

Todescan, G. (2018, December 17). INN Veneto. Retrieved 2019, from https://www.inn-veneto.it/10-serendpt-cescot/.

Wirsenius, S., et al. How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? Agr. Syst. (2010), doi:10.1016/j.agsy.2010.07.005

Yuan, Z., Bi, J., & Moriguichi, Y. (2006). The Circular Economy: A New Development Strategy In China. Industrial Ecology in Asia, 10(1-2), 1–5. Doi: https://doi.org/10.1162/108819806775545321

## FarmBot Works Cited:

Carbonfund.org. (2016). How We Calculate. Retrieved from https://www.carbonfund.org/how-we-calculate/

Despommier, D. (2009, November 1). Growing Skyscrapers: The Rise of Vertical Farms. Retrieved September 7, 2019, from https://www.scientificamerican.com/article/the-rise-of-vertical-farms/

European Commission. (2019, November 9). Retrieved from Veneto website: https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/veneto

FarmBot. Exploring the Carbon Footprint of FarmBot. (2019). Retrieved from https://farm.bot/pages/footprint

Gentry, M. (2019). Local heat, local food: Integrating vertical hydroponic farming with district heating in Sweden. Science Direct, pp. 191-197. Retrieved from Science Direct database.

Gibson, J. W. (2019). Automating Agriculture. In In Defense of Farmers: The Future of Agriculture in the Shadow of Corporate Power (pp. 135-174). University of Nebraska Press.

Krzemińska et. al. (2019). Cities of the future—bionic systems of new urban environment: Environmental Science and Pollution Research (Vol. 9).

Sky Greens. (2014). Retrieved September 19, 2019, from https://www.skygreens.com/

Vincent, J. (2019, May 2). Robotic Farming Startup. Retrieved September 19, 2019, from https://www.theverge.com/2019/5/2/18526590/Robot-farming-startup-iron-ox-california-leafy-green-bianchinis

## Microgreens Works Cited:

Best Times to Visit Venice. (2019). Retrieved December 10, 2019, from Venice Travel Guide website: https://travel.usnews.com/Venice_Italy/When_To_Visit/

Buckley, J., & Peterson, C. H. (2015, September). Wisc. Retrieved October 1, 2019, from https://fyi.extension.wisc.edu/foodsystemstoolkit/files/2015/09/Buckley-Peterson-cost-ben-150904-more-index.pdf.

Bulgari et. al. (2017). Yield and quality of basil, Swiss chard, and rocket microgreens grown in a hydroponic system. *New Zealand Journal of Crop and Horticultural Science*, *45*(2).

Carr, H. (2019, April 3). RHS: inspiring everyone to grow. Retrieved December 2, 2019, from https://www.rhs.org.uk/advice/grow-your-own/herbs/parsley.

Domingues, D., Takahashi, H., & Camara, C. (2012, June). *Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production*. Retrieved from Science Direct database.

French, A. (2019, March 12). Soilless Agriculture: An In-depth Overview. Retrieved from https://www.agritecture.com/blog/2019/3/7/soilless-agriculture-an-in-depth-overview

Jensen, M. H. (1997, October). *Hydroponics*. University of Arizona: Department of Plant Science.

Jones Jr, J. B. (2016). Hydroponics: a practical guide for the soilless grower. CRC press.

Kyriacou et. al. (2016, November). *Trends In Food, Science, and Technology: Vol. 57. Micro-scale vegetable production and the rise of microgreens*. Retrieved from Science Direct database.

Patterson, S. (2009, August 10). Aeroponics vs. Hydroponics. Retrieved from https://www.doityourself.com/stry/aeroponics-vs-hydroponics

Petre, A. (2018, March 6). Microgreens: All You Ever Wanted to Know. Retrieved 2019, from https://www.healthline.com/nutrition/microgreens.

Saez, E. (2007). Berkeley. Retrieved October 1, 2019, from https://eml.berkeley.edu/~saez/course131/costbenefit_ch08.pdf.

VE19-Farm

Saaid, M. F. (2015). *Automated pH controller system for hydroponic cultivation*. Retrieved from IEEE Xplore database.

Simply Hydroponics and Organics. (2008). Basic Hydroponic Systems and How They Work. Retrieved from https://www.simplyhydro.com/system.htm


## Organic Waste Works Cited:

City Population. (2011, October 9). Retrieved December 10, 2019, from https://www.citypopulation.de/en/italy/localities/veneto/venezia/02704210022__giudecca

Donahue, P. (Ed.). (2017). Black Soldier Fly Biowaste Processing: A Step-by-Step Guide. Retrieved September 10, 2019, from https://pdfs.semanticscholar.org/4982/a69fd8dafeafab9564ca1c9c9cce65d6ab0c.pdf.

Fera Science. (2019, April). The Insect Biomass Industry for Animal Feed – the Case for UK-based and Global Business . Retrieved from https://www.cielivestock.co.uk/wp-content/uploads/2019/07/00-Final-Insect-Biomass-TF-Paper-Mar19.pdf.

Mertenat et. al. (19, February). *Science Direct: Black Soldier Fly biowaste treatment – Assessment of global warming potential*.

Riera, A. (n.d.). Black Soldier Fly: A Circular Economy Solution for Scotland. Retrieved September 10, 2019, from https://www.zerowastescotland.org.uk/sites/default/files/Black Soldier Fly - a circular economy solution for Scotland.pdf.


## Vertical Farming Works Cited:

AeroFarms. (2019). Retrieved September 19, 2019, from https://aerofarms.com/story/

Despommier, D. (2009, November 1). Growing Skyscrapers: The Rise of Vertical Farms. Retrieved September 7, 2019, from https://www.scientificamerican.com/article/the-rise-of-vertical-farms/

Gentry, M. (2019). Local heat, local food: Integrating vertical hydroponic farming with district heating in Sweden.
Science Direct, pp. 191-197. Retrieved from Science Direct database.

