NOVEMBER 28, 2019

QVFT

VERTICAL FARMING TEAM

SPONSORSHIP PACKAGE

QUEEN'S VERTICAL FARMING TEAM

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1.0 Introduction

1.1 Background

A global trend of increasing concern is the diminishing supply of arable land per capita. The United Nations Food and Agriculture Organization (FAO) projects that by 2050, this supply will fall to one third of the amount available in 1970. This is a combined result of climate change, freshwater depletion, urbanization, soil depletion, soil degradation, and a world population expected to increase from 7.7 billion (2019) to 9.7 billion (2050). [1] [2]

An emerging technology which is addressing these concerns is vertical farming, a food cultivation method in which crops grow in an indoor, urban, climate-controlled facility. This approach is associated with dramatically reduced water consumption, slashed transportation costs, massive improvements in per-acre land productivity, increased plant productivity, and the freedom to cultivate crops in any location, year-round. Refer to *Section 2* for further information about vertical farming. [2]

1.2 Our Mission

Thank you for your interest in the *Queen's Vertical Farming Team* (QVFT). As **Canada's first student-run post-secondary vertical farming design team**, QVFT's mission is to develop a functional, small scale vertical farm inspired by the best current industry practices. QVFT fosters an excellent community for student growth, drawing from the expertise of those in a wide range of academic disciplines. With your generous support, QVFT will pursue its goal of gaining a foothold as an innovator in this dynamic, rapidly developing industry.

2.0 Information & Design

2.1 Background

Vertical farming is an emerging method of food production in which plants grow in an urban, climate-controlled facility, made possible through **controlled environment agriculture (CEA)**. CEA allows for the artificial optimization of environmental inputs such as lighting, temperature, moisture, and nutritional availability. CEA is facilitated by a software-based monitoring and controls system, further discussed in *Section 2.2.*

Table 1: Sample Benefits of Aeroponic Vertical Farming

Benefit	Description
Land Efficiency	Example: *Plenty,* a San Francisco-based vertical farm, occupies 1% of the land of a traditional farm of equivalent production. [3]
Water Efficiency	Example: *Plenty* requires only 5% of the water consumed by a traditional farm of equivalent production. [3]
Environmental Immunity	Vertical farming is immune to trends of increased weather severity, diminishing arable land, depleting freshwater resources, and a changing climate – all existential threats to conventional agriculture.
Ecological Conservation	Vertical farming can spare ecosystems from cultivation and reduce chemical pollution by forgoing pesticides and fertilizers.
Increased Food Security	Vertical farming promises a consistent, local food source immune to the factors which cause gluts and shortages in global food supply. Another benefit is to remote communities, such as those in the Canadian Arctic, which suffer poor health due to the prohibitive costs of importing fresh food.
Geographic and Climatic Independence	Vertical farming can produce crops in any location, at any time of year.
CO_2 Emission Reduction	Vertical farming emits far fewer emissions due to its efficient method of cultivation and dramatic reduction in transportation distances.
Increased Crop Productivity	Through CEA, vertical farming can accelerate plant growth cycles and boost their yield
Organic	Through isolation from pests, chemical contaminants, and pathogens, vertical farming eliminates the need for pesticides and other artificial supplements.

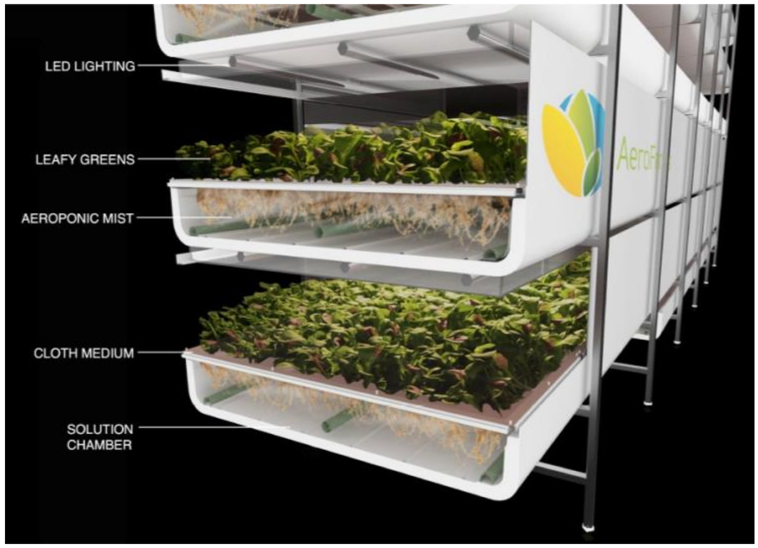

Figure 1: Anatomy of an Aeroponic Vertical Farm [4]

2.2 System Controls

QVFT's CEA system, currently in development, is comprised of a network of sensors controlled and monitored through software. This system intends to maximize the vertical farm's yield and efficiency by providing accurate *environment readings* which allow for the fine-tuning of the vertical farm's internal environment. Given *environment targets*, the system will automatically adjust hardware components to bring the vertical farm's environment closer to those values.

