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MASTER UNIVERSITARIO EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MÁSTER
AUTOMATION OF THE HARVESTING PROCESS OF
VERTICAL FARMS

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Madrid

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AUTOMATION OF THE HARVESTING PROCESS OF VERTICAL FARMS

Jaime Rodriguez Muñoz de Baena

Director: Will Maurer

Collaborating entity: Illinois Institute of Technology

MAIN ABSTRACT

OBJECTIVES

The aim of this project is to assess the benefits of introducing automation into the harvesting process of vertical farms.

A state of the art study will be carried out, where vertical farming is explained, as well as all the current harvesting techniques that are used globally. This is important to understand the current necessities for innovation in the industry.

Then, several companies will be studied that have similar technologies than the one that is being proposed to understand what is currently being done to try to find a solution to this problem.

After that, several solutions will be proposed along with their costs of implementing these technologies to actual vertical farms. This will serve as a reference point to see how much impact these solutions will have in vertical farming and how much profit could be obtained by installing them into real farms.

The main objective is to find a solution that could reduce greatly the costs of vertical farming to make this business more profitable and, therefore, more useful for future generations.

INTRODUCTION

Vertical farming can be defined as the technique that involves growing produce inside a building in rows that are stacked on top of each other to maximize the useful growing area. This method differs from the original way of growing crops in several ways.

The main difference is that soil is no longer needed for the plants to absorb nutrients. The roots of the plant are in contact with a solution of water that contains all the nutrients necessary for the plant to grow healthy. There are various ways of introducing these nutrients into the water that are explained in the project.

Vertical farming has many advantages compared to traditional farming in terms of space, seasonality, use of water, etc. However, most vertical farms are not obtaining benefits due to the fact that labor costs are too expensive. Thus, the aim of this project is to create a device that can cut down on labor costs by reducing all the human capital that is needed to harvest, which accounts for the largest part of the costs of vertical farms.

SOLUTIONS DESIGNS

There are several companies that have already tried to solve this problem such as Iron Ox, Agrobot, or Viscon Hydroponics. All these companies sell technologies that are used to harvest crops with machines and have succeeded in with the functionality of their devices.

However, the companies that are mentioned above don't really solve the problem of creating a machine that can be added to any vertical farm. Some of these machines are used for very specific types of crops, such as strawberries, and all of them are implemented in farms with a very specific layout and are only used on single-level plantations.

The main idea of vertical farming is planting on several levels that are stacked up on top of each other to maximize the space available for planting. Therefore, the next solutions proposed, which are inspired by other technologies like the ones mentioned above, tackle the problem of reducing human labor while also being adaptable to most vertical farms and applied on farms with more than one layer of plantation.

These are the solutions proposed:

- Lift-type robot
- Rail-moving robot
- Whole farm automation

These solutions have different levels of automation and integration with the vertical farms. They are described in more detail inside the paper but basically, one of them is based on a lift truck and moves around the floor of the farm, reaching all layers of the plantation. The second one moves along some rails that are installed above the plants, and the last one involves giant pools stacked on top of each other with moving trays that carry the growing plants around a closed loop process.

Each of these solutions involves different degrees of investment for the farm. Not all of them are suitable for every farm, and each of them will bring different quantities of benefits to the farms depending on their size.

COST ANALYSIS AND CONCLUSIONS

To analyze the benefits of adding these solutions to vertical farms, a model of a real vertical farm was obtained. Then, it was estimated how much labor costs could be reduced and how much would benefits increase by adding these machines to a vertical farm. Then, the effect of adding these tools to different sized vertical farms was analyzed.

The conclusion that was reached is that there is a clear benefit of adding these machines to vertical farms. The first tool was discarded because it was proven that investing in it did not make much sense. However, the other two machines would involve investments with an IRR around 30% and a 3-year payback period.

Therefore, more in-depth designs should be carried out to bring this idea into a real solution that could bring great benefits to our farms.

AUTOMATIZACIÓN DEL PROCESO DE COSECHADO DE GRANJAS VERTICALES

Jaime Rodriguez Muñoz de Baena

Director: Will Maurer

Entidad colaboradora: Illinois Institute of Technology

RESUMEN

OBJETIVOS

El objetivo de este proyecto es evaluar los beneficios de introducir la automatización en el proceso de cosecha de las granjas verticales.

Se llevará a cabo un estudio del estado del arte, donde se explica la agricultura vertical, así como todas las técnicas de cosecha actuales que se utilizan a nivel mundial. Esto es importante para entender las necesidades actuales de innovación en la industria.

Después, se estudiarán varias empresas que tienen tecnologías similares a la que se propone para comprender qué se está haciendo actualmente para tratar de encontrar una solución a este problema.

A continuación, se propondrán varias soluciones junto con sus costes de implementación de estas tecnologías en granjas verticales reales. Esto servirá como punto de referencia para ver cuánto impacto tendrán estas soluciones en la

agricultura vertical y cuánto beneficio podría obtenerse al instalarlas en granjas reales.

El objetivo principal es encontrar una solución que pueda reducir considerablemente los costes de la agricultura vertical para que este negocio sea más rentable y, por lo tanto, más útil para las generaciones futuras.

INTRODUCCIÓN

La agricultura vertical se puede definir como la técnica que implica cultivar productos dentro de un edificio en filas que se apilan una encima de la otra para maximizar el área de cultivo útil. Este método difiere de la forma original de hacer crecer los cultivos de varias maneras.

La principal diferencia es que la tierra ya no es necesario para que las plantas absorban nutrientes. Las raíces de la planta están en contacto con una solución de agua que contiene todos los nutrientes necesarios para que la planta crezca saludable. Hay varias formas de introducir estos nutrientes en el agua que se explican en el proyecto.

La agricultura vertical tiene muchas ventajas en comparación con la agricultura tradicional en términos de espacio, estacionalidad, uso de agua, etc. Sin embargo, la mayoría de las granjas verticales no obtienen beneficios debido al hecho de que los costes laborales son demasiado elevados. Por lo tanto, el objetivo de este proyecto es crear un dispositivo que pueda reducir los costos laborales al reducir todo el

capital humano que se necesita para la cosecha, que representa la mayor parte de los costes de las granjas verticales.

DISEÑOS

Hay varias compañías que ya han intentado resolver este problema, como Iron Ox, Agrobot o Viscon Hydroponics. Todas estas compañías venden tecnologías que se utilizan para cosechar cultivos con máquinas y han tenido éxito con la funcionalidad de sus dispositivos.

Sin embargo, las compañías mencionadas anteriormente no resuelven realmente el problema de crear una máquina que se pueda agregar a cualquier granja vertical.

Algunas de estas máquinas se utilizan para tipos de cultivos muy específicos, como las fresas, y todas se implementan en granjas con un diseño muy específico y solo se usan en plantaciones de un solo nivel. La idea principal de la agricultura vertical es plantar en varios niveles que se apilan uno encima del otro para maximizar el espacio disponible para plantar.

Por lo tanto, las siguientes soluciones propuestas, que están inspiradas en otras tecnologías como las mencionadas anteriormente, abordan el problema de reducir el trabajo humano al tiempo que se adaptan a la mayoría de las granjas verticales y se aplican en granjas con más de un nivel de plantación.

Estas son las soluciones propuestas:

- Robot de tipo elevador
- Robot de carriles

- Automatización completa de la granja

Estas soluciones tienen diferentes niveles de automatización e integración con las granjas verticales. Se describen con más detalle dentro del proyecto, pero básicamente, uno de ellos se basa en una carretilla elevadora que se mueve alrededor del piso de la granja, llegando a todos los niveles de la plantación. El segundo se mueve a lo largo de algunos railes que se instalan por encima de las plantas, y el último involucra piscinas gigantes apiladas una encima de la otra con bandejas móviles que transportan las plantas en crecimiento alrededor de un proceso de circuito cerrado.

Cada una de estas soluciones implica diferentes grados de inversión para la granja. No todos son adecuados para cada granja, y cada una de ellas aportará diferentes cantidades de beneficios a las granjas en función de su tamaño.

ANÁLISIS DE COSTES Y CONCLUSIONES

Para analizar los beneficios de agregar estas soluciones a granjas verticales, se obtuvo un modelo de una granja vertical real. Luego, se estimó cuánto se podrían reducir los costos laborales y cuánto aumentarían los beneficios al agregar estas máquinas a una granja vertical. Luego, se analizó el efecto de agregar estas herramientas a fincas verticales de diferentes tamaños.

Se llegó a la conclusión de que existe un claro beneficio al agregar estas máquinas a las granjas verticales. La primera herramienta se descartó porque se demostró que invertir en ella no tenía mucho sentido. Sin embargo, las otras dos máquinas

implicarían inversiones con una TIR de alrededor del 30% y un período de recuperación de 3 años. Por lo tanto, se deben llevar a cabo diseños más profundos para convertir esta idea a una solución real que pueda aportar grandes beneficios a nuestras granjas.

AUTOMATION OF THE HARVESTING PROCESS IN VERTICAL FARMS

BY

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LIST OF SYMBOLS

Symbol	Definition
CEA	Controlled-Environment Agriculture
DWC	Deep Water Culture
IRR	Internal Rate of Return
NFT	Nutrient Film Technique
NJ	New Jersey
NPV	Net Present Value
SF	Square Feet
USA	United States of America

ABSTRACT

Vertical farming is the technique used to grow crops indoors without using soil as a growing medium. Instead, the roots of the plants are in contact with a water solution containing the minerals that are necessary for them to grow healthy. The source of these minerals and the way that they are given to the plants divides vertical farming into three different techniques: hydroponics, aquaponics and aeroponics.

