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ALEX ANDREW CAOBIANCO TRIMBO

ECONOMIC SUSTAINABILITY OF INDOOR VERTICAL FARMING IN SAO PAULO

SÃO PAULO

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Thesis presented to Escola de Administração de Empresas de São Paulo of Fundação Getulio Vargas, as a requirement to obtain the title of Master in International Management (MPGI).

Knowledge Field: Management and competition in global companies.

Adviser: Prof. Dr. Sérvio Túlio Prado Jr.

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INSPIRATION

"Today we stand at an interesting, albeit daunting, crossroad. We continue to urbanize without incorporating the necessary skills to live sustainably, and struggle to understand enough about the damaging effects our penchant for consuming everything in sight is having on ecological process."

Dr. Dickson Despommier

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I would like to thank my entire family and friends. Together they have supported me over the two years I've spent throughout the world for my Master's degree. This specially applies to my mother who has dearly incentivized me over this period and to whom I have so much gratitude that could never be paid back. From the bottom of my heart, thank you all!

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Thank you all for the help and contributions to my studies!

ABSTRACT

Vertical farming, the practice of growing produce either vertically or in vertically stacked layers, has received growing attention from investors, media, and scholars – specially in most recent decades. Until recently, the vertical farm's lack of cost efficiency in comparison to traditional farming methods has prevented much practice and its academic exploration up until the 21st century. The fast paced, ongoing technological advancements, primarily led by growth in electrical efficiency, have occurred over the past two decades and greatly lead to the surge of vertical farms globally. The technological growth has motivated research on indoor vertical farming as an investment opportunity, exploration of its current state, production rate, and future potential. Because of the recency of much of the research and fast-paced technological development, much of the content concerning cost efficient methods is largely generalist, technologically outdated, and unrelated to the business environment of developing countries.

Therefore, this study uses a cost comparison of the main components required for the production of different crops from a potential deployment of a modern hydroponic vertical farming structure in the city of São Paulo, assessing its economic viability in both short and long term in comparison to the utilization of the same, and already profitable, structure's cost in the US. This research aims to answer the following question: what are the cost benefits and disadvantages of having a vertical farming system in the city of São Paulo? These findings demonstrate whether the population of São Paulo could benefit from locally produced products from this alternate farming method and if farmers can expect to invest in vertical farms in the present and/or near future.

KEYWORDS:

Vertical farming, hydroponics, aeroponics, aquaponics, HAVOC, CO2 supply unit, LED lighting.

RESUMO

A agricultura vertical, a prática de cultivar produtos verticalmente ou em camadas empilhadas verticalmente, tem recebido crescente atenção de investidores, mídia, e estudiosos – especialmente na década mais recente. Até recentemente, a falta de eficiência de custos em comparação aos métodos tradicionais de agricultura impediu sua prática e exploração acadêmica até o século XXI. Os rápidos avanços tecnológicos em andamento, liderados principalmente pelo crescimento da eficiência elétrica, ocorreram nas últimas décadas e levaram ao aumento de fazendas verticais globalmente. O crescimento tecnológico motivou a pesquisa em agricultura vertical como uma oportunidade de investimento, exploração de seu estado atual, taxas de produção e potencial. Devido à recência de grande parte das pesquisas junto com o desenvolvimento tecnológico acelerado, grande parte do conteúdo referente a métodos econômicos é amplamente superficial, tecnologicamente desatualizado e não relacionado ao ambiente de negócios em países em desenvolvimento.

Sendo assim, este estudo utiliza uma análise de mercado sobre uma potencial implementação de uma moderna estrutura agrícola hidropônica vertical na cidade de São Paulo, fazendo uma análise de custo de produção de diferentes hortaliças em comparação com a mesma estrutura, já rentável, nos EUA. Esta pesquisa tem como objetivo responder à questão: um sistema agrícola vertical pode ter um custo economicamente viável na cidade de São Paulo? Esses resultados ajudam a demonstrar se a população de São Paulo poderia usufruir de produtos produzidos localmente com esse método alternativo de agricultura e se os agricultores podem esperar investir em fazendas verticais no presente e/ou futuro próximo.

PALAVRAS-CHAVE:

Agricultura vertical, hidropônicas, aeropônicas, aquapônicas, luz LED, HAVOC, unidade de fornecimento de CO2.

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

HVAC	Heating, ventilation, and air-conditioning
LED	Light-emitting diode
NFT	Nutrient film technique
DFT	Deep-flow technique
CO2	Carbon dioxide
CAPEX	Capital expenditure

1. INTRODUCTION

It is predicted that by 2050 the world population will reach a number of nine billion people. 80% of the then nine billion people populating this planet will live in urban areas (Benke & Tomkins, 2017), meaning that while the concentration of people will heighten in an unprecedented manner, traditional farms will continuously be located further from areas where people will concentrate themselves. Through traditional farming, produce would spend even more time in transit, increasing costs and decreasing quality, both nutritiously and taste-wise (Benke & Tomkins, 2017).

The issue with global population continuously growing is not only limited to the concentration in urban areas, as the most severe matters emerge with the decrease in available arable land and scarcity of water for traditional farming. With greater limitations in expanding farming horizontally, the search for alternate farming methods grows in response. The issue extends itself to the environment, as a significant portion of greenhouse gas emissions, 4% in 2010, originates from the agricultural sector (Russell, 2014), while 14% originates from transportation (Intergovernmental Panel on Climate Change, 2014).

Vertical farming, the practice of growing produce either vertically or in vertically stacked layers, solves the origin of the issue at hand: it requires minimum horizontal expansion and does not require arable land. Its farming production could lead to a more sustainable food production in the future, with the interrelation of environment, society, and resource use (Kozai, et al. 2016). Without the necessity of much horizontal expansion, many vertical farms already find themselves located within great urban areas, from New York, San Francisco, to Hong Kong (Agrilyst, 2017). The fact that there are few options available for food production in the long term garnishes demand and consequently economic interest into vertical farming in its present form, proven by the investment of hundreds of near-future construction of vertical farms in resource limited locations, such as in water-scarce China (Zheng, et al. 2010). Despite vertical farming crops being raised free of pesticides, organically, and with high nutritious values, the premium cost and price does not allow it to be purchased by the general population, preventing it to be truly accessible and thus, democratized (Hallock, 2013).

The most enabling technology has been the increase in efficiency of lighting brought by advancements in light-emitting diode (LED) lighting, which has helped in cost reduction, produce productivity, and further allowed for the production of produce in completely enclosed environments and it serves as a substitute for the sun itself. Advancements of LED lighting itself is seen as the most prominent technology by indoor farmers, as further advancements hold the potential for further productivity and cost-reduction (Agrilyst, 2018).

As the world population grows and attempts to feed itself, cost-reduction is key for competitiveness. Despite the benefits of vertical farming providing produce free of pesticides, requiring less transportation time to reach the customer, freshness, and year-round growth, it is the cost-structure that will deem whether vertical farming produce will be competitive with traditional farming, as the premium costs obtained from vertical farming still prevent it from have a price-competitive edge over traditional farming. As prices in different cities for real estate and for inputs such as electricity vary, the financial viability of vertical farms also changes depending on the city.

1.1 SUBJECT CHOICE

The reasoning behind the subject selection was due to the desire of finding an intersection between technology and agriculture that was innovative and had the potential to provide great implications for the world's future and its stakeholders. The current, multimillion investments made in indoor vertical farming startups, which have provided low-polluting organic food, but still not a globally spread practice, validates the decision of utilizing it as the main topic for further research. The author himself possesses a family that works with traditional farms, mainly surrounding cattle and tomato productions, while he himself attended the French coding boot-camp Le Wagon, setting precedence for the desire to seek an intersection between the areas of agriculture and technology.

As a master's double degree student at the Fundação Getúlio Vargas – EAESP (São Paulo) in Management (MPGI) and CEMS International Management, the author's two years of studies has led him to classes on agricultural business, sustainability, and business strategy. As occurs with many innovative business models, indoor vertical farming has yet to obtain wide acceptancy as a profitable venture. It is with this challenge tied with the author's personal

interests that the author intends to demonstrate rather an indoor vertical farming has the potential of being financially viable in his home city – São Paulo.

1.2 RESEARCH GAP AND DELIMITATIONS

Although indoor vertical farming is not a new practice, higher traction has only been obtained with increase in technology that has made more financially viable more recently in the 21st century (Benke & Tomkins, 2017). What has specially made indoor vertical farming more popular in both practice and studies has been the higher cost-efficiency provided by LED lighting in the 2000's, meaning that much of the data and research has either been created in recent years (Toualitos et al. 2016). Furthermore, few researchers have focused on the economic viability of indoor vertical farms. Nonetheless, this research could not find any research related to the economic viability and cost analysis of an existing, commercial indoor vertical farming structure for São Paulo or any other city within Brazil, limiting cost comparisons with revenue.

However, the different methods of vertical farming, structures, crops, and specific technologies use are extremely vast, thus difficult for assessment on all in an individual basis. Therefore, a scope is defined for this dissertation in order to obtain better assessment and allow for in-depth analysis. Due to the previous research and data obtained from current commercially sold indoor vertical farm structures, the researcher decided to focus on performing a cost analysis of a single commercially sold hydroponic vertical farming structure and compare its operations in Denver, US, and with São Paulo, Brazil.

1.3 RESEARCH QUESTION AND OBJECTIVES

This dissertation aims to develop a cost assessment of the potential deployment of an existing commercial indoor vertical farming structure being in a developing urban city, São Paulo, displaying advantages and disadvantages that would be obtained from operating in such place. This will be compared to the results from the same indoor vertical farming structure being operated in Denver, Colorado, where tests have already been conducted and led to profitable ventures. In order to provide full understanding of the indoor vertical farming costs and variation of costs, this paper also aims to provide information on the setup of these structures, current state, and future prospects of indoor vertical farming. As previously mentioned, current

research does not provide an answer to the question at hand: whether a current, commercially operated indoor vertical farming structure could be more cost efficient in urban cities of developing countries.

> What are the cost advantages and disadvantages of a potential commercial indoor vertical farm in São Paulo?

1.4 OUTLINE

This dissertation attempts to discover the cost pain points and advantages of deploying an indoor vertical farm within São Paulo. The paper possesses the following structure: an introduction, in which thereafter the theoretical foundations are placed, followed by an explanation of the methodology utilized. Finally, the results, a summary of findings, and comparison of perspectives is made. The previous analysis is summarized in the conclusion, which includes limitations within the paper itself and possible future steps to be made.

