DESIGN AND DEVELOPMENT OF A SEMI-AUTONOMOUS VERTICAL FARMING MANAGEMENT SYSTEM

EVALUATING THE BARRIERS TO WIDESPREAD IMPLEMENTATION OF VERTICAL FARMING

A Thesis Prospectus
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Bachelor of Science in Electrical Engineering

By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed Date: November 24, 2020

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The ability of technology to bring about positive societal change and reduce social class disparities is heartening. While issues relating to hunger and food insecurity seem negligible to industrialized nations, they are nonetheless prevalent in the United States. According to Holben (2010) 17.1 million American households experience food insecurity at some point during the year (p. 1369). Issues related to food insecurity is closely tied with food deserts or areas "where people have limited access to a variety of healthy and affordable food" (Dutko, Ver Ploeg, & Farrigan, 2012, p. 6). While the definition of food deserts varies among sources, the effects remain largely the same. Many studies explore the relationship between fruit and vegetable intake and prevention of chronic diseases (Hendrickson, Smith, & Eikenberry, 2010, p. 380). Ultimately, food deserts have an adverse impact on nutrition and an individual's health. Vertical farming is a developing technology that could potentially solve the problems created by urban food deserts. Vertical farming is a form of urban agriculture that takes advantage of the limited space in urban settings and cultivates agriculture on vertically inclined surfaces (Kalantari, Tahir, Joni & Fatemi, 2018, p. 1). However, vertical farming's ability to address problems created by food deserts rely entirely upon its universal acceptance and widespread adoption. While the technical project involves creating a semi-autonomous plant management system for a residential application of vertical farming, the STS research paper seeks to address the barriers preventing widespread implementation through a tightly coupled report.

There are several major deadlines for both the technical project and STS research paper. Figure 1 on page 2 provides an overview of tasks for the thesis portfolio, which includes the proposal and final report for the technical project as well as the prospectus and research paper for the STS portion of the portfolio. The entirety of the technical work will take place during the fall semester.

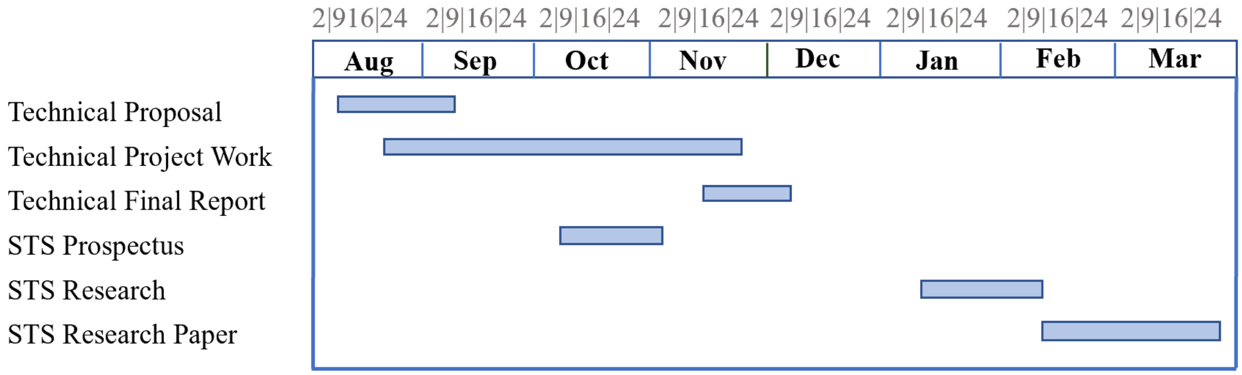

Figure 1: Overview of Undergraduate Thesis Portfolio Tasks. Major tasks for the technical project include the proposal and final paper as well as the project itself. The prospectus and research paper comprise the major tasks for the STS portion of the portfolio. (Nilsson, 2020).

CREATION OF A VERTICAL FARMING MANAGEMENT SYSTEM

As the amount of land available for agriculture use diminishes and the population continues to increase, it is paramount to find a reliable source of food. The amount of arable land or hectares per person in 2016 is around half as much as the amount in 1961 (United Nations Food and Agriculture Organization [FAO], 2016). The reduction in arable land is largely due to the negative impacts of climate change where increasing temperatures, limited fresh water supply, and shorter growing seasons contribute to unfavorable agriculture conditions (Fedoroff, 2015, p. 6). Ultimately, the reduction in available arable land coupled with a growing population poses a threat to the world's food supply.