There are many clear advantages when comparing vertical farming with traditional farming in terms of sustainability, growing periods and closeness of the final product to the selling points and, therefore, the final customer. However, the growing process has not been optimized yet and most vertical farms don't make profit yet. This is mainly due to the high labor costs and the fact that much space is wasted in order to leave space for workers to move around the farm.

The aim of this project is to study ways of automating the harvesting process to reduce labor costs and increase space utilization. Several designs have been proposed along with their costs and the possible introduction to several vertical farms, varying in size. The different solutions involve different amounts of investment and farm improvements.

After carrying out a detailed financial study with the little information that can be found online about this business it has been made clear that if these technologies were to become available to farms with a certain size they could be quite interested and might invest great amounts of money to increase their margins.

Therefore, there is a great opportunity for someone to start a business that sells these solutions to farmers, as there are very few options right now in the market and lots of farms that could improve their margins dramatically.

CHAPTER 1

INTRODUCTION

This chapter will serve as an introduction to the world of vertical farming and to explain how the insertion of automation to the harvesting process might be able to change the profitability of this business.

This chapter will also provide insight on the current situation of vertical farming in the USA and some of the harvesting techniques that will have to be taken into account when designing possible automation solutions.

1.1 VERTICAL FARMING

DEFINITION

Nowadays, most fruits and vegetables that are consumed daily by the entire population are grown in traditional farmlands far from the cities. However, with the current pace of population growth in the cities there will be soon a huge demand for crops grown in the suburbs of most urban areas. This is where vertical farming comes in to play: a faster, healthier and more sustainable way of growing a great amount of produce all year round. All the benefits of vertical farming are soon to be included in most of our cities. But before, there are some major issues that have to be solved in order to make a profitable business out of vertical farms. The main factor that is holding back vertical farming from growing is labor costs. These might be reduced with the introduction of automation to the harvesting process.

Vertical farming can be defined as the technique that involves growing produce inside a building in rows that are stacked on top of each other to maximize the useful growing area.

This method differs from the original way of growing crops in several ways. The main difference is that soil is no longer needed for the plants to absorb nutrients. The roots of the plant

are in contact with a solution of water that contains all the nutrients necessary for the plant to grow healthy. There are various ways of introducing these nutrients into the water that will be commented further along this chapter. Another difference is the use of controlled-environment agriculture (CEA) solutions to control factors such as light, humidity or temperature. The use of control software ensures that all the plants receive the ideal conditions to achieve their optimal growth.



Figure 1. Vertical farm (The Himalayan Times, 2015)

ADVANTAGES OF VERTICAL FARMING

This kind of farming has some clear advantages vs. traditional farming that should make us consider investigating and investing money in this business so that it becomes profitable. If vertical farming were to become profitable there would be some considerable improvements to our current way of growing and distributing crops.

To start with, the seasonality of the harvests would come to an end. This is due to the fact that conditions such as temperature and light can be mimicked and, therefore, growing produce is

no longer dependent on natural conditions. This permits growing most crops anywhere on the planet, any time of year.

Crops are protected from outside weather conditions. There are many unpredictable weather conditions that might ruin a whole batch of vegetables when grown in traditional farms. As vertical farms are inside buildings, they are protected from these unforeseen circumstances. Therefore plants will grow healthy and will not be affected by weather factors that are out of the farmer's control.

Another main advantage is that the use of water is greatly reduced. Water is reutilized and plants don't need to be watered. AeroFarms, a vertical farm in Newark, NJ uses as much as 95% less water than a traditional farm. This is a massive leap that would be unimaginable when referring to traditional farms.

The use of soil is eliminated from the growing process, which is an advantage itself that comes with other side benefits. These include the elimination of herbicides, pesticides and fertilizers. As the plants are grown in a closed environment, outside contamination can be controlled and the use of these products is cut off. Therefore, the loss of crops due to plagues and diseases is also reduced greatly.

According to the United Nations, the population by 2050 is expected to reach 10 billion and around 80% of them will live in urban areas. The use of vertical farms seems necessary to avoid the creation of additional farmland.

Also, as the growing conditions of the plants are more controlled, the crop production is increased and the plants grow faster. The previously mentioned vertical farm, AeroFarms, can grow greens in 16 days instead of the usual 30 days. This is a significant increase in the

production yield, which along with the fact that there are several levels of plants on top of each other means that the area needed to grow a certain amount of crops is substantially reduced.

The transportation costs are greatly reduced as well. As the plants are grown close to urban areas there is no need for long-distance transports. This also means that the crops are grown closer to the supermarkets and, therefore, the final consumer. It also ensures the buyers that the products they are buying are fresher, even harvested on that same day.

Overall, the expansion of vertical farms along our cities will introduce healthier and cheaper harvests that will make cities more self-sufficient. It will allow for cities to become bigger without food scarcity constrains.

LIMITATIONS OF VERTICAL FARMING

The main limitation of vertical farms is related with costs. Urban land is more expensive than farmland. There are also high amount of costs related with powering the buildings and the technologies necessary to control the plants' environment. However, the main issue today is the labor cost. Currently, according to a study carried out by Agrilyst Inc. labor costs account for more than 50% of the total costs of running a vertical farm in the United States. This is a huge setback for the investment in new vertical farms, as they are not profitable mainly due to labor costs. Actually, only highly scaled vertical farms can be profitable as the individual costs of production can be reduced to match market prices.

Not every kind of crop can be grown using this technique. Many crops can't be grown in vertical farms. This means that farming can't be solely dependent on vertical farms. Therefore, with the technologies that have been developed so far there will also be a need for traditional farming in the future.

Another current limitation is that the use of space is not fully optimized. As not much automation has yet been introduced in terms of harvesting and planting there has to be some space available in the farms for the workers to move around and manipulate the plants. Once automation is introduced to this process the growing space is likely to be optimized, increasing production yield and decreasing labor costs at the same time.

Moreover, if something goes wrong with the supply of nutrients to the plants they can die very quickly, as the mediums used to provide nutrients don't store them like soil does. Therefore, if for some reason the fresh supply of nutrients and water is stopped the plants will be ruined rapidly.

1.2 TYPES OF VERTICAL FARMS

There are several kinds of technologies that permit vertical farming. They vary depending on the source of the nutrients that are provided for the plant to grow and the medium from which the roots obtain such nutrients. Up to date there are three main solutions that are spread worldwide to cultivate vertically grown plants. These techniques are explained in detail in this chapter.

HYDROPONICS

This soil-less technique involves introducing the roots of the plants in a solution of water that contains all the nutrients that are necessary for the plant to grow. There are two ways to achieve this. In the first one, they plants are exposed to a water solution, leaving the roots in contact with the water and the rest of the plant dry. The second way of achieving this is by placing the plants in an inert medium like gravel or perlite that contains the water solution. Neither of them involves the use of soil. All the nutrients come from fish waste, duck manure or normal nutrients.

There are two main methods used to provide the nutrients to the plants. The water can be still in a reservoir known as Deepwater Culture (DWC). The plants are placed in floating trays that hold the plant with the roots in contact with the water. The nutrients are pumped into the water solution. Light is not allowed to enter this solution to prevent the growth of algae. The second method is known as Nutrient Film Technique (NFT). The plants are held in slightly tilted plastic tubes through where the water solution flows with the force of gravity. This system allows plants to grow faster as they obtain more oxygen from the air than the solution itself.

Deep Water Culture (DWC)

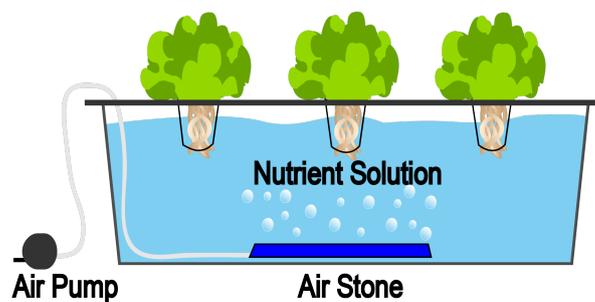


Figure 2. Deep Water Culture diagram (NoSoilSolutions, n.d.)



Figure 3. Nutrient Film Technique (Garden Ambition, n.d.)

AQUAPONICS

This technique is a mixture between hydroponics and aquaculture. Hydroponics is explained in the previous section while aquaculture consists of farming fish under controlled conditions. These two techniques are joined together to achieve aquaponics, a closed loop system where the waste from the fish is used as fertilizer for the plants. The fish are grown in separate tanks, connected by controlled tubes to plants' water solution. Therefore, there is a clear symbiosis between both systems: plants are 'fed' by the waste that the aquaculture produces and the fish tank remains clean as the waste is translated to the hydroponics solution. The water flows from the fish tanks to the hydroponic tanks and then recirculated back to the aquaculture solution.