Jenkins, A. (2018, September 10). Food security: vertical farming sounds fantastic until you consider its energy use.
Retrieved from, http://theconversation.com/food-security-vertical-farming-sounds-fantastic-until-you
-consider-its-energy-use-102657

VE19-Farm

ONG, S. (2018, November 2). Milan's high-rise Vertical Forest takes root. Retrieved September 19, 2019, from https://www.lonelyplanet.com/articles/milan-vertical-forest-high-rise

The Living Wall. (2018). Retrieved September 19, 2019, from https://www.athenaeumhotel.com/en-US/the -living-wall/

Vertical Farming. (2017). Retrieved from https://whatis.techtarget.com/definition/vertical-farming

# Appendix A: Bucket Experiment

Bucket Experiment Data Table:

Table A: Table that people would fill out everytime they brought waste to the bucket

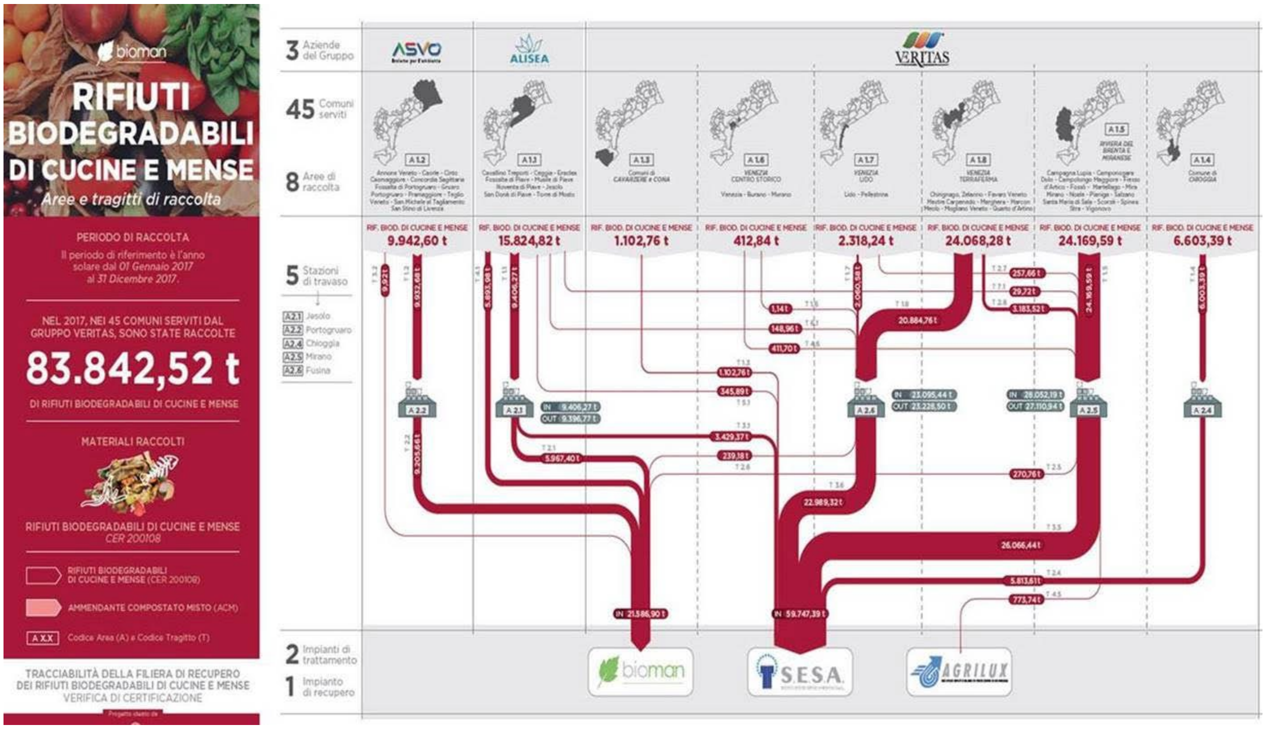
| Date waste brought to bucket | Family Name | Days it took to accumulate waste | Weight of waste |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

Table B: Table that we would fill out before the experiment starts and use for reference