One possible solution to the current predicament is vertical farming. Vertical farming takes advantage of the limited space in urban settings and cultivates agriculture on vertically inclined surfaces such as skyscrapers (Kalantari et al., 2018, p. 1). The concept of vertical farming is not just hypothetical as several large-scale systems exist. For example, there are over a 120 "A-Go-Gro" towers in Singapore that comprise 10% of the city's vegetable market (Benke

& Tomkins, 2017, p. 17). Advantages of vertical farming extend beyond supplying food to conserving water, creating jobs, lowering city temperatures, and saving land (Kalantari et al., 2018, p. 26). The positive effects of vertical farming are only amplified when integrated with controlled environment agriculture (CEA) technology. Controlled environment agriculture systems monitor the growing conditions of plants and regulate resource usage. CEA systems result in higher productivity compared to the productivity of open fields (Jensen, 1997, p. 1021). The combination of vertical farming with CEA technology offers several additional advantages such as reducing greenhouse gas emissions, lowering transportation costs, and mitigating the effects of urbanization (Benke & Tomkins, 2017, pp. 17-18). For the technical project, I will develop a CEA system for a small-scale application of vertical farming for residential homes.

Working alongside fellow Electrical Engineers Brooke Bonfadini and Chloe Tran with Computer Engineers Sonia Aggarwal and Catherine Rogers, I will build and design a vertical farming plant management system. Our technical advisor, Professor Harry Powell, a faculty member of the Charles L. Brown Electrical and Computer Engineering Department, will monitor and supervise our semester-long project. At the conclusion of the semester, we will present Professor Harry Powell with a scholarly article detailing our design process.

The scope of the technical work includes automating a two-tier vertical farm via a semi-autonomous control system. Figure 2 shows the planned physical structure of the vertical farm. The principal components of the semi-autonomous system include the soil moisture sensors, hydraulic pumps that dispense water, microcontroller that allocates resources appropriately, and WIFI module that communicates sensory information to an app. The LEDs are not featured in Figure 2; however, each row has a string of LEDs situated above.

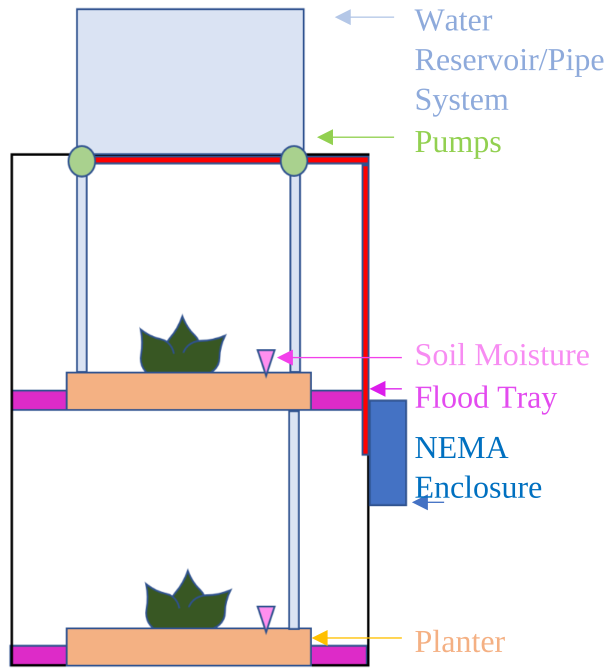

Figure 2: Physical Structure of Two-Tiered Vertical Farm. Piping leads from the water reservoir to peristaltic pumps which dispense water. Planters sit on top of flood trays to catch excess water with soil moisture sensors embedded in the soil. (Adapted by Victoria Nilsson (2020) from Brooke Bonfadini 2020).

The goal of the technical project is to automate the process of checking the reservoir level, dispensing water, and turning on the LEDs. Ultimately, automating the processes outlined above requires integration of hardware and software with mechanical elements. Figure 3 on page 5 outlines the interaction between the hardware, software, and mechanical components.