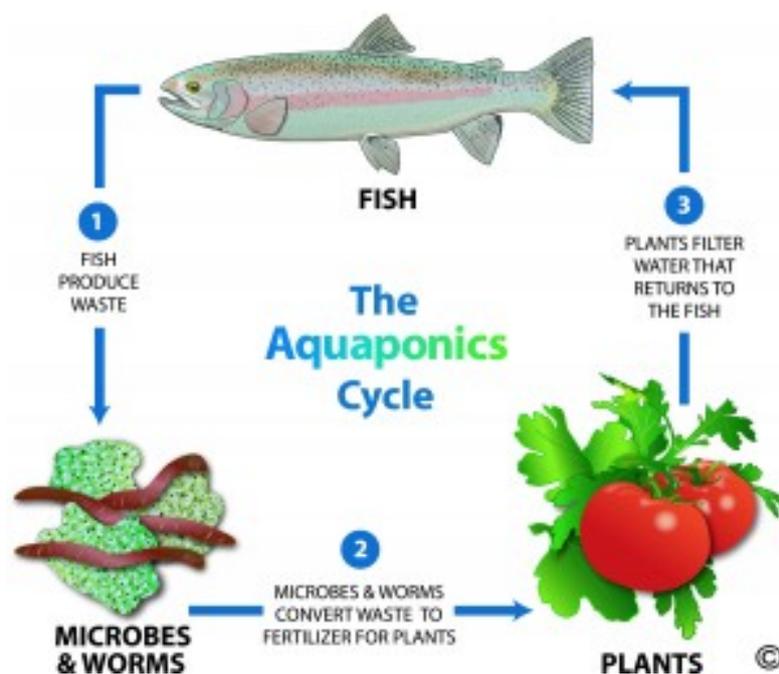


Figure 4. Aquaponics cycle (The Aquaponic Source, n.d.)



Figure 5. Aquaponics farm (Sensorex, n.d.)

Farmers can benefit from this method, as there is also business in growing and selling the fish. Some of the fish that are usually used in this system are tilapia, sunfish, goldfish or koi. However there are many other species that can be used for this task as long as they share similar needs in terms of water temperature and pH as the plants.

AEROPONICS

This method differs from the previous techniques explained in the sense that there is no need for a growing medium. Plants are suspended in a closed air environment. The water solution containing the nutrients is now sprayed to the roots of the plants. This is why sometimes it is considered as a type of hydroponics, as it also uses water to provide nutrients to the plants. The roots of the plants are introduced in a closed closed-cell foam supporting structure where they have more freedom to grow, as there is no physical contact or obstacles other than the air.

This technique allows plants to grow faster and the use of water is reduced compared to the other methods mentioned.



Figure 6. Aeroponics diagram (AeroFarms, n.d.)

1.3 CURRENT SITUATION OF VERTICAL FARMS

This chapter is focused on analyzing the current situation of vertical farms across the world, especially in the USA. This data will aim to provide the reader with a full perspective of how advanced the actual vertical farms are in terms of automation, profitability and possibilities for future development.

VERTICAL FARMING IN THE USA

Most of the data used for this part comes from an extensive research that Agrilyst Inc. performed to analyze the current situation of vertical farms in the USA during the year of 2017. This company helps indoor farms managing their crops and taking profitable product decisions.

Currently, 76% of the indoor farms of the USA use the soil-less systems that have previously described in this report: hydroponics (49%), aquaponics (15%), aeroponics (6%) or a mixture of them (6%).

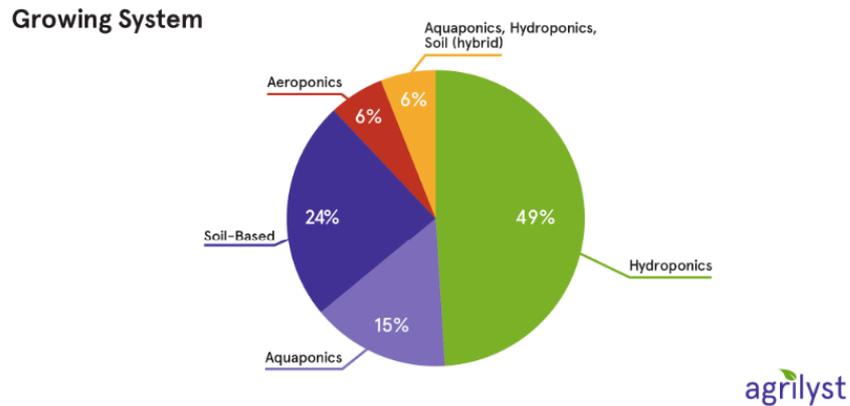


Figure 7. Growing systems (Agrilyst, 2017)

According to the kinds of crops grown, leafy greens account for (57%) of the market. The rest of the popular crops are tomatoes (16%), herbs (11%), flowers (10%) and micro greens (6%).

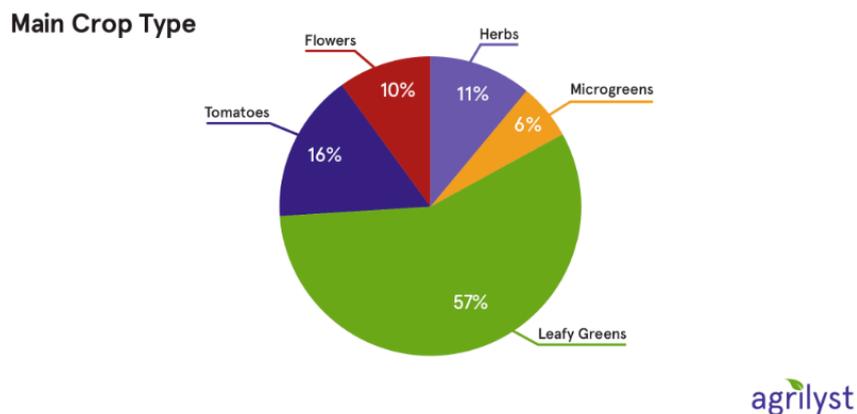


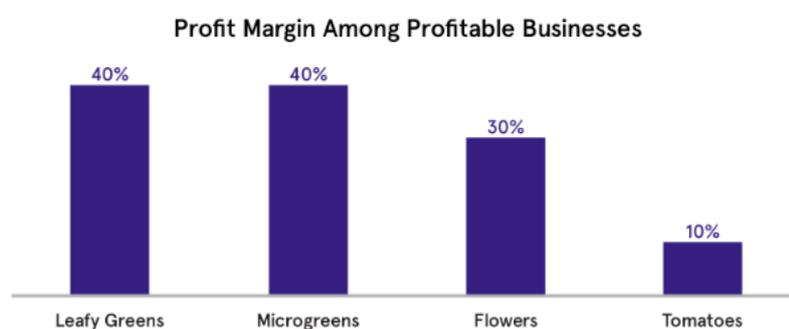
Figure 8. Main crop types (Agrilyst, 2017)

More than half of the indoor farmers are growing leafy greens. “It’s important to note why these make good crops to grow indoors. It is costly to operate an indoor facility (we’ll dig into these costs in a later section). In order to operate profitably therefore, farmers have to grow crops that are high revenue generating. To do this, you can grow crops that are specialty items, like flowers, or you can target crops that have quick growth cycles, like leafy greens. If you think

about a vertical growing system, you want to grow crops that are physically short (so you can get many layers), that have short growth cycles (so you can turn your facility over many times), and are highly perishable (more valuable when grown locally)” (Agrilyst, 2017).

The average age for profitable farms is 7 years, while the average age for unprofitable farms is 5 years. From this figures it can be said that it takes a long time for farmers to start running profitable vertical farms.

Another piece of data that is quite relevant is that most farms that grow microgreens, tomatoes and flowers are profitable. Farms that grow herbs and leafy greens tend to lose money. However, among the profitable businesses, the most profitable are leafy greens and microgreens, which margins of around 40%.



 agrilyst

Figure 9. Profit margins among profitable farms (Agrilyst, 2017)

Finally, there is a clear tendency that shows that during the past 5 years there has been a constant increase in the number of vertical farms. Moreover, this study from Agrilyst shows that farmers are most excited about investing in automation in order to cut down costs. Also, around 80% of them said that they would be willing to buy technology form a start up.

Timeline of Farm Openings by Type

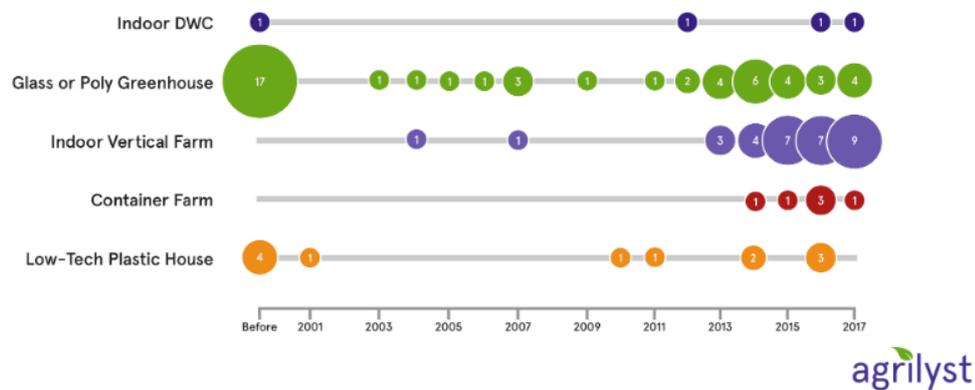


Figure 10. Farm openings timeline (Agrilyst, 2017)

Therefore, this study is quite relevant to understand the current situation of vertical farms in the USA. It is blatant that it is a growing market that needs to optimize its operations to cut down on costs and start making profit out of the most profitable products: leafy greens and microgreens. Most farmers are willing to invest in new automation tools, even if they come from a small start-up company, in order to reduce their operation expenses. Right now all of the planting and harvesting is done manually and comes up as quite expensive. Therefore, there is a blue ocean here to be exploited. A company who can provide automation solutions for vertical farms, thus, the objective of this research project, could earn a lot of money.