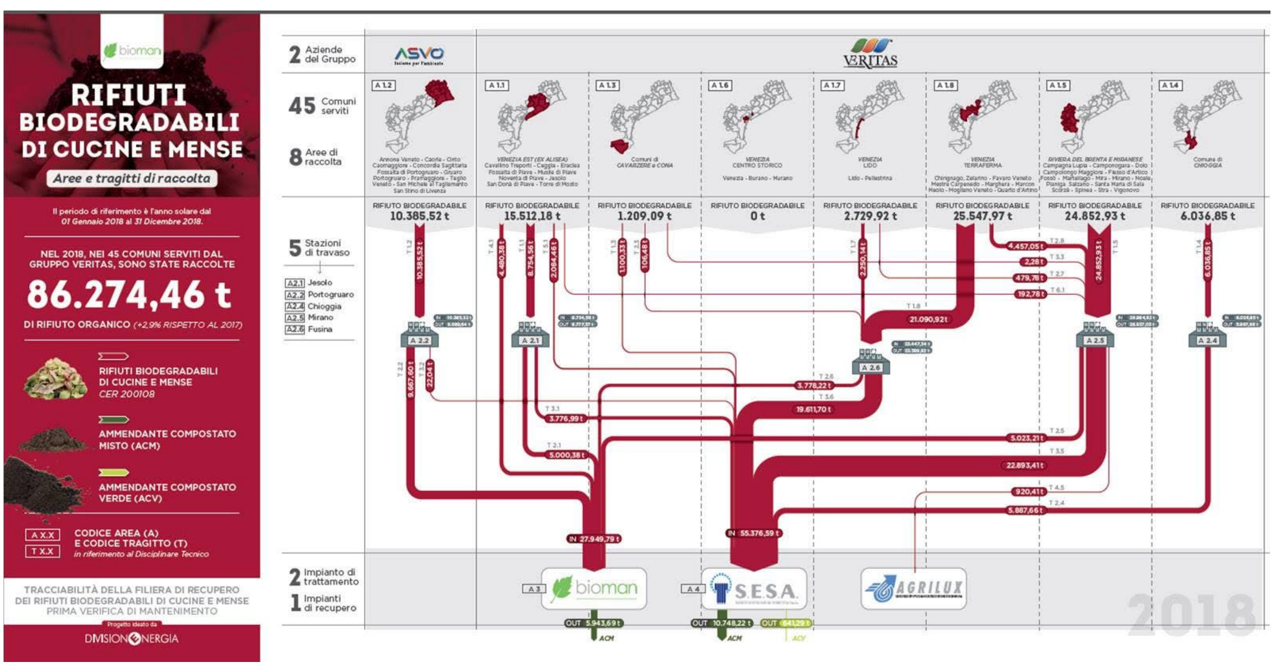
| Family Name | Head of Household age | Number of people in the family | | Where live/relation to SerenDPT | Contact email or number |
|---|---|---|---|---|---|
| | | Adults | Children | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

# Appendix B: Veritas Infographics

2017 Veritas Biodegradable Infographic:




2018 Veritas Biodegradable Infographic:



# Appendix C: Veritas Waste Calculations:

**2017 Data**:
83,842.52 tonnes of biodegradable waste collected total - 2,318.24 tonnes from Lido
Current Population of Lido - 20,000
2,318.24 tonnes = 5110844.35 pounds = 255.54 pounds (115.9) per person per year = 4.9 pounds (2.22 kg) per person per week

**2018 Data:**
86,274.46 tonnes of biodegradable waste collected total - 2,729.92 tonnes from Lido
Current Population of Lido - 20,000
2,729.92 tonnes = 6018443.39 pounds = 300.92 pounds (136.5 kg) per person per year = 5.77 pounds (2.62 kg) per person per week

Other Calculations:

% increase from 2017 to 2018
115.9 kg →136.5 kg
136.5/115.9 = 1.18 x 100% = 118% increase
Correlation with Giudecca (based on 2018 data) - (City Population, 2011)
Giudecca population = 6,147 people - based on census on October 9, 2011
Lido population = 15,719 people - based on census on October 9, 2011

*even though we have a more current Lido population estimate, I used the population data collected from the same census as the Giudecca data (the most recent one I could find) to calculate the fraction of population Giudecca is to Lido and I am assuming that since 2011 their populations are growing at the same rate.

15,719 / 6147 = 2.56 (Lido is about 2.5 times bigger than Giudecca)
2,729.92 tonnes / 2.56 = 1,066.38 tonnes per year from Giudecca

Compost created (from black soldier flies team values):
1,066.38 tonnes →**37 tonnes of fat, 53 tonnes of meal, 213 tonnes of Frass**

Info from black soldier flies composting methods (Smart Fly data): For every 100 kg of organic waste, 3.5 kg of fat, 20 kg of Frass, and 5kg of meal is produced

# Appendix D: Vertical Farming In the Bell Tower

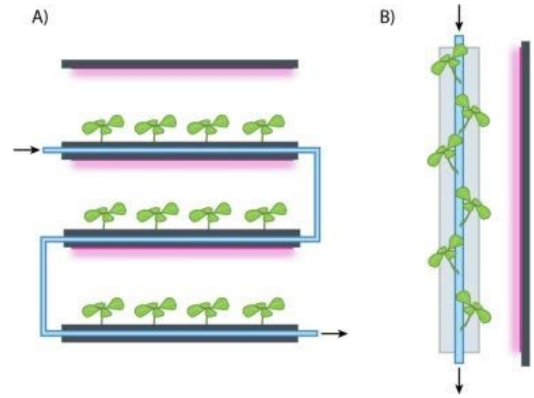
In our original project proposal our group had a fourth objective: to determine the feasibility and viability of using bell towers for vertical farming. However after arriving in Venice and speaking with our sponsors, we agreed that we should prioritize the other three objectives and save the vertical farming objective for another group who can dedicate more time and effort toward it. Since we already spent a good amount of time researching and preparing for this objective we will be presenting the most important information we learned here to help any future IQP groups who come along after us.

## Background

Vertical farming is loosely defined as "the practice of growing produce in vertically stacked layers" (Vertical Farming, 2017). Vertical farming can be extremely beneficial to rapidly growing societies because it provides a more efficient use of land and water, maximizes space, reduces transportation costs and transportation associated pollution, can have an almost unchanging production level throughout the entire year, and can lead to improvements in resource usage and growth efficiency. "A one-square-block farm 30 stories high could yield as much food as 2,400 outdoor acres, with less subsequent spoilage." (Despommier, 2009). One potential drawback to vertical farming is the energy consumption. Due to artificial lighting and climate control systems, the energy consumption for vertical farming is significantly larger, for example, lettuce grown in traditional greenhouses requires around 250 kWh of energy (per square meter), while lettuce produced through vertical farming methods requires around 3,500 kWh of energy (per square meter) (Jenkins, 2018). Another potential drawback for vertical farming is that since it is a relatively new concept, there is not much research on its long term economic viability (Despommier, 2009).