2. LITERATURE REVIEW

2.1 BACKGROUND

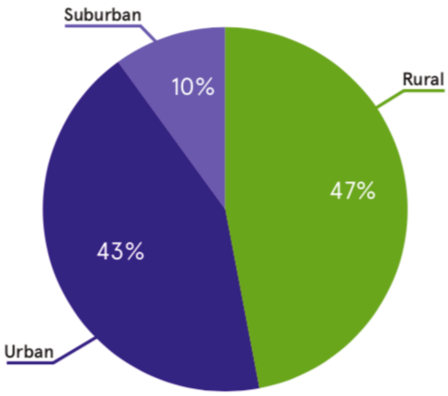
This literature review is broken down into three areas in order to better understand the evolution of indoor vertical farming and state. First, it will display and analyze the variations of indoor vertical farming setups. Second, it will grasp the history and current momentum of indoor vertical farming. Last, it will review and analyze traits native to the city of São Paulo that will mainly impact the potential success or failure of an indoor vertical farming.

2.2 INDOOR VERTICAL FARMING SETUP

2.2.1 Location

Indoor vertical farms can be set in three different locations: urban, sub-urban, and rural areas. People assume that either indoor or vertical farms is equivalent to urban farming, but these farms are typically situated near the points of sale or where cost and production efficiency can be maximized (Agrilyst, 2018). For a mushroom grower, this may entail utilizing a container in a rural area with cheap energy and close to a distribution center.

Figure 1: Indoor farms by location



(Source: Agrilyst, 2018)

This is one of the main advantages of indoor vertical farms. Due to the control over climate, nutrition, lighting, and nearly all components required for the farming procedure, the farm itself can be situated anywhere. In fact, Figure 1 shows that most indoor farmers are in reality located in rural areas rather than urban.

2.2.2 Growing Systems

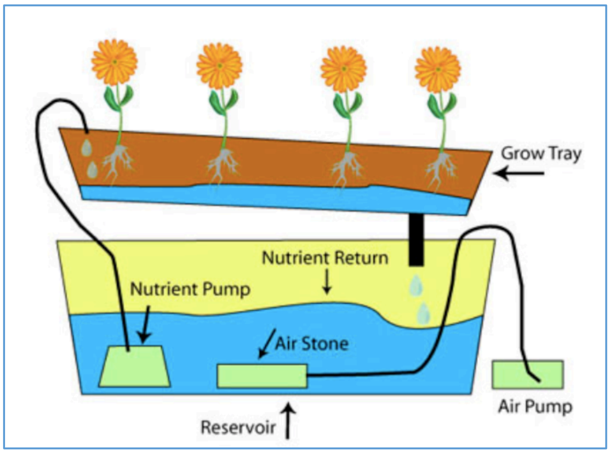
Indoor vertical farming can be established and grown in a variety of manners which will impact the operational costs, optional produce variety, and consequently final cost. The three most common vertical farms include one or a mix of the following methods: (1) hydroponics, where plants are grown in water, (2) aeroponics, where plant roots are suspended in the air with a nutrient solution, (3) and aquaponics, where plants are grown in water (Al-Kodmany, 2018).

Hydroponics are growing systems in which crops are placed in a nutrient composition typically without soil and in an indoor location (Aldrich et. al, 1994). It is not a new growing method, rather a proven technique with the ability to optimize material and resource utilization (Sardare et al. 2013). There are two main types of hydroponic techniques that have gained commercial use which are the nutrient film technique (NFT) and the deep flow technique (DFT) (E. Son, et al. 2016).

In the NFT, roots are continuously supplied with nutrients due to a thin film of water which continuously flows through a pipe, placed into a growing tray always maintaining contact with

the roots (Jones, 2005). The growing tray is angled to a level that allows for the water to continuously run down back to its reservoir.

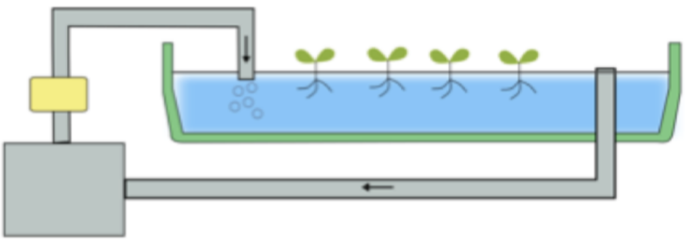
Figure 2: Hydroponics NFS sample system



(Source: Incemehmetoglu, 2012)

Through this method, ample oxygen is also supplied to the plants since the roots are exposed above the thin layer of water nutrient solution as seen above in Figure 2. In the DFT system, nutrients are instead provided automatically to water whenever the concentration is lower than a set value desired, thus maintaining a constant exposure to a certain nutrition level (Loman, 2018).

Figure 3: Hydroponic DFT sample system

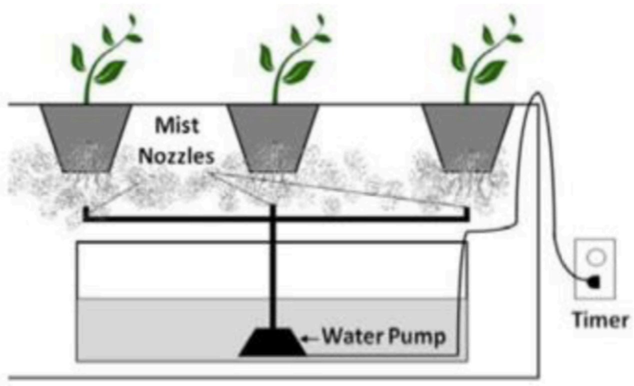


(Source: Loman, 2018)

The largest difference between NFT and DFT systems is that NFTs are suspended in an angled grow tray in order for the water to flow through the root system, thus leading to a lower water level. In the other hand, the level of water and nutrition in DFTs is kept at a more stable level and supplied according to demand, having excess nutrition return to its reservoir and recycled as seen in Figure 3.

A variant of the hydroponics system is the aeroponics. Aeroponics involves the spraying of plant roots with a nutrient solution or mist while the plants themselves are suspended in air as seen below in Figure 4. (Christie et al. 2004).

Figure 4: Aeroponics sample structure

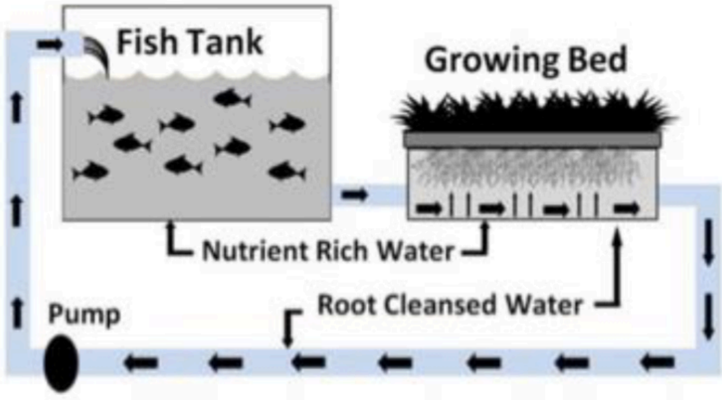


(Source: Loman, 2018)

This allows for the roots to be continuously and fully exposed to oxygen, easing their growth. In a test by NASA, they found aeroponics to reduce water usage by 98% and fertilizer usage by 60%, however crop yields had significantly increased (Dunbar, 2007).

A combination of hydroponic systems and aquaculture has led to the creation of aquaponics. It entails the utilization of any version of hydroponic system (DFT or NFT) with an aquaculture tank (Cardarelli et al. 2010). In this system, animal by-products from the aquaculture are broken down by nitrifying bacteria and provide most of the nutrients to the plants. The water is then recirculated back to the aquaculture system as seen in figure 5.

Figure 5: Aquaponics sample structure



(Source: Loman, 2012)

All of these structures growing systems can be structured in a manner that allows for either vertical crop production or vertically stacked crop production indoor. This allows for total environmental control and for higher productivity on a per square foot basis, more adequate for an urban setting (Despommier, 2010).

2.2.3 Suitable Crops

Indoor vertical farming results in a higher production rate per square feet in comparison to traditional farming and other horizontally expansive farming methods. Nevertheless, this may arrive at the expense of higher costs to build and operate the indoor farm itself, specially in urban areas where cost of land is more expensive. For these reasons, certain crops characteristics are preferable for indoor vertical farming:

- **Short production cycle**. The greater the life of a crop until the moment of harvest, the greater are its expenses with costly factors such as artificial heating, lighting, ventilation, and other fixed costs (rent, equipment depreciation, etc.) (Kozai, et al. 2013).

- **Short stature**. Due to the nature of a vertical farm's structure, the shorter the crop, the greater volume of crops that can be planted in a cost efficient manner, as artificial

lighting itself can be utilized in a more efficient manner (Kozai, et al. 2013).

- **Quickly perishable.** One of the main advantages of vertical farms is its ability to be located anywhere, meaning that it could be located next to the distributor or retailer itself (Kozai, et al. 2011). With lesser time spent between harvest and distribution to the point of sale, not only will the product last longer at the point of sale, as should also be of better quality (Lucena, et al. 2014).

- **High value & value added**. Because indoor farms can adjust their environment according to crops, rarer crops or crop types can be produced and thus have a higher local value to lower supply. By not using pesticides more value can be added to the crop itself. (Kozai, 2011)

- **Year round demand**. While nearby traditional farms must adjust their crops according to favorable seasons and compete with each other, indoor vertical farms may produce according to the crops that have most demand, achieving higher prices for each crop on a year-round basis (Despommier, 2010).

Figure 6: Samples of suitable crops for indoor vertical farming

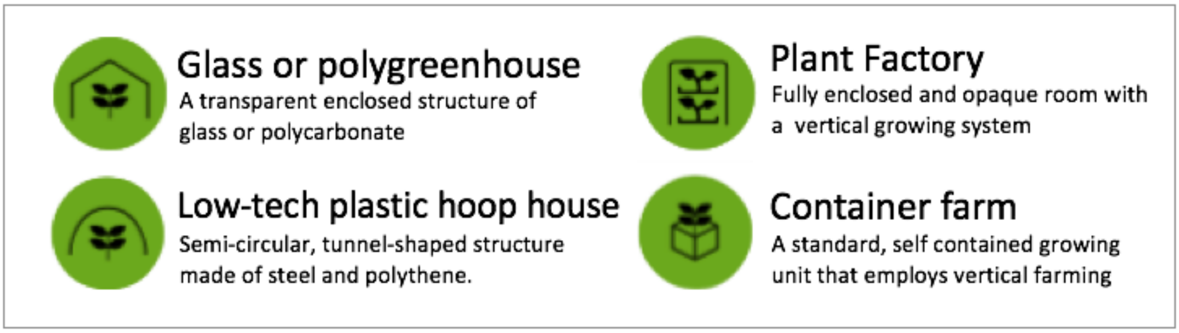
Leafy Greens	Herbs	Fruiting Crops
• Kale	• Rosemary	• Strawberries
• Collard Greens	• Mint	• Cucumbers
• Swiss/Rainbow Chard	• Thyme	• Bell Peppers
• Bok Choy	• Basil	• Habanero Peppers
• Mustard Greens	• Chives	• Ghost Chilis
• Radicchio	• Italian Parsley	• Tabasco Peppers
• Tat Soi	• Cilantro	

(Source: self provided)

2.2.4 Facility Types

There are four main types of facilities in which indoor vertical farms can be made as identified by the 150 indoor farmers in Agrilyst's 2017 survey and are described in figure 7.