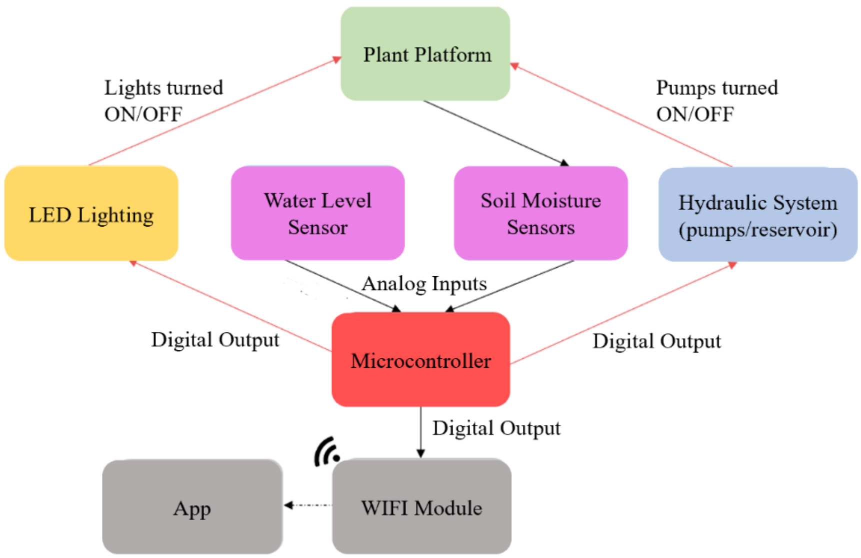

Figure 3: Communication Exchange Between Key Components. The microcontroller receives sensory information and makes a decision on whether to turn on pumps. The app receives sensory information from the microcontroller via the WIFI module. (Adapted by Victoria Nilsson (2020) from Chloe Tran 2020).

The microcontroller receives sensory information from the soil moisture sensors and the water level sensor. When the moisture of the soil is below a certain threshold and enough water remains in the reservoir, the microcontroller activates the peristaltic pumps which dispense water. The microcontroller turns on the LED strips accordingly such that the plant receives the specified hours of sunlight. Lastly, the microcontroller sends sensory information to an app via a WIFI module.

Completing the semester-long project in the allotted amount of time required working in parallel and dividing the tasks into three main phases: the design phase, the building phase, and the testing phase. The design phase consisted of finding hardware components, choosing a microcontroller, and designing a printed circuit board (PCB). Building the physical structure occurred in the second stage. The testing phase, which is nearing completion, includes checking interactions between software, hardware, and mechanical components as outlined in Figure 3. While the design phase took place outside of the lab setting using circuit design software, tools from the National Instruments Laboratory were accessed during the building phase. The testing phase will also require access to the undergraduate lab.

By automating three central processes of plant upkeep, the responsibility shifts from the plant owner to the semi-autonomous system. Furthermore, displaying sensory information on an app adds an interactive element that will hopefully increase user engagement. Finally, the automated system reduces the stress involved with plant upkeep while away from home.

EXAMINING THE SOCIETAL SIGNIFICANCE OF VERTICAL FARMING

The increased prevalence of food deserts among urban communities in the U.S is a concerning figure for public health officials. According to the USDA, "food deserts are areas where people have limited access to a variety of healthy and affordable food" (Dutko et al., 2012, p. 6). Importantly, the definition of food deserts changes depending on the context, predominantly urban or rural, and source. For example, Hendrickson et al. (2006) restrict the earlier definition of food deserts to "areas with 10 or fewer stores and no stores with more than 20 employees" (p. 372). As such, this paper only discusses food deserts in the context of urban settings and defines them as areas with limited access to healthy, affordable food due to the geographic location of supermarkets and food pricing.

Walker, Keane, and Burke (2010) outline several causes of urban food deserts including emigration of affluent customers to the suburbs, zoning laws that increase costs associated with renting land, and competition from large supermarkets which phase out smaller grocery stores (p. 2). Monetary gain is a key factor determining the location of supermarkets and, in consequence, the establishment of food deserts.

Regardless of the cause, the effects of food deserts are universal. Individuals living in areas with limited access to healthy, affordable food may experience "social disparities in diet and diet-related health outcomes” (Beaulac, Kristjansson, & Cummins, 2009, p. 1). Many studies investigate the influence of diet and nutrition on health. Bazzano et al. (2002) showed a positive correlation between proper intake of fruits and vegetables and lower rates of mortality from cardiovascular diseases (p. 99). Other diet-related health outcomes include diabetes and obesity. As such, an individual’s inability to access and purchase nutritious food has an adverse impact on health.