VERTICAL FARMS AROUND THE WORLD

Vertical farming is spreading around the world. Some of the biggest plants are in the United States but they can also be found in countries like Singapore, Japan or Holland; with new projects being built in Dubai, Sweden, France, Canada and Philippines. Some of these farms will be commented in this chapter.

One of the biggest vertical farms ever built is FarmedHere, in Chicago. This company was founded in 2009. Their facility was about 90,000 ft² and they sold greens to about 100 stores

in Chicago. These greens were harvested the day before selling them, ensuring good quality products for the consumers. However, they had some problems and ended up shutting down their operations in 2017 because they weren't able to make the business profitable. This is one example of a vertical farm that could still be running today had they had the appropriate machinery to optimize their operations and cut down their costs.



Figure 11. FarmedHere Chicago (Schutz, 2014)

The Spread factory in Kameoka, Japan, produces 21,000 heads of lettuce every day, which are shipped to places all around the country within 24h. This vertical farm allows the region to harvest greens every single day of the year in a place where farmers usually have to stop growing 4 to 5 months a year due to adverse climate conditions. Their mission is to "continually work towards the realization of a sustainable society while protecting the environment through the use of food technology for the comfort and safety of our children and of future generations" (CNN, 2016).



Figure 12. Kameoka Farm (YOSHIDA, 2017)

PlantLab is located in Den Bosch, Holland. It produces three times more yield than the average greenhouse in its three-story building. They grow crops in a fully closed environment where everything is controlled. They don't have any automation however for planting or harvesting.



Figure 13. PlantLab farm (Halper, 2011)

An interesting project is being built in Dubai. They have invested \$40 million in a 130,000 ft² vertical farm that will start being constructed by November 2018. They will grow leafy greens 365 days a year. Around 6,000 pounds of lettuce will be harvested every day, which will be used for in-flight meals as well as for airport lounges. It will be the world's largest vertical farm in the world.

As a small-scale indoor farm we can find Metropolitan Farms, in Chicago. They grow leafy greens and basil using aquaponics. They sell their crops and Tilapia locally and have automation to control the growing conditions of the plants but no automation for harvesting. According to their founder, Benjamin Elliot, they are willing to invest money in automation as long as it has a payback period smaller than 3 years.

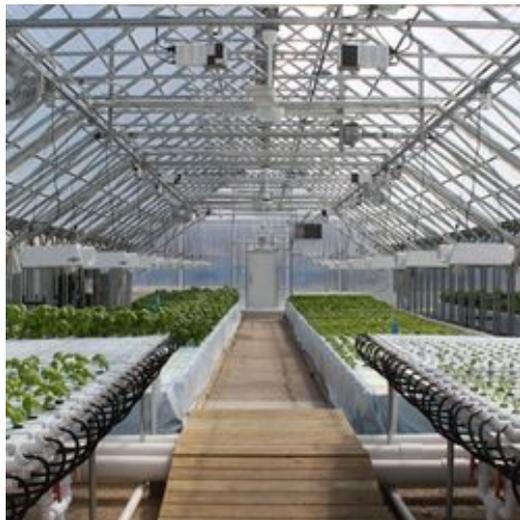


Figure 14. Metropolitan Farms (Yelp, n.d.)



Figure 15. Metropolitan Farms fish tanks (Fuller, 2016)

1.4 MAIN CROPS & HARVESTING TECHNIQUES

In order to successfully develop a machine that can harvest vertically grown crops it is important to understand what kinds of plants are suitable to grow indoors, their growing process and the harvesting techniques. This chapter contains a list of plants that can be grown in vertical farms along with their harvesting techniques.

MAIN CROPS GROWN IN VERTICAL FARMS

The main crops that are usually grown in vertical farms are leafy greens, microgreens, herbs, flowers and tomatoes. As it was seen in the previous chapter, when vertical farms start to be profitable, the crops with the highest margins are leafy greens and microgreens. Therefore, this paper will focus on the automation of these crops. Among leafy greens lettuce is the most popular due to the high demand, facility to grow and fast growing cycles. Arugula is also an interesting leafy green as it is considered a premium product with high market prices. In terms of herbs, basil is quite popular on the market and also has premium market prices. Hence, these three crops (lettuce, arugula & basil) will be the main focus in this research as they have high potential and are attractive products for the farmers. As it will be seen further along this chapter,

basil and arugula have a complicated harvesting process during their growing life. This is a challenge for the design of a precision tool that can harvest the leaves at an affordable price for the farmers.

HARVESTING TECHNIQUES

The first plant that will be explained is lettuce. Lettuce usually takes around 45 to 55 days to mature. However, when grown in a vertical farm this time is reduced considerably to about 20 days. The harvesting method is quite simple, as the plant is removed completely at the end of the ground cycle and replaced by a new one. The fully-grown plant gets its roots removed and is ready to be sold. Therefore, the automation technology necessary to harvest lettuce won't be complicated.

When it comes to arugula and basil things get more complicated. This is due to the fact that the same plant will be harvested several times during their growing cycle. Both plants have some of their leaves harvested selectively when they grow in full size, allowing for the smaller leaves to continue growing. This will add a level of precision to the harvesting machine that is not necessary when it comes to harvesting lettuce. Therefore, the automation solution will come at a higher expense. However, as these are premium crops, the difference in cost might be worth it.

Arugula takes around 60 days until it reaches maturity. After this time, leaves are no longer as tasteful. The harvesting takes place before these 60 days. After four weeks, the plant can start to be harvested. These times are lower in vertical farms, as the conditions are ideal. The harvesting is done, one specific leaf at a time, to let the others grow fully. The leaves that can be harvested in an arugula plant are the outer leaves. The inside of the plant contains the smaller leaves that will continue to grow when the outer leaves are removed. The complication with this

harvesting technique is that the machine will have to distinguish between the outer, fully-grown leaves between the inner ones that must not be harvested yet. Therefore, this machine will have to have some kind of vision system that can recognize when the plant is ready to be harvested and which leaves to remove. Plus, an end-of-arm tool that can cut these leaves precisely. All these technologies will come at an additional cost. In the next figure, a diagram can be found that shows the structure of arugula when the outer leaves are ready to be harvested.

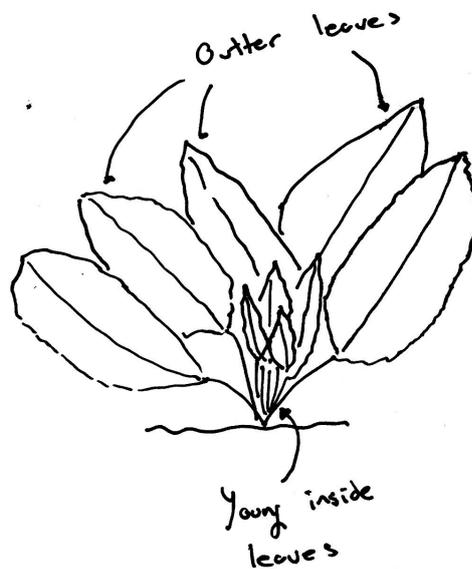


Figure 16. Arugula harvesting

When it comes to basil, the complications are similar as the ones that come with arugula, as the level of precision needed is similar. Again, the whole plant is not harvested at once but it rather involves cutting certain leaves at a certain stage of growth of the plant. Basil grows in separate stems that contain the leaves and the flower on top of the stems. When they are ready to harvest, the stem must be cut above the lowest leaf pair, allowing for the optimal future growth of the plant. In the next figure, a diagram of the plant is shown to explain this in more detail. Similarly to arugula, the machine needed will need vision to recognize the structure of the plant and decide where to cut.

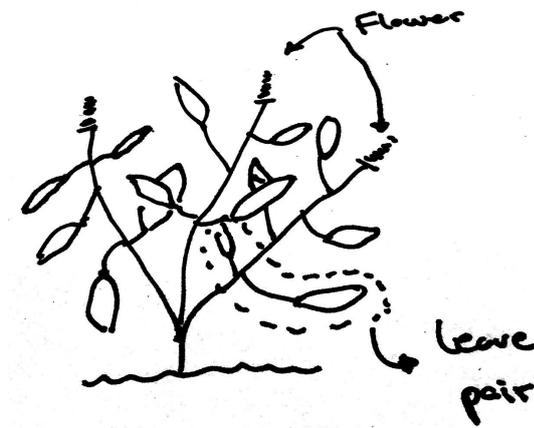


Figure 17. Basil harvesting

To summarize the amount of precision that the machine will need to have, there are two clear levels. The first one needed to harvest lettuce, which will be purely mechanical; and the second, more elaborated level, involves a more complicated vision system to decide when and where to cut. The next table reviews the technologies that will be put together to automate the harvesting process of these crops.

CHAPTER 2

SOLUTION DESIGNS

This chapter will show the automation designs that will be used to harvest the crops that have been explained in the previous chapter. A state of the art analysis will be performed to describe the current technologies that are available in the market. After that the proposed solutions will be explained in detail. These are structured from simple to more complex and expensive.