Figure 7: Vertical indoor farming common facility types



(Source: self provided)

While the structure types and materials inherently impact costs, the main difference relies on their ability to utilize external lighting or not. While both glass/polygreenhouse and the low-tech plastic hoop house utilize external sunlight due to their transparency, both plant factory and container farms require artificial lighting. Nevertheless, plant factories can be situated in buildings in the most concentrated urban areas, while glass/polygreenhouse and the low-tech plastic hoop house are typically found in less dense, suburban or rural areas (Agrilyst, 2018).

2.3 EVOLUTION OF VERTICAL FARMING

2.3.1 History

Despite the growth of indoor vertical farming in recent years, having gathered attention from policy makers, scientists, and businesses, it is not a new technique. Since its introduction from as a concept, in which the term "vertical farming" was first coined by geologist professor Gilbert Bailey in 1915 (Bailey, 1915). Bailey's concept of vertical farming was still in open fields and highly soil dependent, but already conceived the necessity of a water nutrient solution for plant growth (Bailey, 1915). The US Military first utilized hydroponics to supply troops in Pacific & Japan post war in 1946 (Crumpacker, 2018), having the first commercial hydroponics appearing in France and the UK in the 1950s, followed by the first vertical, hydroponic plant factory in Japan in 1983 (Newbean Capital, 2017). Nevertheless, it has taken almost a century until its popularity gained traction, resulting in few studies related to the study of indoor vertical farming systems.

The most renowned supporters of indoor farming utilizing complete environmental controlling systems were Despommier D. and Kozai T, with their first main works around the subject being published in 2010 and 2013, respectively. Both believed that indoor farms, also known as plant factories, had the potential to resolve one of humanities currently growing food supply issues. With higher population growth ever more concentrated in urban areas and lesser available arable land, urban vertical farms would lead to efficient production of a multiple variety of foods (Despommier, 2010). Since vertical farming typically involved farming techniques that are soil-less, the farming method could be further explored in areas that lack of arable land and take advantage of less resource usage, such as water and fertilizers, and less requirements for transportation and storage (Toualitos et al. 2016).

Both authors helped introduce the spectrum of indoor farming and demonstrated its importance by navigating the world's current and future problems with the potential benefits indoor vertical farming possess. The world's feeding supply issues were further displayed by other, non-indoor farming specialists, but food sustainability experts Morgan K. and Sonino R. (2010). They set three pillars as the main areas to be tackled in the near future:

1. A surge in world prices, such as in 2007-2008, leading to food insecurity (Morgan, et al. 2010).

2. Climate change affecting droughts, heat waves, and ecosystem damage.

3. Land disputes of arable land with increasing social tension. Despite not providing a single, specific solution to the issue, they further set the stage for the importance of finding alternative, sustainable food productions.

While both Despommier and Kozai possessed initial positions that were incredibly supportive of indoor vertical farming, they shed light on current limitations of indoor vertical farming on their later works. Vertical farming can only better suit a selection of crops, mainly salads and herbs, that will not grow taller than the average height of the shelves, which is around 40 cm (Kozai, et al. 2016). Crops that are not well suited for this kind of cultivation are staple crops including, e.g. rice, corn and potatoes (Kozai, et al. 2016).

Furthermore, in areas where electricity is expensive, many building are not well suited for plant factories as they would require to be more translucent in order to take advantage of external sunlight (Despommier, 2013). Additionally, indoor farms cannot be mistaken with urban green areas. Urban green areas posses plenty of socio-economic benefits for the population ranging from recreational, climate regulating, rainwater infiltration, and health benefits, but due to the fact that indoor farming occurs "indoor", many of these benefits are not applied to indoor vertical farming (van Leeuwen, et al. 2010).

2.3.2 Current state

Despite evidence of vertical farming predating the 18th century, it is only with recent technological advancements that indoor vertical farms have grown in production (Despommier, 2010). While the definition of vertical farming involves the practice of food production vertically or in vertically stacked layers, the modern idea of indoor vertical farming uses controlled environment agriculture technologies (CEA), which allow for the control of artificial lighting, humidity, temperature, and gases (Loman, 2018).

These modern farming systems have led to production rates per square feet that can be up to 100 times more efficient than traditional farming methods, with startups like Plenty allegedly producing from 150-200 times as much as field crops. The work done until now is largely due to the partnering of environmentalists, urban farmers, architects, agronomists, and public health experts who seek to solve issues of population growth, food scarcity, environmental issues, and of a more urbanized future (Al-Kodmany, 2018).

This has led to much investment in vertical farming startups, of which the most noteworthy is Softbank's US$200 million investment in Plenty, the largest funding of a vertical farm startup yet. This has allowed Plenty to be in the forefront of indoor farming automation, having robots and AI involved in every step of production while planning to create over 300 vertical farms in China alone over the next 10 years (Abboud, 2019). Its largest farm possesses over 100,000 square feet and produces millions of crops annually.

Plenty is not alone, having other American companies such as AeroFarms raise US$40 million in 2017 and Bowery Farming raise US$90 million in 2018. These are examples of companies that sought for production at scale to achieve higher cost efficiency.

Despite such investments, the US was not the first location where vertical farms increased in popularity. Countries such as Korea, Japan, and Hong Kong, where arable land is scarce, were early adopters of vertical farming techniques, having the US see a boom in recent years as venture capitalists invested in the trend (Abboud, 2019).

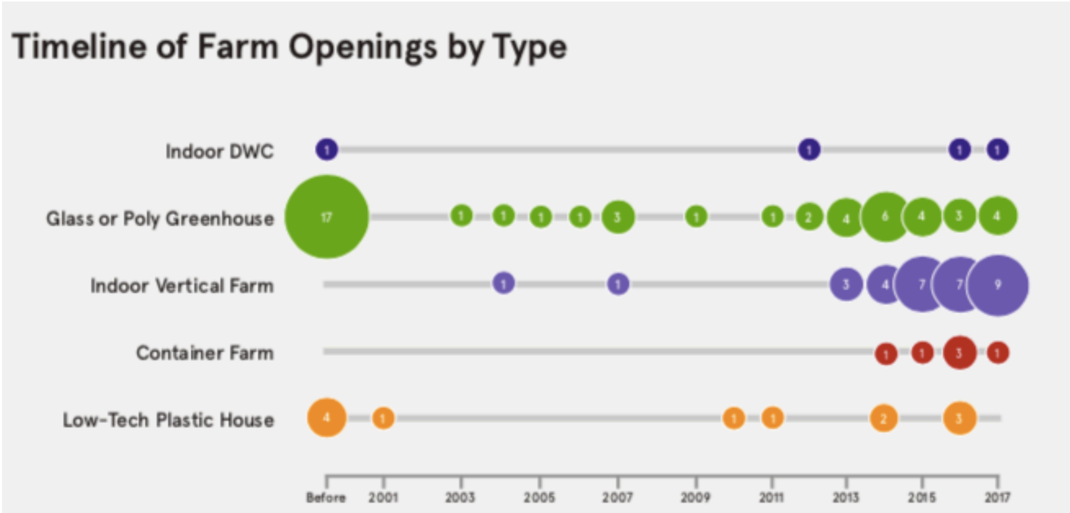
Nevertheless, most vertical farms currently in operation do not dispose of such investments and operate in a much smaller scale. They diverge in matters of location, growing systems, and facility types. Many still argue that vertical farms are simply too expensive too operate in both short and long term, but some vertical farms with different sizes, setups, and structures have been capable of achieving profits (Agrilyst, 2018). With opposing and favorable arguments, it is considered to be a farming method that is still under development.

2.3.3 Trends

An important factor to be taken into account is the rapid advancement of technologies and their impact on indoor vertical farming efficiencies (Sardare et al. 2013). Therefore, understanding the current state of indoor vertical farming is essential to obtain a current, business prospect of the farming method. Agrilyst's report analyzes the statistical state of indoor farming in 2017 by obtaining 150 individual responses of indoor farmer around the world, of which 81% came from the United States (Agrilyst, 2017).

Although studies on indoor farming provide general statistical data on costs and revenues, there has not been a report which breaks indoor farming into all different categories of production currently in use by different businesses. Agrilyst (2018) has accumulated the largest dataset related to active indoor farming businesses in 2017 at a global scale, displaying trends of both hydroponic farming and indoor vertical becoming increasingly popular and continuously selected as a farming method from 2013 to 2017 with an increase of 1,500% as seen in Figure 8. However, the study does not focus on profitable ventures in which indoor farming systems production efficiency outweigh the costs related to it, rather grasps the general picture.

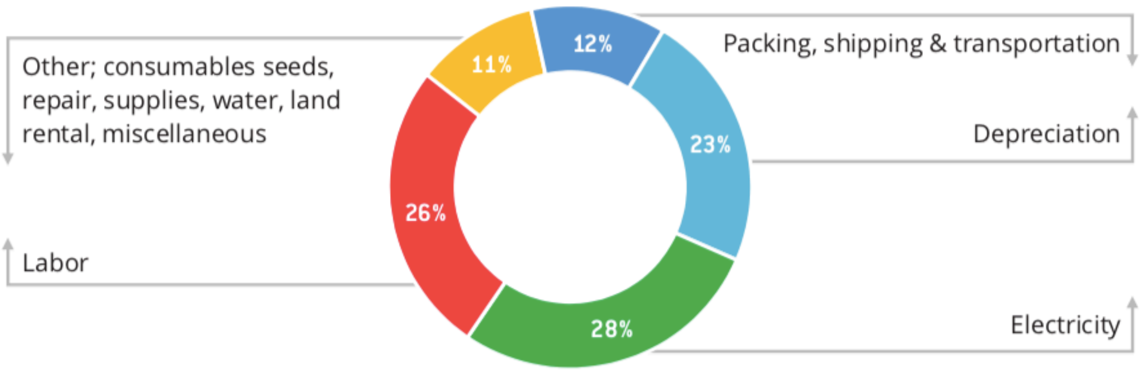
Figure 8: Timeline of farm openings by indoor structure



(Source: Agrilyst, 2018)

Similar to Agrilyst's report, Newbean Capital's research focuses on the broad spectrum of indoor farming, obtaining data from over 56 indoor farms, originated from both United States and Canada. It expects 30.7% CAGR for global vertical farming markets between 2015 and 2020 (Tiwari, 2019). Furthermore, the cost of electricity and label are identified as two of the main drivers of production costs Figure 9.

Figure 9: Vertical farming plant operating costs



(Source: Newbean Capital, 2017)

Both studies have identified a significant a growing trend in the usage of heating, ventilation, and air-conditioning (HVAC) systems, robotics, and automation. It has also identified that by

combining crops such as microgreens, leafty greens, and herbs, farmers can achieve higher pricing than by producing single, commodity crops.