### Vertical Farming Methods

Vertical farming is commonly completed through various soilless farming methods, mainly aeroponics and hydroponics. Hydroponics, a technique where plants are grown with their roots submerged in a nutrient rich bath (Jones, 2016), is the most common method utilized for vertical farming. In terms of vertical farming, hydroponics is split into two sub techniques; nutrient film and drip irrigation. The nutrient film technique, as displayed in Appendix D figure 1, involves water being pumped through the channel where the roots hang. The nutrient water flows through each level, is collected at the bottom, and then re-circulated through the top of the system. For this method, LED lightning is placed or hung above each tray. The second technique, drip irrigation, as displayed in Appendix D Figure 1B, involves the nutrient water being drip fed through a column. The column is filled with a wicking material that helps draw the water to the roots, and any extra water will flow out of the bottom of the tower to be recirculated. For this method, LED lights can be placed on each side of the column (Gentry, 2019). Both of these vertical farming methods are commonly used, however the drip irrigation technique is more popular due to its physical characteristics, since this system is gravity fed it requires less energy and a less complex frame.




Appendix D Figure 1: Hydroponic techniques for vertical farming
A) Nutrient Film Technique B) Drip Irrigation (Gentry, 2019)

### Applied Vertical Farming

Over the last decade, the popularity of vertical farming in urban environments has increased substantially, and many companies, architects, and botanists worldwide have started to implement vertical farming methods into their work/potential start up ideas.

In London, a hotel called the Athenaeum installed a vertical garden on one side of their hotel from street level to the tenth floor. This wall was installed in 2009 by artist and botanist, Patrick Blanc. The wall has a mix of native and exotic plants with over 260 species total. Other than this wall, Blanc has installed over 140 other vertical gardens for institutions all around the world (The Living Wall, 2018).

In Milan, architect Stefano Boeri designed two towers in Porta Nuova as part of his project to create an urban forest (Appendix D Figure 2). These two towers, one 116m and the other 85m, feature 700 trees and over 20,000 types of shrubs and plants. The plant life is said to equal three hectares of forest and can convert as much as 30 tonnes of $CO_2$ each year. The towers, which opened in 2014, also filter dust particles, control noise pollution, and create a microhabitat for many birds and insects. Boeri is now working to continue his project in Paris by creating a 54m building that will incorporate a hectare of woodland (Ong, 2018).

In Newark, New Jersey, a start up called Aerofarms is using aeroponic vertical farming to grow two million pounds of produce annually. The growing system is sunless, soilless and yields a fresher, cleaner produce with a smaller risk of contamination. The system is a closed loop system and uses “95% less water than field farming and 40% less than hydroponics." The company started in 2004, has four different farms within Newark, and supplies fresh produce to grocery stores and restaurants in New Jersey (Aerofarms, 2018).

Appendix D Figure 2: Sustainable tower designed by Stefano Boeri in Milan (Ong, 2018)

## Methodology

In order to determine the feasibility and viability of using bell towers for vertical farming and complete our objective, our group planned to use the bell tower at H3 to quantify the yield potential of the bell tower, conduct a small scale grow tent experiment to determine climate control costs, and complete a cost analysis to ultimately determine if vertical farming in bell towers is feasible.

### Quantify Yield Potential

To quantify the yield potential we planned to calculate the available surface area for farming and then using our compiled information about potential farming methods and products, decide how we want to grow our produce and what produce to grow. Our group was planning on only focusing on microgreens as a potential product to grow because we are already determining the microgreen market for other parts of our project, but a new team who takes on this objective could explore growing full sized plants in the bell tower if wanted. With a chosen farming method and product our group planned to research the total yield potential for a specific unit area and then be compiled with our already calculated available surface area to ultimately quantify the yield potential for vertical farming in the bell tower at H3. We were aware that this yield potential will approximate the actual yield potential since they are many variables and unknowns to account for with this broad of a calculation.

### Grow Tent Experiment

Another aspect of this objective that we planned to complete was a grow tent experiment where we would construct a climate controlled tent in one of the rooms on the bell tower and use the tent to assess how difficult and expensive it is to create a climate controlled area. One of the reasons why we didn't end up completing this objective is because another IQP group needed the bell tower for their project. Our group highly recommends that a future IQP project team conducts an experiment similar to our proposed "grow tent experiment" because we believe that the most challenging aspect of vertical farming in the bell tower is creating a climate controlled atmosphere.

We recommend starting with a grow tent type structure on a small scale and using sensors, measure the differences in climate (temperature, humidity, CO2) between the inside of the grow tent and other areas in the bell tower (top and bottom of bell tower). The grow tent should have lights and a fan to help with air flow and provide heat. Also, even though the exact plants grown during the experiment is arbitrary, it would be helpful to record the general conditions of the plants throughout the experiment.

### Cost Analysis

The final aspect of the vertical farming objective was to conduct a cost analysis of the bell tower and determine if vertical farming within the bell tower is a worthy investment. The cost analysis would tie in the calculated yield potential and data from the grow tent experiment. By calculating the yield potential, our group would know approximately how much the bell tower can produce and from our small scale-grow tent experiment, we would have determined rough climate control costs. Through additional research we would determine how to bring the necessary utilities to the bell tower, the cost of such utilities, as well as the potential market for whatever product we decide to sell. After completing this cost analysis, our group (and any other future IQP group) would be able to ultimately recommend, through a written report, if vertical farming in the bell tower is worth it.