Vertical farming has emerged as a prominent solution to urban food desserts where individuals are able to grow economical produce in close proximity to their residence. However, the efficacy of vertical farming as a solution to food desserts relies upon its widespread adoption. Figure 4 provides a brief overview of the challenges facing vertical farming as a technology.

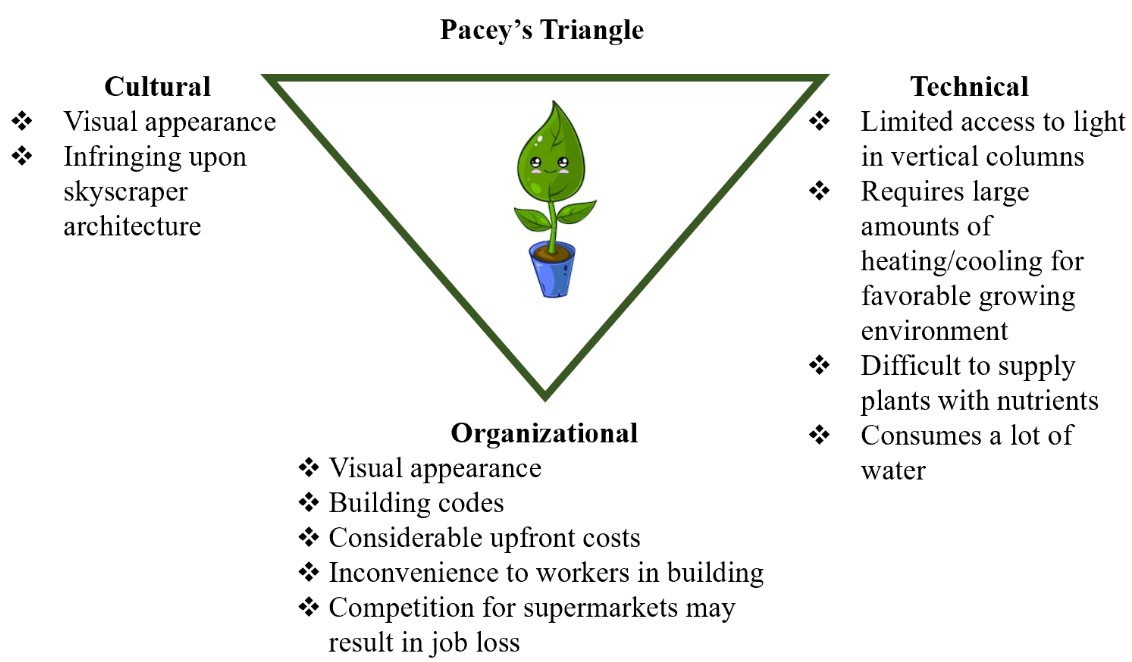

Figure 4: Challenges to Vertical Farming. The challenges facing vertical farming were categorized as either cultural, technical, or organizational, which corresponds to the three categories of Pacey’s triangle. (Nilsson, 2020).

While there are numerous case studies of vertical farms, the challenges listed in Figure 4 explain why the technology has not yet been universally adopted. Addressing each individual challenge will not alone lead to widespread acceptance of vertical farms. The interests of human and technical agents must be taken into account. Using Law and Callon's Actor-Network Theory (ANT) as the main approach, I will identify the various human and non-human actors barring or enabling the widespread adoption of vertical farms and discuss the complex sociotechnical interactions taking place (1988, p. 285).

ACTOR-NETWORK THEORY AND VERTICAL FARMING'S EFFICACY

One advantage to the ANT approach is that it considers both human and technical agents in analysis. Furthermore, when thinking about adoption of vertical farms by urban communities, it is imperative to understand the "complex technical-natural-political environment" surrounding the technology (Jolivet & Heiskanen, 2010, p. 6748). Figure 5 showcases the human and technical agents associated with vertical farming and some potential concerns of each actor.