What can also serve as further explanation for the increase in both supply and demand of vertical farming systems and products is an analysis conducted by Lyson (2008) in which the market in the 21st century demonstrated that people continuously desire to create and develop relationships as part of their purchasing experience. In urban settings, an advantage is provided urban vertical farms due to there natural proximity to the final consumer in comparison to traditional rural farms, allowing for better relationship fostering. Furthermore, as nutritional education rises, urban farming has the potential to diminish food deserts, which are areas of higher poverty that do not have access to fresh vegetable and fruits within a 10-mile radius (Adams, 2016). Therefore, urban vertical farming could provide the supply to this regional, leftover demand.

2.3.4 Economic Viability

In 2012, Chiaratan's published one of the first study that builds on and contributes to work in the financial and methodological feasibility of vertical farming. In order to define the technical concept and cost basis of the structure (given the many available options) the study performed a concurrent engineering study in which an engineering group provided a systematic design for a super structure of vertical farming designed for upmost efficiency in cost's return for productivity rate. As such, this study provides an additional insight into the structural breakdown of vertical farms, with incredibly detailed analytical focus on design and mechanical elements, agricultural sub-systems, LED lighting, environmental regulation, and waste management sub-systems, enabling contribution at detailed levels (Chiaratan, 2012).

After defining the vertical farming system and structure, a cost and market analysis is made in order to determine the feasibility of the specific large scale vertical farm. Although certain reports (State of Indoor Farming, 2017) have identified vertical farming's average cost and productivity, little analytic attention has been paid to potential and upmost efficient production methods which have been proven profitable in specific business ventures, rather utilizing hypothetical structures. Nevertheless, it is one of the first studies that joined the areas of engineering, as large-scale structure was proposed, and business, with a cost assessment and potential revenue defined, making a hypothetically economically viable, large scale production.

With the aim of developing a vertical farming structure that could feed a population of 15,000 with a 2,000 kcal, Chirantan Banerjee's (2014) research demonstrated how a 37 floor vertical farming building could obtain that objective. Utilizing a mixture of aeroponics and aquaponics, Banerjee obtained production and cost estimates for the vertical farming structure in Berlin with building and equipment costs of over €200 million. The structure itself allowed for the production of both vegetables and fish with costs between €3.50 and €4.00 per kilo, although no mention of profitability was made.

The financial key to any farming project is the capital expenditure (capex) required to build and operate the site. Depending on the growing system, techniques and building adaptation or construction, Capex may range widely depending on the quantity of levels of production utilized (Loman, 2018). Current commercial grower's sentiment indicates that starting a vertical farm is still risky and is not quick money (Loman, 2018). For instance, only a quarter of Japan's plant factories are profitable, and half break-even (Kozai, 2016). Economic viability of indoor vertical farms is a case by case scenario.

The main challenge met by developers of indoor vertical farms is the costs of a lighting system and energy required to run it (Shimizu, et al., 2011). According to Kozai, Niu & Takagaki (2016) the lighting of a vertical farm, lit by artificial light, accounts for 70-80 % of the total electricity costs which makes it one of the most important aspects. When the LEDs were first introduced to the market, the energy consumption from illumination decreased considerably; nonetheless, it has still been found to be the main use of energy.

Despite the inherent business risk of developing an indoor vertical farm, claims that a vertical farm can produce up to 200 times more per square meter than a traditional farm have led to many investors, which eventually expect a return (Abboud, 2019). Over US$550M has been invested in indoor farms from 2017 to mid-2019, primarily led by Softbank's investment in Plenty (The Economist, 2019).

2.3.5 Future prospects

One of Bentke & Tomkins (2017) most recent studies, they analyze and predict further importance that controlled-environment agriculture will possess in indoor vertical farming systems. Australia, which recently had farming issues due to environmental adversities, applied careful planning, great management, and both research and development into traditional farming in order to counter such issues. However, the continuous shifting and drastic climate change together with inflicting pests, and soil degradation resulted in unsatisfactory production rates that could later display a global pattern if controlled-environment agriculture isn't applied where it can be maximized: indoor (Bentke & Tomkins, 2017).

Indoor vertical farming can already produce at substantially higher rates than traditional farming in the same area. However, expected increase in innovative usage of rainwater, robotics automation, humidity and air-temperature controls, utilization of efficient solar panels, and more efficient LED lights, have the potential to increase productivity while decreasing costs. A near-future expected innovation occurred after the discovery that blue wavelengths from LED lights change the concentration of nutritionally important metabolites in high-value, specialty crops, meaning that by an optimum amount of exposure to blue wavelengths would lead to higher productivity of these crops. (Kospell et al. 2015).

As global market research firms report vertical farming market value of US$2.23 billion in 2018 and predict $12.7 billion in 2026 (Patil et al. 2019), skepticism and doubts have grown concerning the true potential of indoor vertical farming. The limited variety of crops that can be produced in vertical farms, evolution of traditional farming methods and technology, and higher produce pricing due to higher production costs (Kox, 2017). Under Japanese researcher's Toyoki Kozai's 2013 paper which estimates an average of 1,200 KwH are required for 1kg of produce, over half of the entire US electricity would be required to produce the total annual vegetable crops produced in the United States (Kox, 2017). While indoor vertical farming can be an alternate solution in areas with scarce arable lands, proposing it as a substitute of traditional farming is a far-fetched challenge.

3. METHODOLOGY

The main focus of this section is to present how the research is conducted. To begin, an explanation of the research approach and explanation of why this paper utilizes a mixed quantitative and qualitative approach with basis of the obtained cost-related data and established literature review of the topic. Next, in order to ensure a seamless and objective research paper, a study design is recognized and explained. In order for a critical assessment, a review of the validity and reliability of this paper is made. Finally, this section will reflect on the data gathered for the study and its utilization.

3.1 RESEARCH APPROACH

This paper attempts to assess and compare the benefits and disadvantages of operating an indoor vertical farm in the city of São Paulo, which currently does not possess any indoor vertical farm operating at commercial scale. In order to so, an indoor vertical farm will be hypothetically replicated in São Paulo using a current, profitable, indoor vertical farming structure being operated elsewhere.

This paper hypothesizes that an indoor vertical farm designed from scratch can be susceptible to multiple design errors and flaws that would make the operation of a hypothetical structure improperly analyzed for its costs, as it hasn't been tested and/or succeeded in an actual business environment. Since the largest vertical farms have received most funding globally, they have gained access and capabilities to the best productive and cost-efficient technologies and possess the advantage of scalability for increased production efficiencies, creating a cost structure that provides a competitive advantage. Therefore, it is further hypothesized that the detailed cost structure of these companies contains sensitive information of which they are unwilling to share to its fullest, making these structures unrealistically replicable in an accurate manner. Hence, this Master dissertation focuses on obtaining quantitative data by obtaining the entire cost structure from a company which sells vertical farming structures, leveraging their willingness to share cost-related information to its fullest as they are obliged to provide all product details involved in the operation of the vertical farming structure.

However, costs are considered to be "expensive" or "cheap" depending on revenue obtained from the investment. In regards to revenue, there is no precedence in regards to the customer

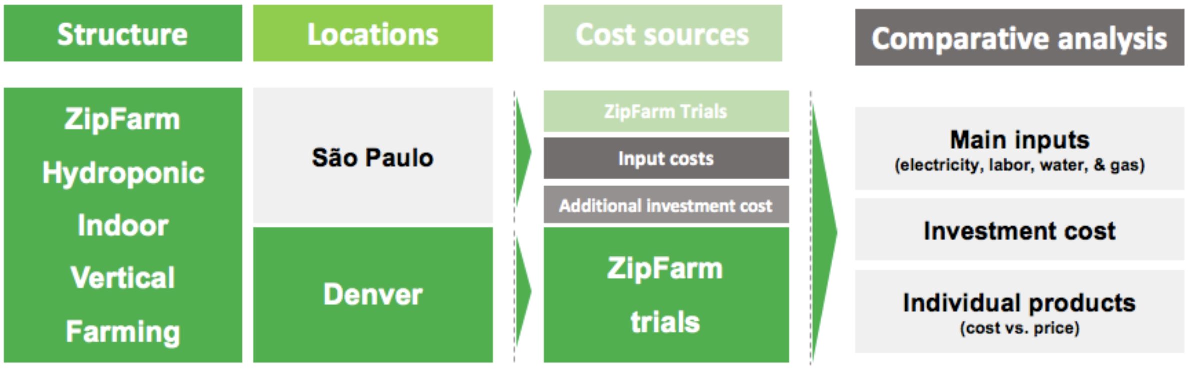
acceptability, pricing, and sales for vertical farming produce in São Paulo, therefore preventing accurate quantitative analysis from being made. Consequently, a qualitative analysis will be utilized with in order to identify possible strengths and weaknesses, providing a larger grasp of the economic viability of operating the indoor vertical farming structure.

At a general level, the integration of these quantitative and qualitative methods is utilized to generate a more thorough investigation of question at hand, leading to fewer limitations and development of stronger arguments (Creswell, 2010). This will better paint a picture of the benefits and disadvantages that an indoor vertical farming structure could have for both farmers and local population in São Paulo, having the quantitative section being enriched by the qualitative area.

As a mixed study, this paper presents some of the main characteristics of a quantitative study as presented by (Creswell, 2013). The data collected by the research was obtained from the operation of ZipGrow vertical farming structure, a subsidiary of Plenty, the most funded indoor vertical farming startup, and possesses a historical track record and proven cases of profitability in the United States and Canada.

According to Crewswell (2013), a quantitative approach allows for comparison of a single or multiple variable impacting a specific outcome. By utilizing a hypothetical experimental research approach, this paper seeks to test for the existence of impactful differences between the main cost contributors of ZipGrow's hydroponic vertical farming structure that lead to advantages or disadvantages in its potential operation in São Paulo as opposed to the same structure's current operation in Denver, Colorado, further depicted in Figure 10 below.

Figure 10: Methodology depiction



(Source: self provided)

3.2 BACKGROUND OF THE RESEARCH APPROACH

ZipGrow is a brand that produces a hydroponic vertical farming structure. It is currently owned by BrightAgrotech, which was purchased by Plenty in 2017 (Cosgrove, 2017). The structure itself comprises of was specifically chosen for research data due to the amount of data provided by the company, based on 84 harvesting periods over a four-year period with 18 different crops. It also possesses multiple cases of profitability with customers originating from different regions of the US and Canada. As producers of the vertical farming system itself, they possess and have demonstrated high willingness to share information and are liable in regards to the accuracy of their product description. ZipGrow has provided the quantitative data for the Colorado-operated indoor vertical farming structure required for this research and sent directly to this thesis' author through electronic files.