# Appendix E: Microgreen and FarmBot Calculations

| Row | Weight | | Modifier (avg (3 sample) clean green weight/total weight of sample) | Weight w/ dirt + plate | Hudmidity Level | Amount Planted | | Ratio of ammount planted to amount harvested | "Winner Square from round 1" | Cost per Bag | | Cost Per Amount Planted | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Arugula Microgreen (2)** | | | | | 80 | | | | | | | | |
| Sparse | 14.4 | g | N/A | N/A | 80 | 5 | g | 2.88 | Arugula Microgreens | 2 | euro | 2 | euro |
| Moderate | 7.5 | g | N/A | N/A | 80 | 10 | g | 0.75 | | 2 | euro | 4 | euro |
| Dense | 2.8 | g | N/A | N/A | 80 | 15 | g | 0.1866666667 | | 2 | euro | 6 | euro |
| **Parsley Microgreen (4)** | | | | | 80 | | | | | | | | |
| Sparse | 154.2 | g | 0.622 | 254.8 | 80 | 11 | g | 14.01761818 | Parsley Microgreens | 2 | euro | 1.5 | euro |
| Moderate | 212.3 | g | 0.665 | 326.2 | 80 | 21 | g | 10.11116667 | | 2 | euro | 3 | euro |
| Dense | 192.5 | g | 0.669 | 294.8 | 80 | 32 | g | 6.016660156 | | 2 | euro | 4.5 | euro |
| **Parsley Microgreen (8)** | | | | | 60 | | | | | | | | |
| Sparse | 112.1 | g | 0.573 | 202.6 | 60 | 11 | g | 10.19419091 | | 2 | euro | 1.5 | euro |
| Moderate | 124.5 | g | 0.75 | 172.9 | 60 | 21 | g | 5.928571429 | | 2 | euro | 3 | euro |
| Dense | 151.0 | g | 0.651 | 238.8 | 60 | 32 | g | 4.717715625 | | 2 | euro | 4.5 | euro |
| Plate | | g | | | | | | | | | | | |
| **Parsley Full (3)** | | | | | 80 | | | | | | | | |
| Sparse | 4.5 | g | N/A | N/A | 80 | 0.19 | g | 23.68421053 | Parsley Full Size | 2 | euro | 0.1 | euro |
| Moderate | 4.4 | g | N/A | N/A | 80 | 0.26 | g | 16.92307692 | | 2 | euro | 0.17 | euro |
| Dense | 4.6 | g | N/A | N/A | 80 | 0.39 | g | 11.79487179 | | 2 | euro | 0.21 | euro |
| **Parsley Full (7)** | | | | | 60 | | | | | | | | |
| Sparse | 2.6 | g | N/A | N/A | 60 | 0.19 | g | 13.68421053 | | 2 | euro | 0.1 | euro |
| Moderate | 4.7 | g | N/A | N/A | 60 | 0.26 | g | 18.07692308 | | 2 | euro | 0.17 | euro |
| Dense | 6 | g | N/A | N/A | 60 | 0.39 | g | 15.38461538 | | 2 | euro | 0.21 | euro |
| **Arugula** | | | | | 60 | | | | | | | | |
| Sparse | 13.6 | g | N/A | N/A | 60 | | | | | | | | |
| **Parsley** | | | | | 60 | | | | | | | | |
| Sparse | 75.9 | g | N/A | N/A | 60 | | | | | | | | |
| **Cabbage** | | | | | 60 | | | | | | | | |
| Dense | 193.8 | g | N/A | N/A | 60 | | | | | | | | |

Figure 8.4 FarmBot data points

## Calculations for a FarmBot full of Spare sowing Parsley Microgreens at 80% Humidity:

Potential Yield for Spare Sowing Parsley Microgreens at 80% Humidity = 154g
Total Yield from FarmBot Full = (Yield per square) x (# of Squares)
Total Yield from FarmBot Full = 154g x 24 Sectors
**Total Potential Yield from FarmBot Full = 3,696g = 3.7kg - Including 10% immortality rate**

Time to grow = 14 Days Thus 26 Times a year
Total Yield from FarmBot Full Year = 3.7kg x 26 Times a year
**Total Yield from FarmBot Full per Year = 96.2kg a year**

“Price to sell Microgreens = €80 / 1kg” - Michele Sovargno
**Total Revenue from FarmBot per Year = 96 x 80 = €7,680**

Cost of Seeds = €2.15 per bag
0.75 Bag is used per Sector for sparse
Cost per plant = €2 per bag x 0.5 Bag is used per Sector for sparse

Cost per plant = €1 per plant

Cost for a Full FarmBot = 24 Sectors x  €1 per bag
**Cost for a Full FarmBot = €24 per plant**

Cost for full year = Cost for a Full FarmBot x Plants per year
**Cost for full year = €24 x 26 = €624 per year**

Profit = Revenue - Cost
**Profit = €7,680 - €624 = €7,055 per year**

## Calculations for a FarmBot full of Spare sowing Arugula Microgreens at 80% Humidity:

Potential Yield for Spare sowing Arugula Microgreens at 80% Humidity = 14g
Total Yield from FarmBot Full = (Yield per square) x (# of Squares)
Total Yield from FarmBot Full = 14g x 24 Sectors
**Total Yield from FarmBot Full = 336g = 0.336kg**

Time to grow = 14 Days Thus 26 Times a year
Total Yield from FarmBot Full Year = 0.336kg x 24 Times a year
**Total Yield from FarmBot Full per Year = 8kg a year**

Price to sell Microgreens = €80 / 1kg
**Total Revenue from FarmBot per Year = 8kg x 80 = €640**

Cost of Seeds = €2 per bag
1 Bag is used per Sector for sparse
Cost per plant = €2 per bag x 1 Bag is used per Sector for sparse
Cost per plant = €2

Cost for a Full FarmBot = 24 Sectors x  €2 per bag
**Cost for a Full FarmBot = €48 per planting**

Cost for full year = Cost for a Full FarmBot x Plants per year
**Cost for full year = €48 x 26 = €1248 per year**

Profit = Revenue - Cost
**Profit = €640 - €1248 = -€608 per year**

**Loss of = €608 per year**

# Appendix F: Types of Restaurants for Input App

When adding data into the InputApp our group specified the types of restaurants in Giudecca into seven categories. The types we declared were Fast Food, Take Away, Fine Dining, Cafe, Casual Dining, “Tourist Trap,” and “Other."