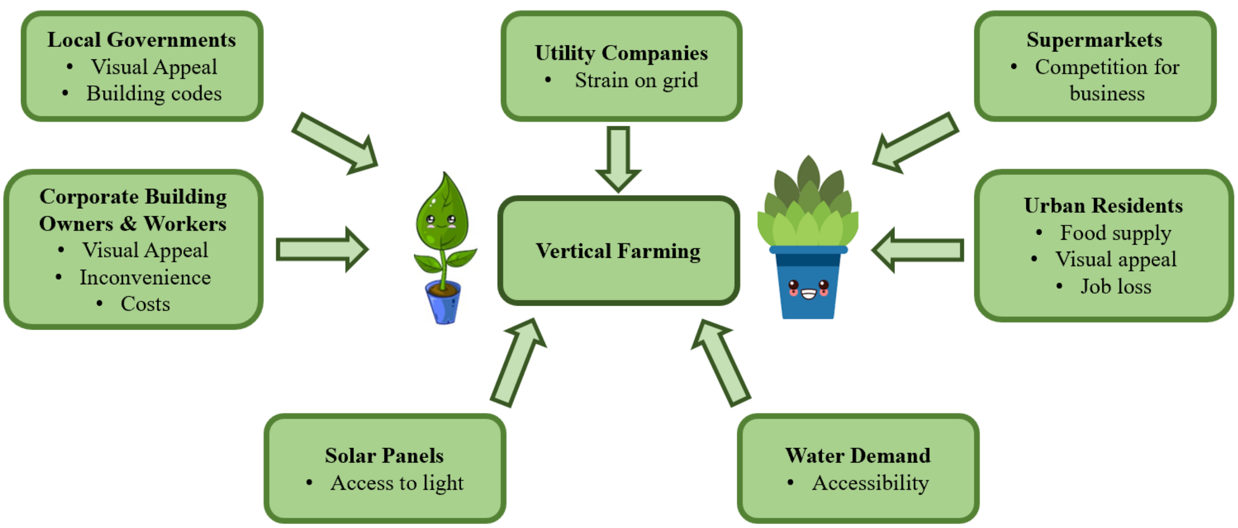

Figure 5: Key Human & Technical Actors of Vertical Farming. Human actors include supermarkets, corporate building owners and workers, utility companies, local governments, and urban residents. Technical considerations include solar panels and water consumption. Pertinent concerns are listed below each actor. (Nilsson, 2020).

Each actor shown in Figure 5 has the ability to negatively or positively impact vertical farming installations. Concerns of local governments include whether the installations are visually appealing and abide by city code. Corporate building owners and workers are also concerned about the visual appearance of the installations as well as the cost and inconvenience associated with the excessive amount of electricity used to maintain proper growing conditions. Unless local or federal governments afford tax breaks, it will be difficult to garner their support. Similarly, cost is a concern for supermarkets who will likely lose business. Supermarkets losing business also translates to job loss. The main worry for utility companies is the increased demand placed on the grid from large-scale vertical farming installations. These installations require constant air conditioning and heating, two processes that consume the most amount of electricity. With the increasing number of electric vehicles, resources of utility companies are already strained. Finally, urban residents stand the most to benefit from vertical farming, especially in areas with limited access to healthy, affordable food otherwise known as food deserts. Still, individuals working at supermarkets whose jobs are at risk will oppose the adoption of the technology. Some important technical issues include the practicality of solar panels given the limited access to natural light as well as the amount of water consumed by large vertical farms.

In order for widespread acceptance and adoption of vertical farming, concerns of each stakeholder must be thoroughly addressed along with the obstacles outlined in Figure 4 on page 8. The implications of vertical farms will be discussed further in a scholarly article functioning as my STS research paper.

VERTICAL FARMING AS A TECHNOLOGICAL ARTEFACT

The integration of technology into society is a complex process involving many actors with various interests. In order to reap the benefits of a particular technology, it is imperative to carefully evaluate the sociotechnical environment in which it exists as well as appease relevant stakeholders. The technical project involves creating a vertical farming plant management system which monitors growing conditions autonomously. Ultimately, vertical farming has many advantages including its ability to combat the negative effects of food deserts. In order to overcome the issues surrounding food deserts, cities must universally adopt the technology. The STS research question centers around evaluating the efficacy of vertical farming and the barriers for widespread implementation using the ANT approach. As such, the two principal components of the thesis portfolio serve their intended purpose of developing a technology and thoroughly evaluating its societal application.

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