The first machines that are presented serve as an adaptation to vertical farms that are already built, while the last one involves remodeling the whole plant to achieve the maximum degree of space optimization.

When discussing the machines, they will be classified according to the adaptability to an existing farm, the space available for planting and the degree of precision of the robot.

2.1 STATE OF THE ART

In this section, some of the current automation technologies that inspired the solutions described further along this paper will be explained. There are other companies that have similar performances as the ones described below.

IRON OX

The first company is Iron Ox and is based in the San Francisco bay area. They offer a fully automated product that controls all the growing process, from planting to harvesting. They sell the whole hydroponics system along with the harvesting robot. This harvesting robot moves around picking grown plants and planting new ones. However, there are several disadvantages with this technology. To start with, an existing plant will can't use their own hydroponic system. They will have to adapt completely and buy all the new equipment from Iron Ox. Next, this is

thought for just one level of production. This takes away the benefits of vertical farming, where you can stack your production in several heights to increase the growing area. Furthermore, it doesn't have the ability to harvest individual leaves, but just the whole plant. Therefore it only serves for lettuce. Premium crops like basil or arugula can't be harvested using this product. It is a good product but needs much development to be able to adapt to large-scale vertical farms.



Figure 18. Iron Ox robot (IRON OX, n.d.)

AGROBOT

Agrobot is a very interesting company that sells robots whose task is harvesting strawberries. It uses artificial intelligence to recognize the fruits that are ready to harvest. Then it grabs and cuts the stem along with the fruit. This robot shows that there is technology available to create a 3D image of the plant and precisely cut in a desired spot. This will be quite useful when designing a machine that can harvest basil and arugula. However, AGROBOT is designed to cut strawberries in one level only so it can't be used in a vertical farm.

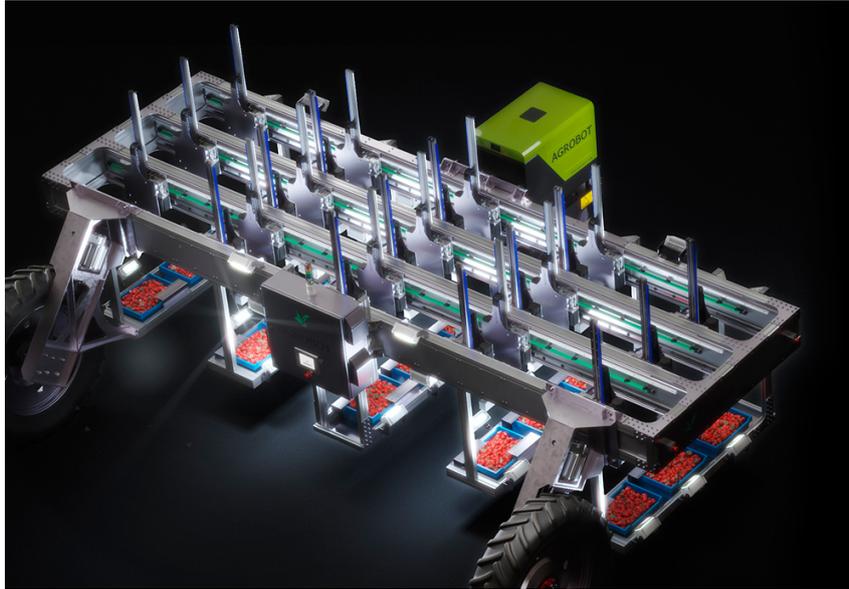


Figure 19. Agrobot robot (AGROBOT, n.d.)

VISCON HYDROPONICS

This company has created a product that simplifies the planting and harvesting process so that it can all be done in one place. It is based on a system where the plants are planted in a tray. This tray is then placed on a giant pool where the trays move along until they reach the end ready to be harvested. Therefore, the youngest plants can be found at the beginning and the oldest at the farthest end of the pool. This is a very smart idea because it maximizes the space available for growing crops, as there is no space at all between trays. However, it only serves for one-time harvests like lettuce, it is designed for only one level of plants and the harvesting is done manually. Then, this technology maximizes the space but could be more beneficial if it was applied to multiple levels of racks stacked on top of each other and they were to automate the harvesting in planting, reducing labor costs to a minimum.



Figure 20. Viscon hydroponics (Viscon Hydroponics, n.d.)

2.2 LIFT-TYPE ROBOT

DESCRIPTION AND FUNCTIONING

This robot looks like a lift truck with a robotic arm attached at the top of it. The robot also has a basket where it places the harvested plants and another compartment that contains new plants that are ready to be planted. The robot is a regular industrial-type robotic arm with a special end-of-arm tool and a camera that allows for the robot to distinguish which plants are ready to be harvested and plant new ones when needed as well.

The end-of-arm tool is a combination between a gripper and a scissor. It has two actuators that allow it to cut specific leaves with great precision. One actuator controls the gripper, which holds the stem of the leaf while the other actuator, the scissor, cuts it. Then, the harvested leaf is moved to the basket and dropped there.

If the whole plant was removed, there will be a new spot available for planting. In this situation, the robotic arm will reach to the basket where it has new plants. It will pick one with the gripper thanks to the artificial vision from the camera and place it in the new planting spot.

This robot is designed to move around the farm. It can adapt to the existing layout of any farm as long as the reach of the robotic arm is bigger than the depth of the racks that contain the plants. In other words, it is valid for the farm if the robot can reach all the plants.

A specific installation will have to be done so that the robot can adapt to the layout of each farm. This involves designing a specific circuit for the robot to move along plus the number of rows the farm has for planting and the height of each of these rows.

This robot will decrease the amount of labor needed for planting and harvesting, which accounts for most of the labor costs. However, it will not increase the space available for planting. It is designed to minimize the installation costs and allow the farm to keep its current configuration and layout of the farm. The labor that is still necessary regarding planting and harvesting is for someone to pick up the harvests from the basket and introduce in the other basket the plants that are ready for planting. There will also be someone in charge of supervising the correct functioning of the robot and provide solutions if some problem comes up.

The robot will move through the farm with some sensors that will allow it to know its location at all times and where to go. As to the functioning of the camera, it will allow the robot to know the exact place where to cut, with a similar technology used by Agrobot. It will recreate a 3D image of the plant that can distinguish between sizes and colors. This, added to the farm's database that contains all the data of when everything was planted, will allow the robot to judge which leaves are ready to be harvested and what type of plant should be planted next.

The farm will be divided by sections so that the plants are organized by date of planting and harvesting. The robot will have the capacity of deciding what to plant and where to plant it so that its movements around the farm are minimized. Therefore, each time the robot goes on to the field it will only have to focus on a certain area of the farm, maximizing its efficiency. These

decisions will also be based on the current demand of crops that the farm is receiving, so that the products cultivated correspond to what the farm is going to sell during the next periods.



Figure 21. Agrobot's intelligent vision (AGROBOT, n.d.)

DRAWINGS & DIAGRAMS

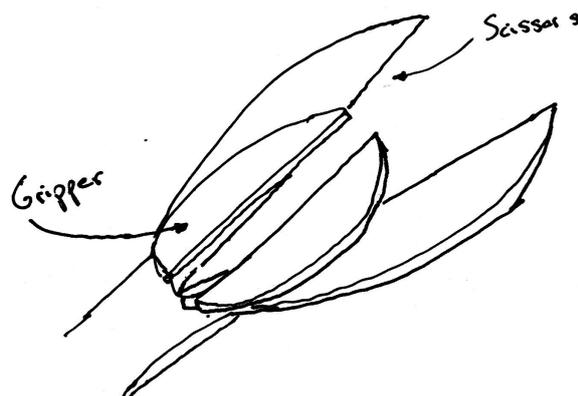


Figure 22. EOAT diagram

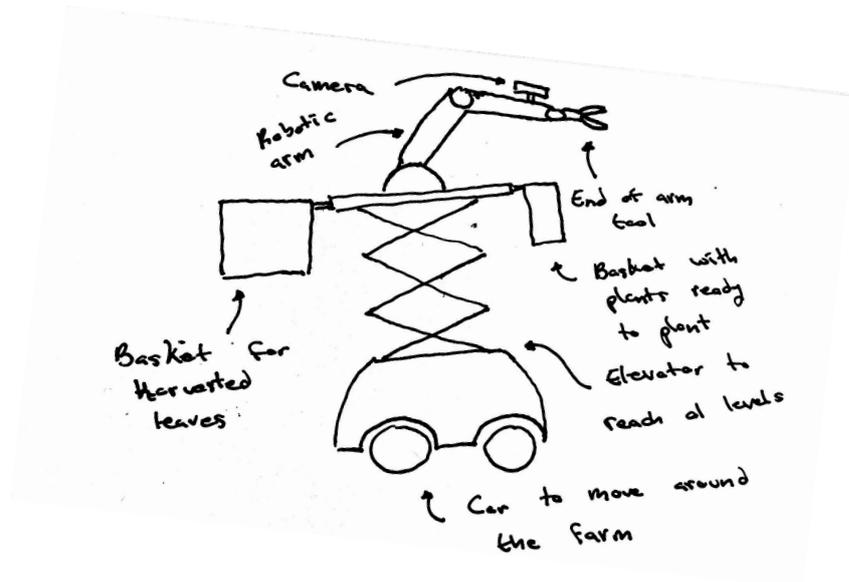


Figure 23. Lift-type robot diagram

COMPONENTS AND ESTIMATED COSTS

These are the estimated bare costs of each of the components that make up this robot. Additional markup costs will have to be added for the company that will sell this machine to the farm plus the installation and maintenance costs.