Fast Food is defined as a restaurant that is intended to be quick and cheap. Some common examples of what we define as Fast Food include McDonalds, Burger King, and KFC. This category was not limited to common fast food restaurants either, the ones listed are just the more common ones.

Take Away refers to a restaurant with little seating with the intention that their customers take their food outside and bring it elsewhere. We defined “little seating” as a restaurant with seating to fit less than two five-person families. Often these restaurants are small pizza joints intended for someone to grab food on their way to an event.

Fine Dining is described as a restaurant often fancier than the rest. They usually have a hostess outside escorting guests to a table. The waiters often dress fancier; whether that be a white collared shirt or a suit. These restaurants tend to be more expensive than the rest.

A Cafe is a restaurant that often focuses on serving snacks, breakfast items, or morning drinks (Cafe Latte, Cappuccino, Espresso). These restaurants have a small seating section and tend to be open in the morning more commonly than at night. Foods served aren’t usually meals, but a small take away sandwich or pastry if available.

Casual Dining is a sit-down meal for a good price. Waiters are dressed in uniform, but the menu is not nearly as high in price. Meals served could range from breakfast, lunch, and dinner.

“Other” is defined in case we would encounter any other restaurant not defined. The only encounter we had that would fit in this category was a bar/nightclub. Here we filled in the blank and described it as necessary. A bar sometimes serves food, however its target audience is more commonly those interested in nightlife.