3.3 DATA COLLECTION PROCEDURE

Data referring to the operations of ZipGrow vertical farming structure was gathered directly from ZipGrow representatives, allowing for better data accuracy. Most data was sent from their archives in relation to experimental testing periods of the specific vertical farming structure and 18 specific crops. The data requested and delivered from ZipGrow involved the annual average datasets from the experimental testing period and included: utility costs, operational costs, seed quantities, capital investment, and estimated production quantities. Data in regards to costs of input prices in São Paulo was gathered from a multitude of sources, primarily from governmental bodies and distributors, which provide annual pricing reports that adhere to local

governmental laws. Data for labor and real estate were obtained from companies that collect, possess and display publicly large data sets of the relevant fields in the current regional market, leading to up-to-date prices. All of the before mentioned data is utilized for further analysis and is provided in the Appendix. These data sources were selected in attempt to deliver an objective data collection procedure, in order to maintain academic standards and provide academic contributions as a result.

3.4 VALIDITY AND RELIABILITY

This research aims to be as objective as possible, thus has provided qualitative validity through cross checking of the input and labor costs provided by ZipGrow with governmental databases, while also maintain qualitative reliability by assuring consistency of this dissertation with other researcher's works (Gibbs, 2007), assuring that the vertical farming system provided by ZipGrow possesses standard equipment and factors present in other economic researches concerning indoor hydroponic vertical farming systems, such as HVAC, lighting, plumbing, and seedling kits.

3.5 AUTHOR'S BACKGROUND & BIAS

The objective of this section is to describe the author's relationship with the study and further provide information in regards to his background. The author of this dissertation is half Brazilian and half American, having most of his family from his mother work own and work within farms in both north and southeast Brazil, involving both cattle and crop plantations. However, the author himself has never worked with any agricultural work itself.

The author was first exposed to the idea of indoor farming through a close, Uruguayan friend who is part-owner of a shitake farm produced in containers in Uruguay. The shitake farm itself is struggle to obtain profitability despite high production volumes, mainly due to lack of consumer awareness of the product and lack of willingness to pay for higher-value products. Therefore, before beginning this research, the author possessed skeptical views towards potential profitability of indoor farming methods, despite understanding the potential in terms of the production itself.

4. FINDINGS & ANALYSIS

4.1 INVESTMENT COST

The total investment cost required in order to obtain the structure itself, including all mechanical components required to operate the ZipFarm hydroponic vertical farming structure is of US$566,350. However, in order to operate in São Paulo, it would have to undergo through import and depreciation costs, unlike its operations in Denver. Nevertheless, both would have to purchase an indoor property in order to correctly operate the structure.

4.1.1 Import & depreciation costs

As commercial indoor vertical farming systems are not in operation in São Paulo and the author of this paper could not find any production in Brazil, it would be the first time an indoor vertical farming structure would be imported to operate in Brazil. Given its complex technological and design elements (ex. LED lights, automation mechanisms, HVAC, etc.) importing a proven vertical farming structure possesses less productivity risk than creating one.

However, the Brazilian taxing system is complex and can be a burden for many businesses. While many different taxes apply to imports, three specifically standout for vertical farming equipment: the Industrialized Product Tax (IPI), Import Duty (II), and Service Circulation Tax (ICMS) (KPMG, 2018). These taxes together with other, smaller taxes, can increase the total cost of imported products by 40-70% (Tagiaroli et. al, 2009). This specially impacts the capital expenditure (Capex) of the investment made once deprecation costs are accounted for throughout the years over the higher value paid for the imported products (Zeidler et al. 2017).

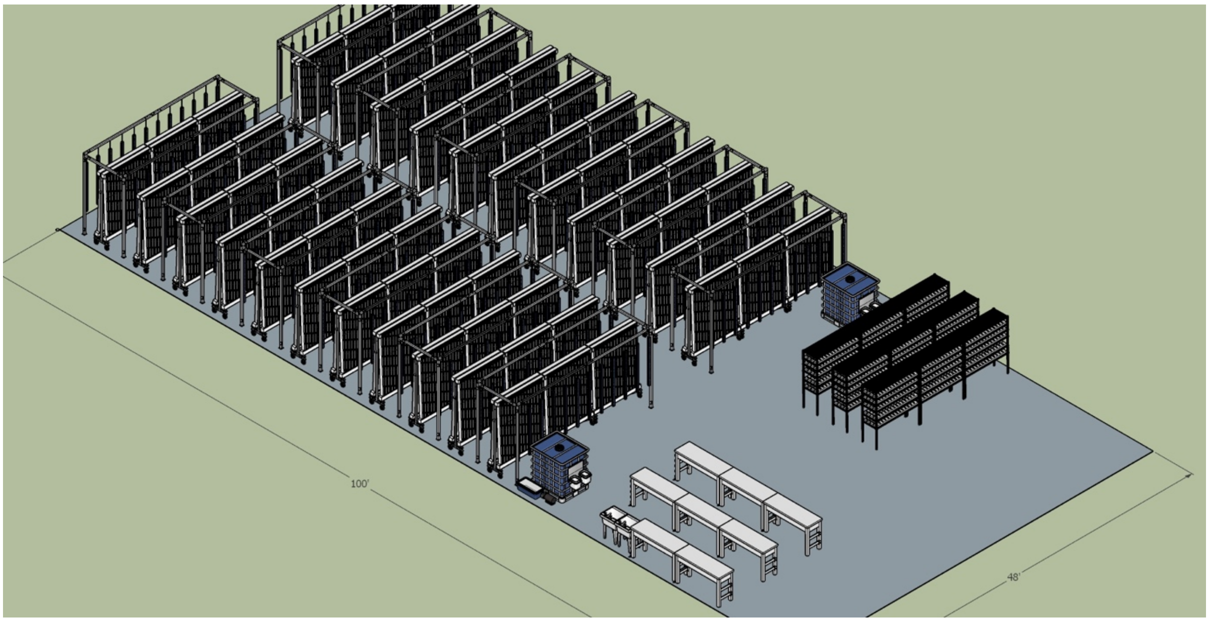
With the import tax range of 40-70%, the initial investment cost for the indoor structure would vary from the optimistic scenario of US$792,890, to the pessimistic, highest range of US$962,795, creating a significant burden for a ZipFarm indoor farming operator in São Paulo. Additionally, if the average equipment lifetime is of 8 years, the same added tax cost would be incurred periodically through depreciation, transforming it into a riskier investment in comparison to its operation in Denver.

4.1.2 Property Costs

Vertical farms can take advantage of the population density in urban cities by staying closer to a higher number of customers, specially if situated in residential areas, and delivering fresher products with less transportation expenses in comparison to rural areas (Toualitos et al. 2016). This occurs in exchange of higher costs per square feet of property area in comparison to rural areas. In São Paulo metropolitan region, 27.7% of households spent over 30% of their income on housing alone, an amount over the recommended budgetary limits (Acolin, 2016). Despite the encouragement of indoor vertical farms to maintain proximity to their clients, in which case marketing initiatives and the proximity itself may be leveraged in order to provide more premium prices to clients as a higher willingness to pay is generated, lowering the investment in real estate by abstaining from higher cost areas would lower Capex costs, an essential element for a successful venture (Zeidler et al. 2017).

According to real estate company ImovelWeb (2017) with basis of 2 million real estate in the city, São Paulo possesses varying real estate costs per square feet according to different neighborhoods. The lower-end priced residential areas include neighborhoods such as Cidade Tiradentes, José Bonifácio, and Vila Prudente, which vary between BR$2,915 – BR$3,659 per square meter, or approximately US$67 – US$85 per square foot. On the other hand, the upper-tier priced neighborhoods Itaim Bibi, Jardim Europa, and Vila Nova Conceição vary between BR$12,694 – BR$16,292 per square meter, or approximately US$295 – US$378 per square foot. The medium value is of BR$6,043 per square meter, or approximately US$140 per square foot.

Figure 11: Sample ZipFarm ~5,000 feet structure



(Source: ZipFarm, 2019)

As exemplified by the image above, the entire structure requires approximately 5,000 square feet of space to operate. With the average real estate space in São Paulo being of US$140 per square feet (ImovelWeb, 2019), the total expenditure in property purchase would be of US$700,000. On the other hand, Denver possesses a 269% higher real estate average cost of US$377 per square feet (Zillow, 2019) resulting in a required investment of US$1,885,000.

4.2 INPUT COSTS

ZipGrow input costs are based on Table 1 and Table 2, on Section 4.4.

4.2.1 Electricity

One of the main components of indoor vertical faming are the LED lightings required for crop growth. Possessing cheap electricity is a major cost advantage for an indoor farm and is decisive when selecting a location for the farm. Although the electricity of Brazil is not considered expensive by global standards, it is also not cheap. According to Statista (2018), both United States and Brazil have an average cost per KwH of electricity of US$0.13. For effects of comparison, Japan, which possesses some of the largest indoor vertical farms (Despommier, 2013), has the average cost of US$0.22 KwH (Statista, 2018). However, in the city of São Paulo itself, the distributor of electricity in São Paulo ENEL has displayed costs of BR$0.25 per KWH, or approximately US$0.0625 (ENEL, 2019).

Furthermore, most energy consumed in Brazil comes from natural sources, having 63.7% derived from hydroelectric, 9.1% biomass, and 8.1% from Eolic production, meaning that at least 80.9% of electricity originates from clean energy (MME, 2018). On the other hand, 36% of the United States energy consumption possesses only 11% derived from renewable energy, having 36% originated from petroleum and 13% coal (EIA, 2018). This signifies that a potential commercial vertical production would possess cleaner energy that could be economically taken advantage of through marketing initiatives (Kozai, et al. 2016).

The average cost of electricity incurred by the ZipGrow farm in Denver, Colorado over the trial period was of US$0.13 per KwH, meaning that the electrical cost incurred by the same vertical farming structure in São Paulo (US$0.0625) would be 51.9% cheaper, a significant cost saver considering the high electric costs required to operate an indoor farm (Kozai, 2013). As seen in Table 1, when comparing the total annual electric costs required to operate the ZipFarm by location, the farm in São Paulo would expend US$36,918 less than in Denver. Electricity represented the largest utility cost in both São Paulo and Denver, representing

The difference in electricity cost in not only proportionally more expensive in Denver than in São Paulo, but also lead to a significant total cost increase. This may allow for a structure in São Paulo to utilize a selection of vegetables that require longer LED exposure or to allow for a more extensive exposure to reach optimum growth rates, resulting in a shorter harvesting period.

4.2.2 Labor

As common in developing nations, labor in Brazil is cheaper than in more consolidated economies. The monthly minimum wage in Brazil in 2019 is of BR$998.00 or approximately US$250.00 (DIEESE, 2019). In general, rural hands-on worker's salary can be on-par with the minimum wage (CONAB, 2010). In the U.S, minimum wage can vary between states and cities, having the Federal minimum wage as the bare minimum of US$7.25 per hour (Statista, 2019). On the other hand, the United States Department of Agriculture has posted the average agricultural hourly wage from a nonsupervisory position, typically of hands-on workers, being US$13.25 (Zahniser et. al, 2019). On basis of a 4-week month and 40 working hours per week, the hands-on agricultural employee's average monthly payment in the US is of approximately US$2,120.00.