1. End-of-arm tool: \$5,000
2. Camera: \$20,000
3. Robotic arm: \$100,000
4. Adapted lift-truck: \$50,000
5. Software: \$30,000
6. Location and moving system for the lift-truck: \$10,000

2.3 RAIL-MOVING ROBOT

This one is designed to reduce space between racks of plants. It requires a higher degree of adaptation than the lift-type robot. Some rails are installed along the rows of plants. A robot moves along these rails, being able to access any row of the farm.

The robot is similar to the one presented in the previous chapter. However, the channel that is used for the robot to move along the farm is now the rails that are installed above the plants. The robot has the same end-of-arm tool as the one described before, with the scissor and the gripper as actuators.

As there is no need for humans to walk between the racks of plants they can be placed next to each other, increasing the space available for planting. However, this obliges the farm to change its current layout so that the new racks are installed, increasing investment costs.

The railing system creates a network that allows the robot to reach any area of the farm at anytime given. When it reaches an area that needs to be harvested it uses the gripper and scissor to cut the leaves at the desired spot, similarly to the lift-type robot. The harvested leaves are placed in a conduit that is installed between the racks. This conduit is tilted and has water flowing through it. This way, the harvested leaves are moved to a certain area, where the workers can pick them up.

As to the plants to be planted, they will be found in a tray at the end of each rack. This tray will be placed by a worker at demand of the robot. Therefore, once there is an empty spot available for a new plant to be planted, the robot will issue a signal so that the worker takes the tray with the desired crop mix to a specific area of the farm.

The idea for this solution is to sell it in blocks so that the farm can expand when needed. The parts that will be sold to the vertical farm will be: the robot, the rails, the racks and the conduits. There are three types of rails: straight-line, curves (in order to move from one rack to another) and tilted (to move from one level to another).

The robot starts at the end of one rack. It moves along the rails to the end of that rack, where the curved rails are located. After passing through the curve it arrives to a new rack. It

harvests this section until it finds another curve. It continues until it arrives to the end of that level, where the tilted rails are installed, which allows the robot to move onto the next layer of plants. This makes a closed loop that allows the robot to reach easily any area of crops in the farm.

DRAWINGS AND DIAGRAMS

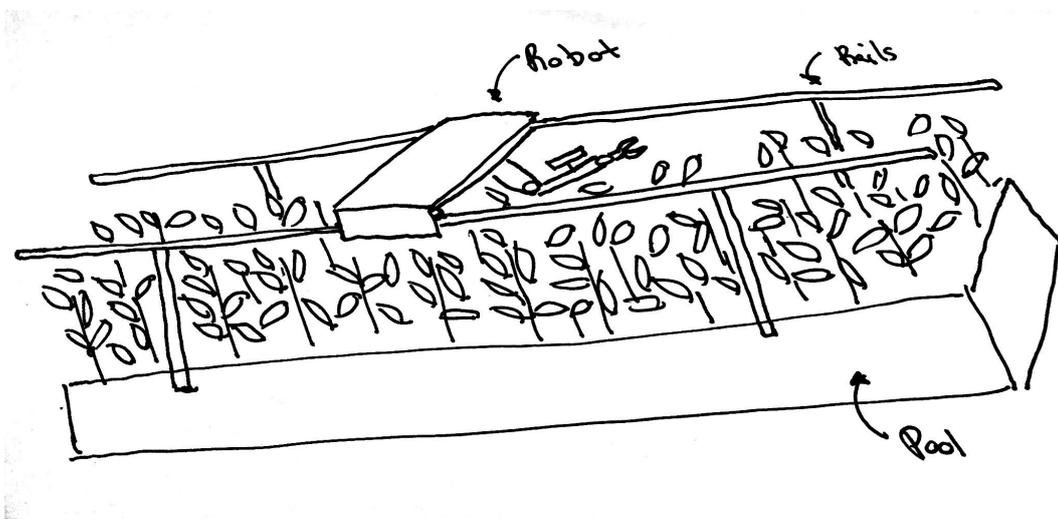


Figure 24. Rail-moving robot diagram

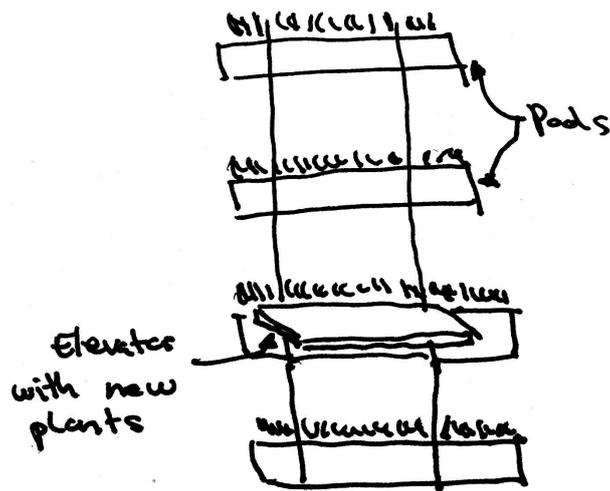


Figure 25. Rail-moving robot elevators

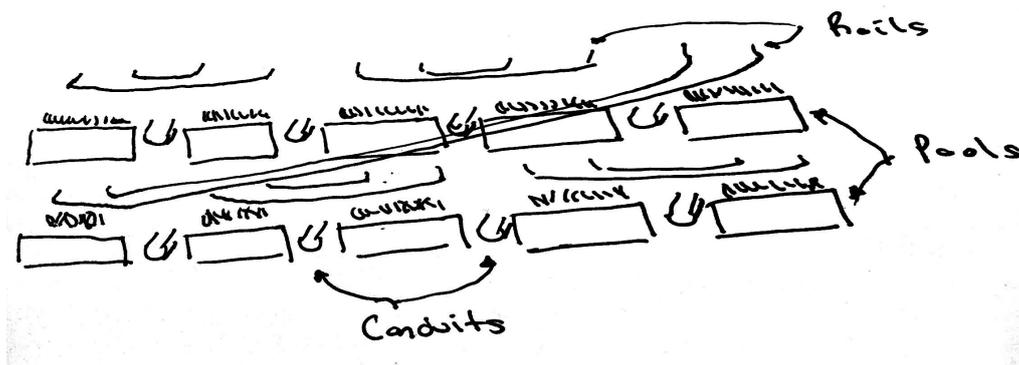


Figure 26. Railing system

COMPONENTS AND ESTIMATED COSTS

These are the estimated bare costs of each of the components that make up this robot. Additional markup costs will have to be added for the company that will sell this machine to the farm plus the installation and maintenance costs.

1. Robotic arm and mount: \$150,000
2. End-of-arm tool: \$5,000
3. Camera: \$20,000
4. Railing system: \$2/SF
5. Special racks, trays and conduits: \$4/SF
6. Tray system for the worker to send the new plants to the robot: \$5,000
7. Software: \$30,000

2.4 WHOLE FARM AUTOMATION

This idea is based on the design by Viscon Hydroponics but applied to various levels. There will be several giant pools on top of each other with a closed loop system among which the trays move around from the beginning of the process, where the crops are planted, to the end, when the plants are harvested. It is designed to maximize the space available for planting. In this

case the space that can be used to plant is greatly increased. The vertical space between pools can be reduced to a minimum and there is no need for human interaction with the growing area.

There are two elevators. The first one will take the newly planted trays to a pool at any level. The second elevator takes the ready-to-harvest trays down to the harvesting machine. The trays of plants move through the pools thanks to some robots that take into account the time left for harvesting so that they are ordered by time-to-harvest, being closer to the end of the harvesting elevator the trays that will have to be harvested sooner.

The elevator takes the trays of plants that are going to be harvested to a system of conveyor belts. The first place that the tray goes through is the harvesting machine. Here, the whole plant is removed (in the case of lettuce) or the necessary leaves are cut (in the case of basil and arugula) and the plant continues to the growing area. In any case, the tray continues its path through the conveyor belt. It passes through a machine that cleans the trays and then arrives to the planting machine, where new plants are planted in the case that the previous plants were removed. Then it goes to the other elevator, which places the tray back again in the pools and order again by the time left to harvest.

This will require the farm to invest a lot of money in the installation of all the equipment but it will allow it to maximize its growing area, increasing their production yield to a maximum. The workers needed, in terms of planting and harvesting, will have to place the ready-to-plant crops in the planting machine and recollect the harvests from the harvesting machine. There will also be a person in charge of supervising the correct functioning of the whole process and fixing the machines when something is not working correctly.