# Appendix G: Giudecca Shop information

Link to google sheet

| Store Name | Address | Latitude | Longitude | NACE Code | Store Type | Type of Restaurant (if applicable) | Cost |
|---|---|---|---|---|---|---|---|
| Cips Club (Hotel Cipriani) | Fondamenta Croce, 9 | 45.427578 | 12.340404 | 55.3.0 | Restaurant | Casual Dining | €€ |
| Bar Zitelle Restaurant | Fondamenta Croce, 37 | 45.426804 | 12.338818 | 55.4.0.2 | Restaurant | Cafe | € |
| Tabacchi | Fondamenta Croce, 56 | 45.426391 | 12.337684 | 52.2.6 | Convenience/ Tobacco | | |
| I Figi Delle Stelle | Fondamenta Croce, 70-71 | 45.426117 | 12.336888 | 55.3.0 | Restaurant | Casual Dining | €€ |
| Bar Da Monica | Fondamenta Croce, 80-81 | 45.426022 | 12.336384 | 55.3.0 | Restaurant | Casual Dining | €€ |
| Hotel Generator w/ Cafe | Fondamenta Zitelle,86 | 45.425877 | 12.336056 | 55.4.0.2 | Restaurant | Cafe | € |
| In Riva | Fondamenta S. Giacomo, 93 | 45.425792 | 12.335695 | 55.3.0 | Restaurant | Casual Dining | €€ |
| Galleria il Resentore | Fondamenta S. Giacomo, 188C | 45.425459 | 12.333063 | 52.4.8.2 | Other (Art Gallery) | | |
| Al Pontil | Fondamenta S. Giacomo, 198 | 45.425427 | 12.332006 | 55.4.0.2 | Restaurant | Cafe | € |
| Farmacia del Redentore | Fondamenta S. Giacomo, 199 | 45.425471 | 12.331887 | 52.3.1 | Pharmacy | | |
| Tabacchi | Fondamenta S. Giacomo, 202 | 45.425748 | 12.331538 | 52.2.6 | Convenience/ Tobacco | | |
| Discount Italiano Prix Quality | Fondamenta S. Giacomo, 203A | 45.425534 | 12.33154 | 52.1.1 | Grocery | | |
| Al Redentore | Fondamenta S. Giacomo, 205B | 45.425413 | 12.331196 | 55.3.0 | Restaurant | Casual Dining | €€ |
| Parrucchiera Ginzia | Fondamenta Sant'Eufemia, 289 | 45.425987 | 12.328306 | 93.0.2.1 | Other (hair salon) | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Banco San Marco | Fondamenta Sant'Eufemia, 318A | 45.426062 | 12.327856 | 65.1.1 | Financial | | |
| Trattoria AI Cacciatori | Fondamenta Sant'Eufemia, 320 | 45.426093 | 12.327749 | 55.3.0 | Restaurant | Casual Dining | €€ |
| Pizzeria Gastronomia La Foca | Fondamenta Sant'Eufemia, 324 | 45.426131 | 12.327534 | 55.3.0.6 | Restaurant | Takeout | € |
| Lavanderia | Fondamenta Sant'Eufemia, 423 | 45.426218 | 12.327299 | 93.0.1.2 | Other (laundry) | | |
| S. Antonio | Fondamenta Sant'Eufemia, 426 | 45.426214 | 12.327079 | 52.2.4.1 | Bakery | | |
| Posteitaliane | Fondamenta Sant'Eufemia, 430 | 45.42634 | 12.326769 | 65.1.1 | Financial | | |
| Macelleria | Fondamenta Sant'Eufemia, 445 | 45.426302 | 12.326603 | 52.2.2 | Other (butcher) | | |
| Farmacia Boldi | Fondamenta Sant'Eufemia, 446 | 45.426336 | 12.326573 | 52.3.1 | Pharmacy | | |
| IL Gazzettino | Fondamenta Sant'Eufemia,447 | 45.426359 | 12.326503 | 55.3.0 | Restaurant | Casual Dining | |
| La Palanca | Fondamenta Sant'Eufemia, 448 | 45.426398 | 12.326545 | 55.3.0 | Restaurant | Casual Dining | €€ |
| Majer Pacifico | Fondamenta Sant'Eufemia, 461 | 45.426415 | 12.326275 | 55.4.0.2 | Restaurant | Cafe | € |
| | Fondamenta Sant'Eufemia, 458 | 45.426454 | 12.326453 | 52.1.2 | Retail | | |
| Majer | Fondamenta Sant'Eufemia,461 | 45.426458 | 12.326179 | 55.3.0 | Restaurant | Fine Dining | €€€ |
| Tabacchi | Fondamenta Sant'Eufemia, 465 | 45.426473 | 12.325973 | 52.2.6 | Convenience/ Tobacco | | |
| Grace ICT | Fondamenta Sant'Eufemia, 517 | 45.426485 | 12.325995 | 52.7.2 | Other (Computer Repair) | | |
| Salumeria | Fondamenta Sant'Eufemia, 518 | 45.426526 | 12.325823 | 52.1.1 | Grocery | | |
| Trattoria Do Mori | Fondamenta Sant'Eufemia,588 | 45.426472 | 12.325762 | 55.3.0 | Restaurant | Fine Dining | €€€ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Eredi Perelda | Fondamenta Sant'Eufemia,590 | 45.426533 | 12.325585 | 52.4.6 | Hardware | | |
| Bar "Al Bateo Central" | Fondamenta Sant'Eufemia, 594 | 45.426572 | 12.325491 | 55.4.0.2 | Restaurant | Cafe | € |
| Ortofrutta Vianello | Fondamenta Sant'Eufemia, 601 | 45.426728 | 12.325135 | 52.2.1 | Grocery | | |
| Ae Botti Pizzeria Steak House | Fondamenta Sant'Eufemia, 607 | 45.426696 | 12.325021 | 55.3.0 | Restaurant | Casual Dining | €€ |
| Ostaria Ae Botti | Fondamenta Sant'Eufemia, 609 | 45.42675 | 12.324937 | 55.3.0 | Restaurant | Casual Dining | €€€ |
| Crosara Claudio | Fondamenta Sant'Eufemia, 655 | 45.426788 | 12.324629 | 52.2.4.1 | Bakery | | € |
| Osteria da MORO | Fondamenta Sant'Eufemia, 658 | 45.426815 | 12.32454 | 55.4.0.2 | Restaurant | Cafe | € |
| Studio d'Arte Claudia Corò | 673 Fondamenta Sant'Eufemia | 45.426941 | 12.324141 | 52.1.2 | Retail | | |
| Harry's Dolci Cipriani | 773 Fondamenta S. Biagio | 45.427135 | 12.323154 | 55.4.0.2 | Restaurant | Cafe | € |
| Trattoria Altanella | Giudecca 268 | 45.425403 5 | 12.328580 3 | 55.3.0 | Restaurant | Casual Dining | €€ |
| Ristorante Al Storico da Crea | Isola di Giudecca, 212 | 45.423632 5 | 12.328880 6 | 55.3.0 | Restaurant | Casual Dining | €€ |
| Oro Restaurant | Giudecca 10 | 45.426034 6 | 12.341268 2 | 55.3.0 | Restaurant | Fine Dining | €€€€ |
| L'Ulivo Restuarant | Fondamenta Zitelle, 33 | 45.426953 1 | 12.338953 9 | 55.3.0 | Restaurant | Casual Dining | €€€ |
| Food and Art Judecca | Campo Junghans, 487B, | 45.424511 7 | 12.326559 6 | 55.3.0 | Restaurant | Casual Dining | € |
| Aromi Restauarant | Sestiere Giudecca, 810 | 45.428267 2 | 12.320061 9 | 55.3.0 | Restaurant | Fine Dining | €€€ |
| Dolcemento Salato | Giudecca 77 | 45.425949 9 | 12.336562 9 | 55.3.0.2 | Restaurant | Takeout | € |
| Ristorante Pizzeria ai tre Scaini | Zitelle, Calle Michelangelo, 53c | 45.426044 5 | 12.338414 7 | 55.3.0.2 | Restaurant | Takeout | € |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Belmond Hotel Cipriani | Fondamenta S. Giovanni 10 | 45.42697 | 12.341241 | 55.1.1 | Hotel with Restaurant | | |
| Bauer Palladio Hotel | Fondamenta Zitelle 33 | 45.426825 | 12.338998 | 55.1.1 | Hotel with Restaurant | | |
| Hotel Giudecca | Calle Ferrando, 409 | 45.425086 | 12.326591 | 55.1 | Hotel | | |
| Hilton Molino Stucky | Fondamenta S. Biagio 810 | 45.428269 | 12.320102 | 55.1.1 | Hotel with Restaurant | | |
| B&B Casa Eden | Fondamenta S. Giovanni 30 | 45.427219 | 12.339588 | 55.2.3.1 | Bed and Breakfast | | |
| B&B Giudecca Bella | Giudecca 490/6 | 45.424157 | 12.32774 | 55.2.3.1 | Bed and Breakfast | | |
| B&B Casa Genoveffa | 30100 Venezia VE | 45.426111 | 12.325772 | 55.2.3.1 | Bed and Breakfast | | |
| B&B Ca' Isabella | Fondamenta S. Biagio 778 | 45.427251 | 12.322841 | 55.2.3.1 | Bed and Breakfast | | |
| Venice Home | Fondamenta S. Biagio, 797 | 45.427883 | 12.321379 | 55.2.3.1 | Bed and Breakfast | | |
| B&B Al Canal Venezia | Giudecca 753/G | 45.427135 | 12.318223 | 55.2.3.1 | Bed and Breakfast | | |
| inCoop | Calle dell'Olio, 484 | 45.425272 | 12.325607 | 52.1.1 | Supermarket | | |
| Tabacchi Convience | Calle del Vaporetto 10 | 45.427734 | 12.31487 | 52.2.6 | Convenience/ Tobacco | | |
| Farmacia Comunale N. 13 | Campo de la Chiesa in Saca 30 | 45.427691 | 12.314238 | 52.3.1 | Pharmacy | | |
| Ai Tre Scaini Restaurant Pizzeria | Zitelle, Calle Michelangelo, 53c, | 45.425948 | 12.33813 | 55.4.0.2 | Restaurant | Cafe | €€ |
| Pasticceria Stella - Bar & Caffetteria | Calle Michelangelo, 55 | 45.425815 | 12.337872 | 52.2.4.1 | Bakery | | €€ |
| Skyline Rooftop Bar | Giudecca, 810 | 45.428465 | 12.320388 | 52.2.5 | Bar | | €€€€ |
| Bacaromi | Giudecca, 810 | 45.428465 | 12.320388 | 55.3.0 | Restaurant | Fine Dining | €€€ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Eredi Caenazzo Adriano S.A.S. Di Pavan Annamaria & C. | 54/O, Giudecca | 45.425362 | 12.338165 | 52.2.5 | Bar | | |
| Bar da Niky e Lela | Calle del Large Lavraneri, 28 | 45.427595 | 12.314505 | 55.4.0.2 | Restaurant | Cafe | € |