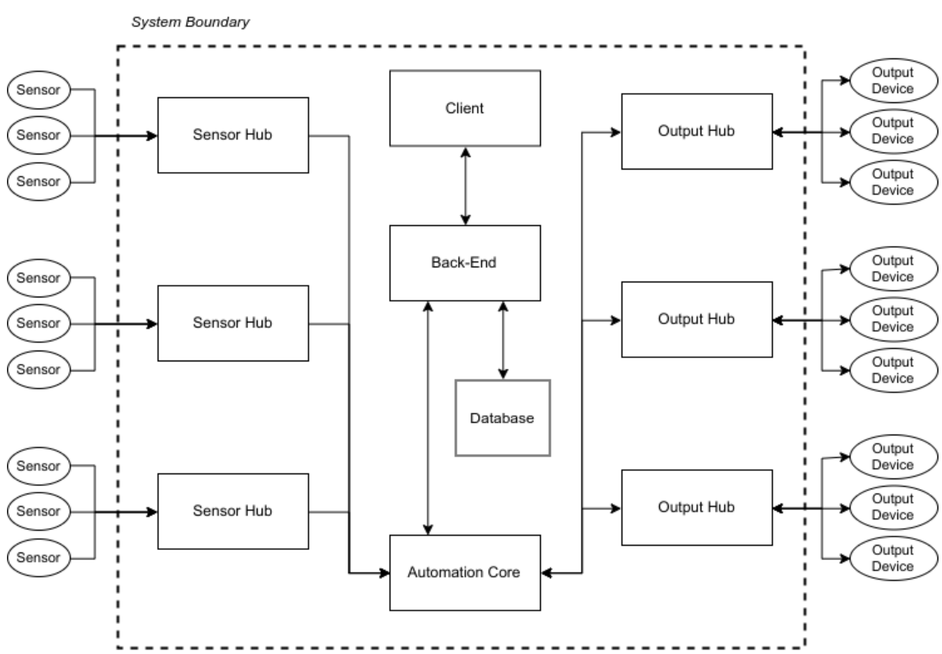

Figure 2: System Architecture

Table 2: System Architecture Details	
Component	**Description**
Automation Core	The Automation Core subsystem is responsible for producing *environment readings* and altering the environment to bring it closer to *environment targets*. It receives *environment readings* from Sensor Hubs and transmits them to Back-End. Automation Core receives *environment targets* from Back-End and alters its instructions to Output Hubs in order to get closer to those targets.
Client	The Client subsystem is responsible for receiving *environment readings* from Back-End and presenting them to the user. It also allows the user to view and modify the current *environment targets*.
Back-End	The Back-End subsystem contains the domain logic of the system—the rules that determine how data can be created, stored, and changed. Back-End receives new *environment targets* from Client and persists their values in the Database. Back-End transmits *environment targets* to Automation Core. Back-End receives *environment readings* from Automation Core and persists their values in the database. It transmits *environment readings* to Client.
Database	The Database subsystem is responsible for data persistence and access. It receives new data from Back-End.
Sensor Hub	A Sensor Hub component parses signals from the sensors into usable *environment readings*. It transmits *environment readings* to Automation Core.
Output Hub	An Output Hub component receives instructions from Automation Core to adjust the signals sent to output devices.

2.3 Crop Selection

In theory, any crop can be cultivated through vertical farming. However, current operations almost exclusively involve small fruits and vegetables such as lettuce, kale, spinach, strawberries, and tomatoes. Leafy greens are popular choices as they meet many of the criteria outlined in *Table 3*. Tree crops such as bananas and apples could be produced through a significant overhaul of the *Figure 1* design, perhaps by dwarfing the tree and rootstock and increasing layer spacing. This, however, exceeds QVFT's immediate goals, which are to develop a functional, micro-scale vertical farm based on the best current commercial practices. For this reason, **QVFT will focus entirely on cultivating small fruits and vegetables** throughout the foreseeable future. [2]