Although both minimum-wage and average costs of hands-on agricultural employees prove to be lower in Brazil in comparison to the United States, it is important to remark that no information was found in regards to wages of hands-on agricultural employees inside the city of São Paulo itself. However, it is expected that the same job pays more in urban areas in comparison to rural areas (Russo et al., 2012), therefore an increase in salary could be expected within São Paulo.

ZipFarm disclosed that its 5,000 square feet indoor farm with 1248 towers fully operates under a single farm manager and two full-time hands-on employees. In Colorado the average annual salary paid for a farm manager and a hands-on employee is of US$43,000 and US$25,000, respectively, resulting in annual labor cost of US$93,000. Labor in São Paulo, as previously mentioned, has proven to be significantly cheaper, with an average annual salary for farm manager of US$21,700 and of a hands-on employee of US$3,500. Table 2 displays that the total annual expenditure in labor required to operate the indoor vertical farm in São Paulo to be 69% cheaper than in Colorado. As a major operational expense, this results in savings of US$64,300 annually for the Brazilian city.

4.2.3 Water

With up to 97% of water usage efficiency in comparison to traditional farming methods (Dunbar, 2007), water is an essential factor for indoor vertical farming but does not not necessarily contribute much towards the total operational costs incurred. Despite increasing costs of water in the United States over the past years, the cost of water continues to be cheap in the US at a global scale (FEMP, 2017). On the other hand, costs of commercial water usage in Brazil are much higher in comparison (ARSESP, 2019).

The ZipFarm company states that its hydroponic vertical farming structure can save 90-95% more water in comparison to traditional farming methods. With low costs per gallon in Denver, the total costs of water spent annually with the plantation is of US$438. On the other hand, São Paulo price per 1,000 gallons of water is approximately 92% higher, leading to a total of US$5,964 annual cost for the ZipFarm. With a difference greater than US$4,500 between total water expenses within these two cities, São Paulo sees water become a significant cost while Denver can enjoy the benefits of its cheap water.

4.2.4 CO_2 gas

While traditional farmers may take carbon for granted, gas may be manipulated in indoor farms in order to optimize product yields through CO_2 supplementation. The CO_2 supplementation is typically included within the HVAC system, as included in the ZipFarm structure itself. Despite the importance of gas in increasing productivity of indoor vertical farms, it is proportionally one of the lowest utility costs of the farms themselves (Agrilyst, 2017).

CO_2 supplementation is typically conducted through the utilization of either natural gas, propane, or CO_2 bottles, containing different concentrations of CO_2 in each type of gas. ZipFarm utilizes natural gas which have the cost in Denver of US$12.50 per 1,000 cubic feet, while São Paulo possesses a cost of US$20.85 per 1,000 cubic feet. Although the cost itself is 40% higher, the total additional cost incurred in São Paulo was of US$1,844. Therefore, despite the proportionally higher costs within the Brazilian city, gas itself does not contribute in a highly significant manner to costs, resulting in a small change despite the cost variation.

4.3 MARKET CONDITIONS - COSTS & PRICING

ZipFarm product costs and wholesale pricing are based on Table 3 on section 4.4.

4.3.1 Brief on costs and pricing comparison

The reduction of costs is important in indoor vertical farming in order to prevent high produce prices, which would prevent a higher reach of sales in volume due to the price inaccessibility of population masses against the competitive, lower-end prices typically provided by traditional farming methods (Hallock, 2013). This does not signify that high prices result in financial failure, as vertical farming sales records demonstrate that it can target and encourage consumption by a financial elite population (Hallock, 2013). Regardless, efficient resource use and production capacity is key to obtain higher sales and healthier margins (Runkle, 2019).

The different variable costs included to measure and compare produce costs involve the major variable costs previously mentioned: electricity, labor, water, and gas. Furthermore, the cost of fertilizer and of seedlings, essential elements required for efficient crop plantation and growth, have also been included. However, reliable comparable brands and/or ingredients could not be found between the fertilizer utilized in the ZipFarm Colorado structure and within the city of

São Paulo. Therefore, both seedling and fertilizer costs were replicated in São Paulo, allowing for a more correct variable cost per product and in its totality, but losing the ability to compare cost advantages/disadvantages within these two categories. The average, total annual cost spent in seedlings and fertilizers in the trials in Colorado's ZipFarm is of US$24,211.

The ZipFarm trials and data provided included 6 leafy greens and 12 different herbs. In order to compare both costs and wholesale prices, only 3 microgreens and 5 herbs were selected as data on wholesale prices in São Paulo for the remaining crops were not found on the database provided by CEAGESP, a governmental organization that observes and provides accurate average prices for different wholesale agricultural products in São Paulo.

The products themselves were separated into categories of leafy greens and herbs, as leafy greens entail plant leaves eaten as vegetables that are more commonly produced, while herbs are typically more specialized products and produced in lesser volume. The categorization is important as the price difference per unit can be drastically different between the two categories (Agrilyst, 2017).

Given that the products were produced within the same structure and the costs here calculated were shared between them equally, the cost of a "basket of products", in which a single unit of each crop is included, is made in order to more accurately compare costs and wholesale prices between Colorado and São Paulo.

4.3.2 Basket costs

In Table 3, the cost for a basket of products was significantly lower for São Paulo in comparison to Denver. While the total basket cost in Denver was of US$5.47, São Paulo possessed approximately 50% cheaper basket by reaching the cost of US$2.70 per basket.

The biggest contributor for this cost difference is the difference paid in labor between the two cities. Additionally, the second largest expense, electricity, was also significantly cheaper in São Paulo. While both CO2 gas and water costs were cheaper in Denver, both represented a small portion of the total costs involved in production.

4.3.3 City costs vs. wholesale prices

An enormous disparity between city wholesale prices occurs, as Denver possessed a basket price of US$19.93, which is 28 times greater than the same basket sold at wholesale in São Paulo, which is worth US$0.71.

It is important to note that the value of wholesale prices in Denver may take into account ZipFarms positioning as an indoor vertical farming brand together with possible marketing initiatives. While this paper does not measure the level of impact these characteristics possessed in the price sold at the wholesales in which ZipFarm products are sold, the wholesale price is 3.6 times larger than the cost to produce the same basket, an enormous difference that points towards a good market for healthy margins. This could also be a result of local competitors having less of a cost advantage in comparison to Denver's ZipFarm. Nevertheless, it can be observed that the greatest margins obtained occurred in the herb category, with some being produced at 1/10th of the wholesale price.

São Paulo's cost to produce the basket of products was 3.8 times larger than the price sold at wholesale for the same basket, displaying the challenging business environment an indoor vertical farm would face in the city. As previously mentioned, most of the vegetables consumed in São Paulo are produced in nearby regions through the traditional farming method (Loman, 2018) that also enjoy the benefits of cheap labor while producing in mass quantities, making prices extremely competitive. The difference in wholesale pricing greatly impacted the IRR of both cities, as displayed in Table 4. The IRR for Denver's vertical farm over a 10-year period significantly surpasses that of São Paulo, being of 14.17% and -19.12%, respectively.

Nevertheless, on a per product basis it is important to note that São Paulo's greatest disparities between production costs per product and wholesale prices occurred with leafy greens, such as the lettuce that costs 1,000% more than the price for which it is sold in wholesale. Herbs, on the other hand, possessed a much lower disparity. Basil was the only product in which the cost to produce was cheaper than the wholesale price being 33% lower, while oregano was only 25% more expensive. In fact, the ratio for cost/price for all herbs are significantly lower when compared to leafy greens. Therefore, the costs benefits and/or productivity rate for herbs lead to more competitive pricing than for leafy greens. Furthermore, given that there is no current

branding or marketing initiative for indoor vertical farms in São Paulo, a higher wholesale price could be achievable with a ZipFarm in the city.

Furthermore, it is important to remark that the prices found in the data are from a specific date, meaning that it does not take into account price volatility. Produce prices may change depending on shifting demand and production capabilities, in which weather may impact the traditional farmer in either positive or negative manners, while the vertical farming production would be constant and independent of weather (Despommier, 2010), providing an economic advantage. Thus, the economic viability of vertical farming would differ throughout time.

4.4 DATA

The data utilized has been summarized in the after mentioned tables. The source of the information utilized within these tables can be further explored in the Appendix section of this paper.

Table 1: ZipFarm utility costs for Denver and São Paulo

in USD

ZipFarm Structure Annual Utility Costs	Denver	São Paulo
Electricity costs	$92,233	$62,686
CO2 costs	$2,761	$4,605
Water costs	$438	$5,964
Total annual utility costs	$95,432	$73,255

Based on Appendix 6, 7, & 8

Table 2: ZipFarm labor costs for Denver and São Paulo

in USD

ZipFarm Annual Labor	Denver	São Paulo
1 Farm manager	$43,000	$21,700
2 Full-time farm hands-on	$50,000	$7,000
Total annual labor costs	$93,000	$28,700

Based on Appendix 5

Table 3: ZipFarm cost of production & wholesale prices in Denver and São Paulo

in USD		Denver, Colorado		São Paulo, Brazil	
Type	Product	Cost per unit of product	Price per unit in wholesale	Cost per unit of product	Price per unit in wholesale
Leafy Greens (lbs)	Lettuce	$1.82	$3.50	$1.01	$0.10
	Chard	$1.59	$3.50	$0.88	$0.10
	Collards	$1.75	$3.50	$0.96	$0.13
Herbs (ozs)	Basil	$0.11	$2.00	$0.06	$0.09
	Cilantro	$0.18	$1.89	$0.10	$0.08
	Oregano	$0.36	$2.00	$0.20	$0.14
	Parsley	$0.18	$1.89	$0.10	$0.03
	Chives	$0.18	$1.65	$0.10	$0.03
Total for product basket		$5.47	$19.93	$2.70	$0.71

Based on Appendix 3, 7, 8, 9, & 10

Table 4: IRR Calculation

IRR Calculation for Denver Vertical Farm			
Initial Investment	Annual gain/loss	Years	IRR
$ 2.451.350,00	$ 473.153,30	10	14.17%

IRR Calculation for São Paulo Vertical Farm			
Initial Investment*	Annual gain/loss	Years	IRR
$ 1.577.842,50	$ -32.378,48	10	-19.12%

*Import taxes at 55%

Based on Appendix 9 & 10

5. FINAL EVALUATION

In this section short summaries of previous chapters are afforded, collecting the insights in order to aid the memory as the latter part of this section will postulate a conclusion with final assessments in the cost comparison of operating a ZipFarm in Denver and in São Paulo.

5.1 SUMMARY OF FINDINGS

Short summaries are provided concerning the literature review, investment & input costs, and market conditions.