# Appendix H: Commercial Organic Waste Calculations

Values we got from La Palanca - organic waste

Bar after 3 → 3.37kg

Kitchen morning + lunch →9.02 kg

Dinner →7.74 kg

Estimated for about 65 people - on a Tuesday

Throughout year average between 60-90 people per day depending on season

Total for a Tuesday in December = 20.13 kg

20.13/65 = **0.31 kg per person per day**

Total amount of waste they would produce in a year: (Best times, 2019)

High tourist months: ( April - October, February) →8 months

-high in February because of Carnival

Low Tourist months: (November - March - Excluding February) →4 months

Throughout year average between 60-90 people per day depending on season

High tourist months = 85 people per day

Low tourist months = 65 people per day

12 Italian holidays →2 january, 3 April, 1 May, 1 June, 1 August, 1 November, 3 December

High tourist months waste:

0.31 kg per person per day * 6 (6 day week) = 1.86 kg person per week

1.86 * 85 (85 people per day) = 158.1 kg per week

8 months high season * 4.35 (1 month = 4.35 weeks) = 34.8 weeks

34.8 weeks - 1 week (6 holidays = 1 week) = 33.8 weeks

33.8 weeks * 158.1 kg = 5,343.78 kg per high months

Low Tourist months:

0.31 kg per person per day * 6 (6 day week) = 1.86 kg person per week

1.86 * 65 (65 people per day) = 120.9 kg per week

4 months low season * 4.35 (1 month = 4.35 weeks) = 17.4 weeks

17.4 weeks - 1 week ( 6 holidays = 1 week) = 16.4 weeks

16.4 weeks * 120.9 kg per week = 1,982.76 kg per low months

Total per year

5,343.78 + 1,982.76 = 7,326.54 kg of waste per year

Total Commercial Giudecca

7,326.54 *32 (32 shops in Giudecca) = **234,449.28 kg** commercial organic waste in Giudecca per year

234,449.28 kg = **234.45 tonnes**

Info from black soldier flies composting methods (Smart Fly data): For every 100 kg of organic waste, 3.5 kg of fat, 20 kg of Frass, and 5kg of meal is produced

234,449.28 kg of organic waste → 46,890 kg of Frass, 11,722 kg of meal, and 8,206 kg of fat

**47 tonnes of Frass, 12 tonnes of meal, 8 tonnes of fat**

**Total amount of organic waste → 234 tonnes + 1066 tonnes = 1300 tonnes**

**45 tonnes Omega-3/fat**
**65 tonnes protein**
**260 tonnes fertilizer**

Assumptions:

- 6 days a week
- Not working on Italian holidays (12 holidays)
- All restaurants produce same amount of organic waste
- High tourist months = 85 people per day
- Low tourist months = 65 people per day

Calculating Potential Profit:

Total organic waste produced: 45 tonnes of fat, 65 tonnes of protein, 260 tonnes of Frass

45 tonnes of Fat (fish oil) →$1000 for 55 gallons

4 kilo = 1 gallon = 0.001 tonnes
45 tonnes = 11,250 gallons = $204,545 = €190,000

260 tonnes of Frass →$26 for 2 ibs

1 ib = 0.00045 tonnes
260 tonnes = 573202 ibs = 7,451,626 →$7 million = € 6.3 million

65 tonnes of protein →$600 for US ton

1 ton = 0.907 tonnes
65 tonnes = 71.6502 ton = 42,990 →$43,000 = €39,000

Calculations for black soldier flies labor hours

- 365/13 = 28 cycles
- 15 • 28 = 421.2 kg per box per year
- We said 130 tonnes per year = 130,000 kg
- 130,000/421.2 = 308 boxes

- 3 people = 21 tonnes a week →7 tonnes per person per week
- 1 box = $0.24m^2$

VE19-Farm

- 308 boxes = 74 $m^2$
- Bell tower H3
    - 26$m^2$
- 3 part time people
    - Average hourly salary €13 an hour
    - 3 * 51 weeks a year (- week of holidays) * 8 hours a day = 1224 hours a year
    - 1224 hours * 13 = €16,000
    - 3 workers = €47,700

-every 13 days go through 15 kg of waste in a 40 x 60 x 15 cm plastic box
- 2 tons of waste per day - 424 sq m facility
- 130 tonnes a year assuming 10% participation