Table 3: Commercial Suitability Factors of Crops [5]	
Factor	**Description**
Growth Cycle	As vertical farming is a cost-intensive food production process, crops that have a **short growth cycle** are preferred.
Harvestable Yield	Plants with **high harvestable yield** (e.g. kale, lettuce, Swiss chard) are preferred as they minimize the amount of energy wasted on unusable parts of the crop. Examples of plants with low harvestable yield include tomatoes, blueberries, and blackberries.
Stature	Plants of **shorter stature** require less spacing between growth layers, meaning greater productivity within a fixed indoor space. Horizontal spacing will account for the expected width of the plants at maturity.
Seasonal Demand Variability	Vertical farms can be optimized specifically for crops with **year-round demand** as they eliminate the need for crop rotation. Consistent demand and crop specialization lend well to increased productivity, profitability, and automation. Watermelon, however, is an example of a crop that experiences seasonal demand variation possibly due to the noticeable quality differences between seasons. If able to deliver consistently high-quality watermelons year-round, vertical farming could perhaps have a competitive edge (and experience elevated demand) outside the summertime.
Geographic Growth Range	Certain crops such as wild blueberries require precise soil and climatic conditions, resulting in a **limited geographic growth range**. Other examples include tropical fruits and coffee beans, which must be imported by those in northern climates year-round. As vertical farming makes geographic constraints irrelevant, it could potentially produce such crops locally and offer a fresher, tastier, more sustainable product.
Automation Compatibility	Crops **conducive to automation** can minimize labour demand.
Perishability	**Highly perishable** crops grown through conventional methods often have a brief shelf life, as time is required to transport from farm to market. By operating within or around cities, vertical farming can deliver produce sooner to consumers and have a distinct advantage in this area.
Market Value	As vertical farming is not yet an economy of scale, food production is inevitably costlier than the conventional alternative. Crops which already demand **premium pricing** such as baby lettuce are better suited to vertical farming given the present realities of the industry.
Potential for Added Value	Vertical farming is able to grow crops of potentially higher quality than that of traditional agriculture through CEA controls and optimization. Organic by design, these crops may also have improved texture, colour, flavour, and shelf life. As a result, crops selected for cultivation should be those which present the **greatest opportunity for improvement on the existing industry standard.**

2.4 Lighting

Studies have found that indoor plants can be manipulated by adjustments made to the intensity and wavelength of LED lights. Wavelengths in the blue area of the spectrum, for example, have been found to increase the concentration of primary and secondary metabolites in vegetables. As these are responsible for plant growth and development, productivity for a certain species can be enhanced by identifying and delivering the wavelength at which maximal metabolite concentration occurs. [2] [6]

Productivity increases are also possible through the manipulation of light intensity and ON/OFF cycles. [2] For example, saplings require greater intensity as they are further away from the light source (see *Figure 1* for reference). As they grow taller, less intensity is generally required. [5] Modulation of light intensity throughout the stages of the plant growth cycle is certainly feasible within QVFT, and presents a meaningful opportunity for student research.

2.5 Growth Substrate

Substrate material composition varies between companies. *Aero Farms*, for example, (see *Figure 1*) has developed its own patented cloth medium woven from post-consumer recycled plastic water bottles. Small holes in the cloth allow for roots to pass through and dangle in the basin below. [4] Based on whichever is better suited to its goals, QVFT will either develop a novel substrate material or purchase an existing option that is readily available.

2.6 Irrigation and Fertigation

Vertical farming systems are broadly classified as either aeroponic or hydroponic, in reference to their mode of nutrient delivery. Aeroponic systems rest crops on a thin, porous substrate (usually a plastic-based cloth) which allows their roots to dangle inside a basin below. Nutrients are dissolved in water (fertigation) and delivered to roots via spray nozzles (irrigation). Unused nutrient solution is then collected by the basin and recycled (*Figure 1*). Hydroponic systems, in contrast, cultivate plants with their roots suspended directly inside the nutrient solution. LED lighting provides energy to facilitate photosynthesis in both types of systems.

Of the two, aeroponic systems are considered to be a superior means of water conservation and nutrient delivery, as they allow the grower greater control over the specific plant nutrient mix. For these reasons, aeroponics are the main focus of QVFT and are the system of reference for all mentions of “vertical farming” in this report. [2]

Fertigation will be facilitated by QVFT's CEA system (*Section 2.2*), with will allow for manual and automatic control of flow, pH, and nutrient levels.

2.7 Climate Control

Maintaining a consistent set temperature is crucial to allow the year-round cultivation of local and non-local plants. Fortunately, Queen's campus facilities already accomplish this through heating and air conditioning, with room temperature staying relatively constant throughout the year. Although this reduces QVFT's control over thermal regulation, maintaining room temperature is vastly cheaper than the alternative, which would require hermetically sealing the farming room and installing large, energy intensive equipment. QVFT will select crops that thrive within the range of the given ambient room temperature.