5.1.1 Theoretical perspective

Indoor vertical farming possesses multiple variations that greatly impact the output and require previous decision-making by the farmer. The location of the farm, being either urban, suburban, or rural, would define the farm's proximity to the end-client as well as greatly impact property costs. The growing system selected, of which the most commonly utilized are hydroponics, aeroponics, and aquaponics, define the types of equipment utilized, input usage, and farming processes, ultimately impacting the productivity of the crops. Due to the vertical plantation nature of the structure, the crop selection is important for optimum use of space resulting in higher productivity for the farmer. While both business operations and academic papers on the area are not bountiful, indoor vertical farms have greatly increased in numbers due to technological innovations led by LED lighting together with the humane necessity to develop alternate farming methods. Nevertheless, many are still skeptical of the economic viability of indoor vertical farming given its high operating costs.

5.1.2 Investment & input costs

The initial investment for the ZipFarm indoor vertical farming structure is additionally large to São Paulo due to Brazilian tax laws that would make it incur from 40-70% of additional costs for the structure's entire price. Nevertheless, another required initial investment, property in which the structure would be place, is significantly more expensive in Denver, thus compensating the initial, required tax payment.

The inputs required to operate the vertical farm are largely cheaper in the city of São Paulo. Electricity and labor, typically the largest contributors to expenses, are both significantly

cheaper in the city. While two other essential inputs, CO_2 gas and water, are cheaper in Denver, both represent minimum costs to the entirety of the operation.

5.1.3 Market conditions

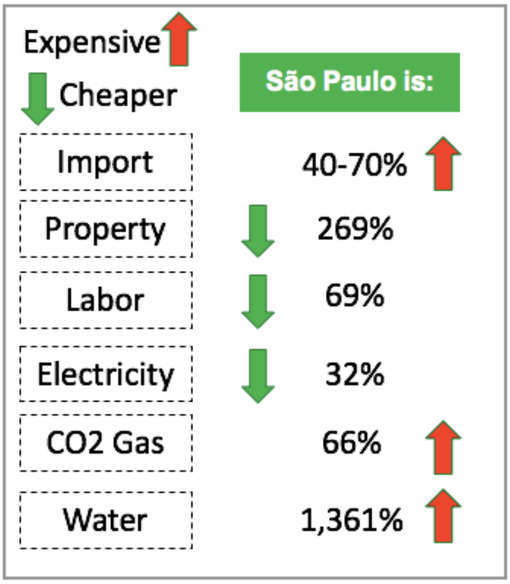
The market conditions greatly favor Denver as wholesale pricing greatly outweighs the cost to produce it. Despite having a larger cost per product basket in comparison to São Paulo, its costs managed to be significantly below wholesale prices, leading to the possibility of healthy margins. In this scenario, wholesale prices are meant for premium, vertically farmed products, influencing the higher prices obtained.

While São Paulo possessed lower costs, the basket wholesale price was extremely lesser than the cost to produce it. This demonstrates the highly price-competitive market within São Paulo. Nevertheless, both São Paulo and Denver possessed better margins in the herb category, displaying better potential for profitability. In order to obtain better margins, the São Paulo structure would require to place premium prices in order to compensate its costs.

5.2 FINAL ASSESSMENTS

Out of the four most cost-incurring categories – import, property, labor, and electricity – São Paulo provides a cheaper environment to all with the exception of import costs due to natural political circumstances, increasing investment costs by 40-70% in the hydroponic vertical farming structure. While the import tax may be lowered through argumentation of its environmental and social benefits to the city and its population, it is an area more dependent on external factors rather than internal. Furthermore, if the indoor farming property is purchased at each city's median price, São Paulo's significant cheaper property would compensate the additional expenses paid on import taxes.

Figure 12: São Paulo cost comparison with Denver

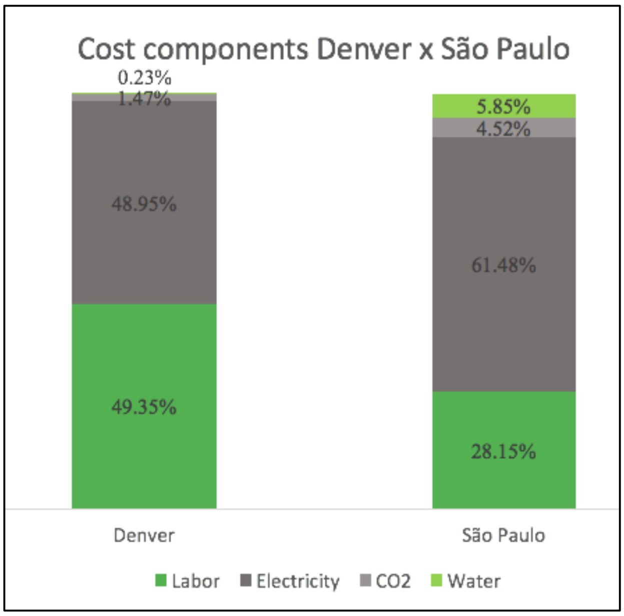


(Source: Self-provided)

As for the main inputs required to operate the vertical farm, labor contributes to a great part of operational costs and is significantly cheaper in São Paulo, followed by electricity. While both CO_2 gas and water are more expensive in São Paulo, their costs contribute in a very small proportion to the total, therefore it is an area in which not much investment should be made.

With different cost compositions of the inputs required for operations in Denver in São Paulo as show in Figure (x) below, Denver now possesses a larger potential to decrease its costs from expected increase in automation. São Paulo, despite its already cheap electric costs, is mostly dependent in the reduction of electric costs as it forms 61.48% of total input costs, nevertheless further advancement in LED efficiencies are to be expected (Kozai, 2016).

Figure 13: Zipfarm input cost components Denver and São Paulo



(Source: Self-provided)

Denver's main contributors to cost are almost equally divided between labor and electricity. Automation, generated from increase in technology, is expected to decrease labor over time, which for a small facility could translate into having full-time hands-on employees into part-time workers. While such technological advancement would significantly decrease costs in Denver, São Paulo's already cheaper labor would incur lesser of a benefit. Additionally, as LEDs becomes more efficient, Denver's current higher cost per KwH in comparison to São Paulo would also lead to higher total savings.

Finally, the largest difference between the two markets is the wholesale pricing. While Denver can produce at a higher cost, the selling point outweighs the prices incurred from the measured inputs. Conversely, São Paulo boasts of a market with highly competitive prices and cannot compete with current wholesale prices. Nevertheless, there seems to be potential on more highly priced crops such as herbs. A correct marketing and branding as an organic, indoor vertical farming producer could allow for ZipGrow's structure to set a higher price to its products and, if planted herbs, would achieve better margins more easily than with leafy greens.

6. CONCLUSION

This paper's introduction heightened the importance for people to find alternate farming methods due to increase in global population and decrease in available arable land. With issues of feeding people, preventing malnourishment, growing urban concentration, and growing environmental concerns, the author believed that either changes to the current traditional farming method or the introduction of new farming methods must be implemented. Indoor vertical farming, which proposes to farm in vertically stacked layers in a controlled environment for optimum productivity and can virtually be deployed anywhere, appears to be a possible solution for the issue at hand.

The largest factor preventing indoor vertical farming from expanding rapidly is its economic feasibility. In its current state, two views are commonly found in regards to its profitability, either it the operational cost is too expensive to generate food that is accessible to the population while maintaining profits, while others argue that technological advancements have allowed for both significant cuts in cost and boosts of productivity efficiency. At the present moment, only few indoor vertical farms are in operation, meaning that many unexplored cities and countries could offer unforeseen cost benefits to the operation that could allow for profitability and a positive social impact. With this in mind, a profitable indoor vertical farming structure in Denver, Colorado, was hypothetically placed in São Paulo, undergoing its cost and price environment.

São Paulo provides an overall, much cheaper environment in comparison to Denver, but possesses market conditions in which its low costs still cannot compete with local, traditional farming product prices, while Denver's ZipFarm has a market in which the evaluated costs are well below wholesale prices. Crop selection has proven to be key in the potential success of an indoor vertical farm in São Paulo, as herbs displayed costs that better matched wholesale prices, leaving space for possible margins. Furthermore, the success of a vertical farm which intends to produce a variety of products would also be dependent on its capabilities of setting premium prices to its own products in order to compensate its own costs.

The cost components of an indoor vertical farm in São Paulo are favorable towards a limited variety of crops and towards products with premium prices, meaning that feeding the city's population with traditional, popular vegetables is currently inconceivable. Nevertheless,

advancements in technology that provide either smaller costs or higher productivity could shorten the gap between the vertical farm’s costs and popular product prices. While businesses may explore the production of specialty crops in the current moment, indoor vertical farm’s ability to replace traditional farming in São Paulo is still very far fetched, technologically dependent, and might never be possible.

7. CONTRIBUTION TO RESEARCH

The dissertation here contributes to existing research as explained previously (Section 1.2).

As many academic research papers focus on indoor farming techniques, current state of indoor farming, and social impact, few focus on its economic viability and none have explored the benefits and disadvantages of utilizing a successful indoor vertical farming structure in a separate geographic location.

Moreover, the paper is the only to compare the utilization of a profitable indoor vertical farming structure in Denver and compare its operations with the conditions in the city of São Paulo, Brazil, where no indoor vertical farms are operating in commercial scale.

8. LIMITATIONS AND FUTURE RESEARCH

In regards to limitations, it was previously discussed that this dissertation would focus on the main cost components of operating an indoor vertical farming structure in Denver and in Colorado. Therefore, there are other cost components that could have been measured in order to obtain a more accurate depiction of the scenario of operating an indoor vertical farming structure in São Paulo. Furthermore, given the different available growing systems, equipment, techniques, and technology, this paper has only focused on the utilization of a single farming structure, a hydroponic indoor farming system from ZipFarm, and therefore does not represent all vertical farming structures. The utilization of different mix and the before mentioned factors would undoubtedly lead to different results and are therefore valid for future research in search of vertical farming best practices.

Lastly the crop selection has greatly limited this paper as different categories and different crops possess highly different productivity rates, costs, and wholesale prices, therefore the exploration of different crops would greatly contribute towards research of indoor vertical farm's economic feasibility in different regions. Furthermore, crops not meant for consumption as food have not been included in this research despite promising financial returns, such as flowers and marijuana, and could deliver significant differences in regards to a farms economic viability.

An additional method that could have been implemented would have been to obtain data sets from more than one vertical farming structure. This would gather more evidence towards the potential profitability of vertical farming and allow for more conclusive assessments.