DRAWINGS AND DIAGRAMS

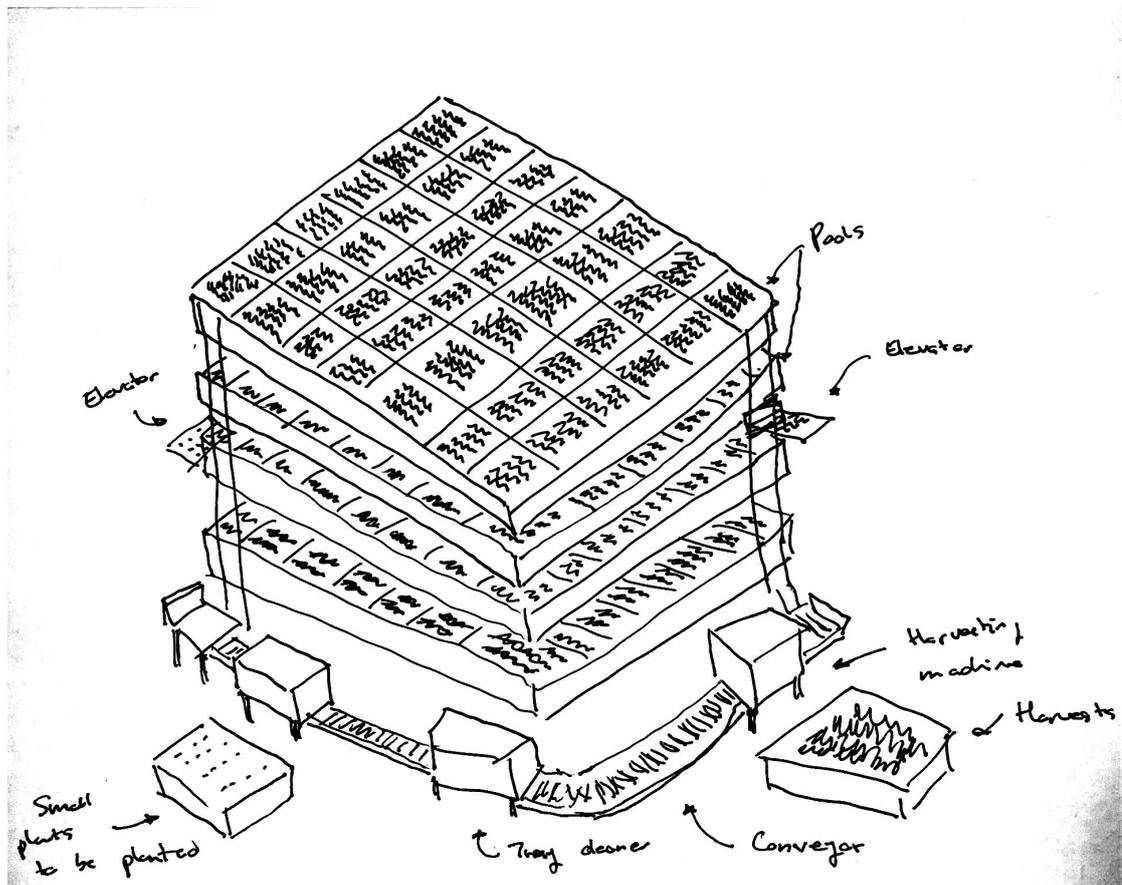


Figure 27. Whole automation diagram

COMPONENTS AND ESTIMATED COSTS

These are the estimated bare costs of each of the components that make up this robot. Additional markup costs will have to be added for the company that will sell this machine to the farm plus the installation and maintenance costs.

1. Harvesting machine: \$125,000
2. Planting machine: \$125,000
3. Harvesting elevator: \$40,000
4. Planting elevator: \$40,000

5. Tray-cleaning machine: \$5,000
6. Pools: \$5/SF
7. Conveyor belts: \$300/FT
8. Software: \$30,000

2.5 ROBOT COMPARISON AND PERFORMANCE

In this chapter, it will be analyzed how each robot contributes to the decrease in labor and how they can increase crop yield. In order to do this a set number of average workers will be defined for a regular farm, as well as the average utilization rate in terms of square feet for planting crops.

AVERAGE FARM NUMBER OF WORKERS

From the Agrilyst report it can be found that the average number of workers varies on the size of the farm. For a big farm (>10,000 sqft) there are 14 part time workers and 37 full time. As to smaller farms (<10,000 sqft) there are 2 part time workers and 3 full time.

AVERAGE FARM UTILIZASITION RATE

For the purpose of this exercise it will be assumed that an average farm only uses a 50% of the potential space that can be used for planting. The rest of the space is wasted for the farmers to walk around the farm and machinery, being able to access the plants for harvesting and planting. This figure has been estimated by professor Blake Davis.

INCREASE IN LABOR EFFICIENCY

To assess how much labor costs can be cut down it has to be determined what part of the labor force accounts for the harvesting and planting process. In all cases it will be assumed that only 3 workers are needed in this process. Two of them will harvest and plant while the other one will be specialized in running the robots and making sure everything works correctly.

It is assumed that around 35% of the labor force can be cut down in the case of installing the three robots. This figure has also been estimated by professor Blake Davis.

INCREASE IN UTILIZATION RATE

As it has been explained before, it will be assumed that the average farm only uses 50% of the available area for harvesting.

The first machine (lift-type robot) won't increase utilization rate, as the farm will keep its original layout. In the case of the rail-moving robot, the utilization rate will be increased to an 80%, while the last solution (whole farm automation) will increase the utilization rate to a 95%.

ROBOT SUMMARY AND COMPARISON

Table 1. Machine costs, utilization rate & labor costs

	Machine costs		Utilization rate	Labor costs
	Fixed costs (\$)	Variable costs (\$/SF)		
Average farm	-	-	50%	100%
Lift-type robot	215,000	-	50%	65%
Rail-moving robot	210,000	6	80%	65%
Whole farm automation	325,000	22	95%	65%

These costs only account for the sum of the cost of each part of the machines. An additional cost will have to be added when analyzing the viability of the products for the farms. These additional costs include installation costs, markup for the company that sells the product and additional maintenance costs. All these costs will be discussed in the next chapter.

CHAPTER 3

COST ANALYSIS

This section is dedicated to analyzing in depth the potential benefits of adding the proposed solutions to a real vertical farm. First, it will be necessary to estimate the operating expenses of a vertical farm and calculate the Net Present Value (NPV) of the investment in each of the harvesting automation tools described above. This vertical farm will be based on the data provided by the Agrilyst. Therefore, all the costs and taxes will be based on the USA, 2017.

Each analysis will be performed for a 10 year forecast period. First, the balance sheet of the average vertical farm will be estimated. Then, it will be seen if it would be beneficial for the farm to invest in any of the technologies proposed.

The crops grown in this farm will be leafy greens and microgreens. As it has already been seen before, they both have similar margins when profitable (around 40%). The vertical farm analyzed will be vertical hydroponics, as it the least profitable right now.

3.1 RELEVANT DATA AND ASSUMPTIONS

In order to carry out this study, some figures need to be estimated such as revenues and costs of an average vertical farm.

The first important number that has to be determined is the cost of the inversion. This number is determined as the costs of each of the components described in previous chapters multiplied by two to account for the installation expenses and the markup for the company that will sell and install these machines.

The revenues will be presented in dollars per square foot. The figure that will be used here is \$41.16 per square foot. This is obtained from the Agrilyst report and accounts for the average profit of vertical farms.

The costs will also be presented in costs per square foot. In this case, the average operational expenses per square foot in profitable vertical farms are \$37.1. As this figure only takes into account the profitable farms, an additional 10% has been added to include the rest of the farms that are not included here. Hence, the total operating expenses figure that will be used is 40.81%.

The revenues will increase proportionally with the rise of the utilization rate of the farm due to the improvements of the investment, as well as the operational expenses. There will also be an estimated \$20,000 annually added for maintenance. This value will be the same for all the machines.

As to the distribution of these costs, 56% comes from labor, 6% are shipping costs, 11% represents the input (seeds, nutrients and growing media) and the rest is 27% (rent, packaging and energy). All these figures have also been obtained from the Agrilyst report.

It will also be necessary to estimate an inflation rate (2%), an interest rate (2.5%) and taxes (21%). These figures have been obtained respectively from Statista, Global Rates and Tax Foundation.

Another data that is quite relevant as well to obtain the NPV will be the expected rate of return. This is the rate that the vertical farms would obtain from investing their money somewhere else. There is not much information about this value so it will be estimated at a value of 30%, as it is a high-risk investment.

Benjamin Eliot, founder and CEO of Metropolitan farms, provided with an interesting value when asked about investment in automation. He stated that they would consider investing in technologies if the payback time was smaller than 3 years. Therefore, this value will be

considered as a reference when studying small vertical farms. For medium farms this time will be assumed to be 5 years and 7 years for big vertical farms.

As to the budget, from the Agrilyst report, small farms have \$7.68 per square foot and big farms have \$9.34 per square foot. For medium farms the value estimated will be in between these two values: \$8.51 per square foot.

Machinery straight-line depreciation will also be introduced in this exercise with a 10-year period.

3.2 FINANCIAL STUDY DETAILS

In order to get the clearest possible vision of the impact of introducing automation in the harvesting and planting process several scenarios will be studied. There will be three average farm sizes: small (5,000SF), medium (40,000SF) and large (100,000SF), with their average income statement based on the data provided in the previous section. Then there will be an analysis of the possible benefits for each farm when investing in the three automation solutions. The best possible solution for each farm, if any, will be determined with the IRR, NPV and payback time.

Once all the solutions have been studied for all the farms a conclusion will be obtained with graphs to explain clearly how much each farm can benefit from automating their operations.

EXPLANATION OF THE CALCULATIONS

The model that has been used for assessing the investment takes into account revenues, operating expenses, depreciation, taxes, inflation, loans and interest rates. The time horizon for these investments will be of 10 years.