2.8 Ventilation

A CO_2 air supplementation system, combined with efficient ventilation, can accelerate growth cycles and produce larger, healthier plants and flowers. While atmospheric CO_2 concentrations hover around 400 PPM, such a system could raise ambient levels to 1000 PPM, which is considered optimal for the growth of most plants. [7] This system, comprised of CO_2 cylinders capped with a regulator, can be integrated into QVFT's automation system. A tent-like structure could be used to isolate the farm from its surroundings and minimize unwanted air exchange.

3.0 Organizational Structure

We are conducting hiring in two stages: Stage 1, which has already been completed, entailed hiring for all red positions listed below. These new hires will spend the remainder of the Fall 2019 semester planning, strategizing, and acquiring sponsorship. Stage 2 begins January 2020, where all beige roles and vacant red roles will be filled. At full capacity, QVFT will contain twenty-three members.

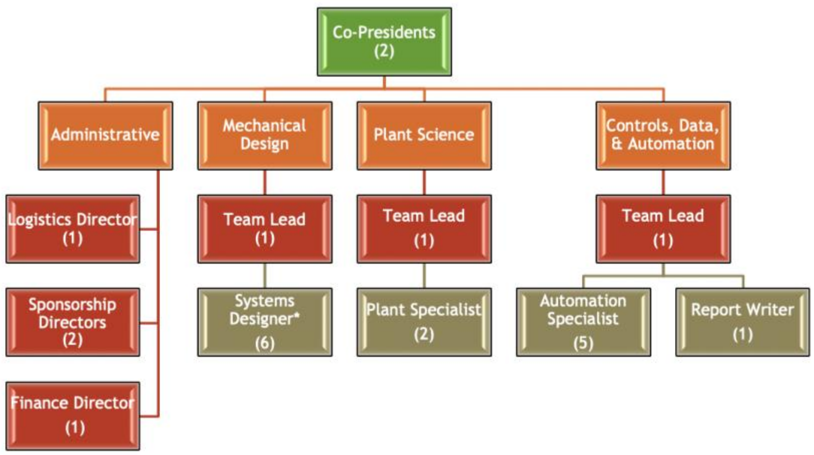

Figure 3: Current Organizational Structure

Table 4: Position Descriptions			
Role	**#**	**Responsibilities**	**Target Programs**
EXECUTIVE POSITIONS			
President	1	Running team meetings, goal setting, operational assistance, industry outreach, office hour availability	Engineering, Plant Sciences, other STEM; previous design team experience
Co-President	1		
(1) Logistics and Finances			
Logistics Director	1	Schedule and timeline oversight, sponsorship coordination, industry outreach, social media outreach, office hour availability	All, but Commerce, Economics, and STEM preferred
Finance Director	1	Budget and inventory oversight, sponsorship coordination, industry	

		outreach, social media outreach, office hour availability	
Sponsorship Director	2	Sponsorship coordination, grant applications, social media outreach, industry outreach	
(2) Mechanical and Electrical Design			
Director	1	Running weekly sub-team meetings, sub-team goal setting, operational assistance, office hour availability	Mechanical Engineering
Systems Designer	6	CAD (growth substrate, layers, piping, etc.), manufacturing, and maintenance of water, fertigation, lighting, and irrigation systems	Mechanical Engineering, previous design team experience
(3) Plant Science			
Director	1	Running weekly sub-team meetings, sub-team goal setting, operational assistance, office hour availability	Plant Sciences, Biology, Life Science, Biomechanical Engineering
Plant Specialist	2	Conducting research (light, air, nutrition optimization) to inform the design and operation of all systems	Plant Sciences, Biology, Life Science, Biomechanical Engineering
(4) Controls, Data, and Automation			
Director	1	Running weekly sub-team meetings, sub-team goal setting, operational assistance, office hour availability	Computer Science, Computer & Electrical Engineering
Automation Specialist	5	Development of farming automation system (*Section 3.2*), data analysis, controls	Computer Science, Computer & Electrical Engineering
Report Writer	1	Synthesis of data into a weekly brief for meetings	STEM, Economics, Commerce
(5) Operations			
Operator	-	Members from other sub-teams will be responsible for daily maintenance	-

Note: bolded text denotes an executive role

4.0 Objectives

4.1 Phase 1: Research & Development (2019 – 2020)

Table 5 describes the team objectives during Phase 1, which entails sponsorship acquisition, hiring, research, design, and prototyping.