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10. APPENDIX

Appendix 1: Pricing for ZipFarm indoor vertical farm 1248 towers structure

Description	Price	Quantity	Amount
Light Rack With Single & Double Sided LEDs	$ 19,000.00	4	$ 76,000.00
Light Rack With Double Sided LEDs	$ 21,000.00	10	$ 210,000.00
ZipRacks Complete With Towers (1248)	$ 2,650.00	78	$ 206,700.00
Plumbing Kit (Dosing/RO/UV/Sump & IBC)	$ 8,900.00	2	$ 17,800.00
Atom Universal Climate Controller & CO2 Injector	$ 8,500.00	2	$ 17,000.00
In Line Plumbing Per Rack	$ 250.00	78	$ 19,500.00
Seedling Starter Area	$ 2,150.00	9	$ 19,350.00
			$ -
		SUBTOTAL	$ 566,350.00
		DISCOUNT	$ -
Pricing in USD		SUBTOTAL LESS DISCOUNT	
		TAX RATE	0%
		TOTAL TAX	$ -
		SHIPPING/HANDLING	$ -
		Quote Total	**$ 566,350.00**

(Source: ZipFarm, 2019)

Appendix 2: Average seedlings for ZipFarm structure trials

624	Green Towers			
# of Towers	crop	Seedlings per tower	loss %	Weekly seedlings
104	lettuce	14	0.1	448
104	chard	14	0.1	374
104	bok choy	14	0.1	374
104	mustard greens	14	0.1	374
104	kale	14	0.1	374
104	collards	14	0.1	374
Total Greens Seedlings per wk.				**2318**

624	Herb Towers			
# of Towers	Crop	Seedlings per tower	loss %	Weekly seedlings
52	basil	16	0.1	256
52	cilantro	32	0.1	427
52	oregano	16	0.1	128
52	fennel	16	0.1	160
52	mint	26	0.1	347
52	parsley	26	0.1	347
52	chives	64	0.1	640
52	thyme	16	0.1	160
52	lemongrass	48	0.1	640
52	nasturtiums	16	0.1	320
52	tarragon	16	0.1	128
52	chervil	32	0.1	512
Total Herbs Seedlings per wk.				**4065**
Total Seedlings per wk.				**6383**

(Source: ZipFarm, 2019)

Appendix 3: Average annual production estimates in ZipFarm Denver trials

5000	Square feet of growing space
1248	# of towers
8	5', 7', or 8' Towers
Indoor	Greenhouse or Indoor

50	% Greens
624	Veg. Towers
0	Towers Left to Allocate

# of Towers	Crop	Wks. to Harvest	lbs./Tower	lbs./Week
104	lettuce	3.6	6.4	184.3
104	chard	4.3	8.8	211.2
104	bok choy	4.3	12.8	307.2
104	mustard greens	4.3	6.4	153.6
104	kale	4.3	6.4	153.6
104	collards	4.3	8	192.0
	Total Greens lbs./wk			**1201.9**
	Total Greens lbs./yr (50 wks)			**60096.0**

50	% Herbs
624	Herb towers
0	Towers Left to Allocate

# of Towers	Crop	Wks. to Harvest	oz/Tower	oz/Week
52	basil	3.6	102.4	1475
52	cilantro	4.3	76.8	921.6
52	oregano	7.2	64	460.8
52	fennel	5.8	153.6	1382.4
52	mint	4.3	76.8	921.6
52	parsley	4.3	76.8	921.6
52	chives	5.8	102.4	921.6
52	thyme	5.8	51.2	460.8
52	lemongrass	4.3	64	768.0
52	nasturtiums	2.9	19.2	345.6
52	tarragon	7.2	38.4	276.5
52	chervil	3.6	108.8	1566.7
	Total Herbs oz./wk			**10421.8**
	Total Herbs oz./yr (50 wks)			**521088.0**

(Source: ZipFarm, 2019)

Appendix 4: Median real estate cost per square foot in Denver & São Paulo

	Median Cost in USD	
Area	**Denver, Colorado***	**São Paulo, Brazil****
Per Square Foot	$377.00	$140.00

*(Source: Zillow, 2019) **(Source: Immovelweb, 2019)*

Appendix 5: Average labor cost in Denver & São Paulo

	Average Salary in USD	
Labor	**Denver, Colorado***	**São Paulo, Brazil****
Farm Manager	$43,000.00	$21,700.00
Full-time Farm Hands-On	$25,000.00	$3,500.00

*(Sources: Statista, 2019) **(Based on: Glassdoor, 2019)*

Appendix 6: Utility costs in Denver ZipFarm structure & São Paulo utility costs

	Costs in USD	
Input Costs	**Denver, Colorado***	**São Paulo, Brazil****
Electricity per KWH	$0.13	$0.06
Natural Gas p/1,000 ft³	$12.50	$20.85
Water per 1,000 gallons	$3.65	$49.75

*(Sources: ZipFarm, 2019) **(Sources: ARSESP, MME, ENEL)*

Appendix 7: Average utility calculations for ZipFarm structure in Denver

# of ZipRacks	78
# of ZipGrow Towers per Rack	16
# of Plumbing Packages	2

Utility Calculations - Denver, Colorado									
Electicity Usage									
		Quantity	Watts p/unit	KW	Hours of Use per Day	KWH	Cost per KWH	Daily Cost	Yearly Cost
Lighting	Intravision Lights Single Sided (8')	88	75	6,6	16	105,6	0,1278	$13,5	$4.926
	Intravision Lights Double Sided 8')	536	150	80,4	14	1125,6	0,1278	$143,9	$52.506
Plumbing	Inline Pump	1	920	0,92	24	22,08	0,1278	$2,8	$1.030
	Active Aqua 550 Pump	2	33	0,066	24	1,584	0,1278	$0,2	$74
	Intellidose	1	60	0,06	24	1,44	0,1278	$0,2	$67
Seedling Kit	Active Aqua 550 Pump	1	33	0,033	24	0,792	0,1278	$0,1	$37
	T5 Lights	9	54	0,486	24	11,664	0,1278	$1,5	$544
Climate Control	MultiGrow	2	100	0,2	24	4,8	0,1278	$0,6	$224
	CO2 Injector	2	60	0,12	24	2,88	0,1278	$0,4	$134
	Dehumidifier	2	1350	2,7	24	64,8	0,1278	$8,3	$3.023
HVAC	General Estimate of 100A Load Annual Cost								$22.464
Buffer	*Overhead lights, other equipment in grow area							5%	$4.005
Total Electric Costs									**$89.034**
CO2	Estimate - assuming use of natural gas		605.15 ft³ p/day		$12.50 p/1000 ft ³			$7.56 p/day	**$2.761**
Water		0,25 gallons/tower/day		500 gallons/month buffer		3,65 price per 1,000 gallons			**$438**
TOTAL									**$92.233**

(Sources: ZipFarm, 2019)

Appendix 8: Utility calculations for ZipFarm structure in São Paulo

# of ZipRacks	78
# of ZipGrow Towers per Rack	16
# of Plumbing Packages	2

Utility Calculations - São Paulo, Brazil									
Electicity Usage									
		Quantity	Watts p/unit	KW	Hours of Use per Day	KWH	Cost per KWH	Daily Cost	Yearly Cost
Lighting	Intravision Lights Single Sided (8')	88	75	6,6	16	105,6	0,06	$6,3	$2.313
	Intravision Lights Double Sided 8')	536	150	80,4	14	1125,6	0,06	$67,5	$24.651
Plumbing	Inline Pump	1	920	0,92	24	22,08	0,06	$1,3	$484
	Active Aqua 550 Pump	2	33	0,066	24	1,584	0,06	$0,1	$35
	Intellidose	1	60	0,06	24	1,44	0,06	$0,1	$32
Seedling Kit	Active Aqua 550 Pump	1	33	0,033	24	0,792	0,06	$0,0	$17
	T5 Lights	9	54	0,486	24	11,664	0,06	$0,7	$255
Climate Control	MultiGrow	2	100	0,2	24	4,8	0,06	$0,3	$105
	CO2 Injector	2	60	0,12	24	2,88	0,06	$0,2	$63
	Dehumidifier	2	1350	2,7	24	64,8	0,06	$3,9	$1.419
HVAC	General Estimate of 100A Load Annual Cost								$22.464
Buffer	*Overhead lights, other equipment in grow area							5%	$2.592
Total Electric Costs									**$52.116**
CO2	Estimate - assuming use of natural gas	605.15 ft^3 p/day			$20.85 p/1000 ft^3			$12.62 p/day	**$4.605**
Water		0,25 gallons/tower/day		500 gallons/month buffer		49,75 price per 1,000 gallons			**$5.964**
TOTAL									**$62.686**

(Sources: ZipFarm, ARSESP, MME, & ENEL)

Appendix 9: Calculations for cost of product basket in ZipFarm São Paulo structure

São Paulo, Brazil (in USD)

1248	# of towers
$62,686	Annual utility costs
$28,700	Annual labor costs*
$24,211	Annual seedling & fertilizer costs
$93	Annual cost per tower

Type	Product	# of towers	Total cost	Weekly production (lbs/ozs)	Annual production (lbs/ozs)	Cost per unit of product	Price per unit in wholesale**
Leafy Greens (lbs)	Lettuce	104	$9,633.08	184.3	9583.6	$1.01	$0.10
	Chard	104	$9,633.08	211.2	10982.4	$0.88	$0.10
	Collards	104	$9,633.08	192	9984	$0.96	$0.13
Herbs (ozs)	Basil	52	$4,816.54	1475	76700	$0.06	$0.09
	Cilantro	52	$4,816.54	921.6	47923.2	$0.10	$0.08
	Oregano	52	$4,816.54	460.8	23961.6	$0.20	$0.14
	Parsley	52	$4,816.54	921.6	47923.2	$0.10	$0.03
	Chives	52	$4,816.54	921.6	47923.2	$0.10	$0.03
Total			$52,981.96		Total for basket of products:	$3.41	$0.70

*Labor = 1 farm manager + 2 full-time hands-on

**Based on CEAGESP average price sold on wholesale

(Sources: Self-provided)

Appendix 10: Calculations for cost of product basket in Zipfarm Denver structure

Denver, Colorado (in USD)

1248	# of towers
$92,233	Annual utility costs
$93,000	Annual labor costs*
$24,211	Annual seedling & fertilizer costs
$168	Annual cost per tower

Type	Product	# of towers	Total cost	Weekly production (lbs/ozs)	Annual production (lbs/ozs)	Cost per unit of product	Price per unit in wholesale**
Leafy Greens (lbs)	Lettuce	104	$17,453.67	184.3	9583.6	$1.82	$3.50
	Chard	104	$17,453.67	211.2	10982.4	$1.59	$3.50
	Collards	104	$17,453.67	192	9984	$1.75	$3.50
Herbs (ozs)	Basil	52	$8,726.83	1475	76700	$0.11	$2.00
	Cilantro	52	$8,726.83	921.6	47923.2	$0.18	$1.89
	Oregano	52	$8,726.83	460.8	23961.6	$0.36	$2.00
	Parsley	52	$8,726.83	921.6	47923.2	$0.18	$1.89
	Chives	52	$8,726.83	921.6	47923.2	$0.18	$1.65
Total	-	572	$95,995.17		Total for basket of products:	$6.18	$19.93

*Labor = 1 farm manager + 2 full-time hands-on

**Price based on average price sold by ZipFarm to wholesale

(Sources: Self-provided)