Table 5: Phase 1 Objectives (Specific)	
Week	**Description**
FALL 2019 SEMESTER	
9 – 12	• Gain official approval, funding, and workspace for QVFT • Recruit and interview candidates for various executive roles (see *Table 4*) • Acquire funding through sponsorship acquisition • Educate the team on vertical farming, industry practices, and the expectations of their roles
WINTER 2020 SEMESTER	
13 – 18	• Complete hiring for all general positions • Sub-teams begin an exhaustive research & design process • Controls, Data, and Automation sub-team begins designing the CEA automation system • Prototype development begins; continuous improvements and revisions will occur through an iterative design process
19 – 24	• CEA automation system is functional • Test crop cultivation begins • Data is continually analyzed to inform areas of improvement for plant productivity, energy efficiency, and water efficiency • An extensive report will be developed of QVFT's research and findings throughout the year

4.2 Phase 2: Innovation & Expansion (2020 – 2021)

Table 6 describes the team objectives during Phase 2, throughout which the team will build on previous experience to increase scale and productivity.

Table 6: Phase 2 Objectives (General)	
Week	**Description**
FALL 2020 SEMESTER	
1-12	• Expand hiring and recruit new members (see *Table 4*) • Educate new members • Streamline prototype farm from Phase 1 and significantly scale up its capacity • Expanded Plant Science sub-team conducts detailed research into the effects of CEA adjustments on plant growth • Report Writer role acquires greater responsibilities
WINTER 2021 SEMESTER	
12-24	• Continue to improve productivity, "real-world" profitability, and efficiency • TBD

4.3 Promotional Events

In the coming months, QVFT will deliver presentations at sustainability-related school events, such as the *Queen's Sustainability Conference (QSUS)* and the *Commerce & Engineering Environmental Conference (CEEC).* These presentations will also allow us to promote our sponsors, increase general awareness of vertical farming, and introduce ourselves to like-minded students who may be interested in joining us.

QVFT's long term goal (3-4 years) is to create a national vertical farming design competition, available to student teams on university campuses across Canada. This competition will encourage other schools to develop vertical farming teams of their own and will provide a venue for students to compete and compare results in a range of categories. The results will be judged by industry professionals, with opportunities to share best practices and network within the industry. This goal will be pursued only after QVFT has reached sufficient maturity.

5.0 Key Members

5.1 Patrick Singal: Founder and President

Patrick is a 3rd year biomechanical engineering student with a passion for sustainable technology and environmental issues. Patrick's interest in agriculture stems from the many summers spent growing up in rural PEI, home to generations of farmers in his extended family. This background has made him keenly aware of the emerging threats faced by agriculture as a whole, from environmental degradation to world population growth. Awareness of these threats motivated him to found QVFT in Summer 2019, while working as a mechanical engineering intern at *MCW Custom Energy Solutions* (MCW CES).

MCW CES is a division of the MCW engineering consulting firm, dedicated to improving the energy efficiency of public buildings through software analysis and HVAC retrofits. This role sharpened Patrick's expertise in CAD (*SolidWorks, Solid Edge*), data analysis (*Microsoft Excel*), material analysis (*HAP*), and schematic development (*Microsoft Visio*). Meanwhile, Patrick spent his spare time drafting a business plan for QVFT, which explored the vertical farming concept, depicted a preliminary system architecture, and outlined the team's purpose, goals, and organizational structure. Once back at school, Patrick and David joined forces and have been working tirelessly ever since to put QVFT's plans in motion.

In his spare time, Patrick likes fishing, reading books on history, live music, and watching the Toronto Maple Leafs.

5.2 David Altrows: Co-President

David is a 4th year biomechanical engineering student with diverse experience in technical and non-technical roles. This summer, he completed the QICSI entrepreneurship program and led a successful start-up organization. He is currently a member of the Queen's Formula SAE design team and works as an *Englinks* workshop instructor and tutor. Given his leadership experience and background in mechatronics and CAD, David brings a well-rounded skillset to his role as co-president of QVFT.

6.0 Conclusion

Unsustainable agricultural practices have taken an enormous toll on the environment. One example is the dramatic decline observed of a crucial contributor to the global food supply: honeybees. North America's agricultural landscape is now 48 times more toxic to these insects than it was 25 years ago, a prime result of widespread use of so-called neonicotinoid pesticides. [8] These declines are occurring alongside continual world population growth and burgeoning food demand. Vertical farming promises a cleaner, hyper-efficient, future-proof alternative.

QVFT's goal is to gain a foothold as an innovator in a rapidly-developing industry. Along with a deeply-rooted sense of purpose, this team will foster an excellent community for student growth and draw from the expertise of those in a wide range of academic disciplines. QVFT's efforts are made possible only through the generous support of sponsors. We look forward to hearing from you.

7.0 References

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