A CAPEX spreadsheet has been created based on a tool provided by the finance professor Cristobal Cantos. The outputs of this spreadsheet are NPV, IRR and payback time. The inputs

that are introduced are the previously mentioned variables: the cost of the investment, revenues, operating expenses, depreciation, taxes, inflation, interest rates and amount of borrowed money in the form of loans.

The investment introduced is the raw figure of the costs for the new machinery. The revenues are the increase in revenues due to the increase in production capability. And the costs are the increment in costs due to decrease in labor and increase in other related machinery expenses.

Once all these data are introduced the final figures are obtained in terms of NPV, IRR and payback time, which will then be assessed to determine whether it is profitable for the farm to invest in these technologies and quantify the benefits of these additions. All the data from these spreadsheets can be found in the appendixes.

3.3 RESULTS

AVERAGE VERTICAL FARM INCOME STATEMENT

In the next tables we can find the average revenues and costs for the three vertical farms that will be analyzed. These three farms are based on the data that has been previously described in this chapter. The three farms vary in size: small (5,000SF), medium (40,000SF) and large (100,000SF).

Table 2. Small average farm

Size	5,000
Revenues	205,800
COGS	67,337
Fixed costs	136,714
EBITDA	1,750
Taxes	437.5
NOPAT	1,312
Margin	1%

Table 3. Medium average farm

Size	40,000
Revenues	1,646,400
COGS	538,692
Fixed costs	1,093,708
EBITDA	14,000
Taxes	3500
NOPAT	10,500
Margin	1%

Table 4. Large average farm

Size	100,000
Revenues	4,116,000
COGS	1,346,730
Fixed costs	2,734,270
EBITDA	35,000
Taxes	8750
NOPAT	26,250
Margin	1%

The margin for all the farms is 1%, as the only difference is in size. The revenues and costs are proportional to the size of the farm.

LIFT-TYPE ROBOT

The benefits of adding the lift-type robot to these farms will be analyzed in this section. The results can be found in the next tables. The CAPEX table analysis for each farm can be found in the appendix.

Table 5. Small farm with lift-type robot

Size	5,000
Investment	430,000
Capacity increase	0%
Labor decrease	35%
Revenues	205,800
COGS	67,337
Fixed costs	96,720
EBITDA	41,744
Taxes	8,766
NOPAT	32,978
Margin	16%
IRR	0%
NPV	-309,905
Payback time	9.9

Table 6. Medium farm with lift-type robot

Size	40,000
Investment	860,000
Capacity increase	0%
Labor decrease	35%
Revenues	1,646,400
COGS	538,692
Fixed costs	773,758
EBITDA	333,950
Taxes	70,130
NOPAT	263,821
Margin	16%
IRR	30%
NPV	-2,638
Payback time	3.2

Table 7. Large farm with lift-type robot

Size	100,000
Investment	1,720,000
Capacity increase	0%
Labor decrease	35%
Revenues	4,116,000
COGS	1,346,730
Fixed costs	1,934,394
EBITDA	834,876
Taxes	175,324
NOPAT	659,552
Margin	16%
IRR	38%
NPV	406,173
Payback time	2.6

For the medium farm the investment is twice as big because the farm will need two robots. For the big farm four robots are necessary so the investment is four times as big.

RAIL-MOVING ROBOT

The benefits of adding the rail-moving robot to these farms will be analyzed in this section. The results can be found in the next tables. The CAPEX table analysis for each farm can be found in the appendix.

Table 8. Small farm with rail-moving robot

Size	5,000
Investment	480,000
Capacity increase	160%
Labor decrease	35%
Revenues	535,080
COGS	175,075
Fixed costs	251,471
EBITDA	108,534
Taxes	22,792
NOPAT	85,742
Margin	16%
IRR	16%
NPV	-186,120
Payback time	5.2

Table 9. Medium farm with rail-moving robot

Size	40,000
Investment	1,800,000
Capacity increase	160%
Labor decrease	35%
Revenues	4,280,640
COGS	1,400,599
Fixed costs	2,011,770
EBITDA	868,271
Taxes	182,337
NOPAT	685,934
Margin	16%
IRR	39%
NPV	469,280
Payback time	2.6

Table 10. Large farm with rail-moving robot

Size	100,000
Investment	4,860,000
Capacity increase	160%
Labor decrease	35%
Revenues	10,701,600
COGS	3,501,498
Fixed costs	5,029,424
EBITDA	2,170,678
Taxes	455,842
NOPAT	1,714,835
Margin	16%
IRR	36%
NPV	827,629
Payback time	2.7

For the medium farm the amount of robots is 2, so the investment is double. For the large farm there will be 3 robots installed, so the installation costs are triple.

WHOLE FARM AUTOMATION

The benefits of adding this robot to these farms will be analyzed in this section. The results can be found in the next tables. The CAPEX table analysis for each farm can be found in the appendix.

Table 11. Small farm with whole automation

Size	5,000
Investment	870,000
Capacity increase	190%
Labor decrease	35%
Revenues	596,820
COGS	195,276
Fixed costs	280,487
EBITDA	121,057
Taxes	25,422
NOPAT	95,635
Margin	16%
IRR	6%
NPV	-528,281
Payback time	7.9

Table 12. Medium farm with whole automation

Size	40,000
Investment	2,410,000
Capacity increase	190%
Labor decrease	35%
Revenues	4,774,560
COGS	1,562,207
Fixed costs	2,243,897
EBITDA	968,456
Taxes	203,376
NOPAT	765,080
Margin	16%
IRR	32%
NPV	141,399
Payback time	3.0

Table 13. Large farm with whole automation

Size	100,000
Investment	5,050,000
Capacity increase	190%
Labor decrease	35%
Revenues	11,936,400
COGS	3,905,517
Fixed costs	5,609,743
EBITDA	2,421,140
Taxes	508,439
NOPAT	1,912,701
Margin	16%
IRR	39%
NPV	1,289,421
Payback time	2.6

BREAK-EVEN ANALYSIS

An additional study has been carried out to define the minimum size a farm needs have in order to invest in automation. As the lift-type robot has been proved as an unprofitable investment, only the other two robots will be assessed.

Table 14. Minimum size to invest in the Rail-moving robot

Size	25,285
Investment	1,446,830
Capacity increase	160%
Labor decrease	35%
Revenues	2,705,855
COGS	885,339
Fixed costs	1,271,669
EBITDA	548,847
Taxes	115,258
NOPAT	433,589
Margin	16%
IRR	30%
NPV	0
Payback time	3.2

Table 15. Minimum size to invest in Whole farm automation

Size	32,610
Investment	2,084,839
Capacity increase	190%
Labor decrease	35%
Revenues	3,892,457
COGS	1,273,588
Fixed costs	1,829,336
EBITDA	789,533
Taxes	165,802
NOPAT	623,731
Margin	16%
IRR	30%
NPV	0
Payback time	3.2

From these tables, it can be concluded that a farm will need a minimum size of 25,000 SF in order to make profit out of an investment in automation.

3.4 CONCLUSIONS

As this business is quite new and there are no large public companies that have similar operations, it is quite difficult to obtain reliable data on the finance structure of vertical farms. This report is mainly based on the data provided by Agrilist to estimate revenues and operating expenses. As to the costs of automating the facilities, they are based on approximate prices of how much the machinery would cost plus installation expenses.

Most of the numbers have been over-dimensioned to account for unexpected costs and try to face the worst-case scenario. Nonetheless, it has been seen that vertical farms can make a great profit out of automating their operations, with great IRRs and increase in profit margin.

In the next figure there is a summary for all the cases that have been studied. The ones that have a positive Net Present Value have been highlighted.

Table 16. Investment summary by farm size and robot type

Farm size	Automation type	Investment (\$)	IRR	NPV (\$)	Payback time (Years)
Small	Lift-type	430,000	0%	-309,905	9.9
	Rail-moving	480,000	16%	-186,120	5.2
	Whole automation	870,000	6%	-528,281	7.9
Medium	Lift-type	860,000	30%	-2,638	3.2
	Rail-moving	1,800,000	39%	468,280	2.6
	Whole automation	2,410,000	32%	141,399	3.0
Large	Lift-type	1,720,000	38%	406,173	2.6
	Rail-moving	4,860,000	36%	827,629	2.7
	Whole automation	5,050,000	39%	1,289,421	2.6

From this table, there are several things that can be concluded. First, there certainly is benefit in adding these machines for farms with a noticeable size. Small farms won't be benefited from introducing any of the solutions suggested, or at least with these prices. Medium farms will obtain a return on the investment when investing in the rail-moving robot or the whole farm automation. The three robots can be beneficial for large farms.

Therefore, from this study it can be concluded that it is not worth developing the lift-type robot but the other two solutions can be very interesting for both medium and large farms. This investment starts to make sense when the farm is bigger than 25,000 SF.

CHAPTER 4

CONCLUSIONS AND FUTURE WORK

CONCLUSIONS

Vertical farming is a relatively new technique of growing crops that has several advantages when compared to traditional farming. Plants are growing in a medium that contains all the necessary minerals for them to grow healthy. Therefore, no soil is needed and water usage is reduced greatly. This farming method knows no seasonality, as all the conditions are controlled indoors and plants are not exposed to extreme weather conditions and pests. Thus, vertical farming is a method that involves growing plants indoors, faster and using space more productively than traditional farms.

However, most vertical farms are not taking advantage of their full potential because they are being held back by cost limitations. These cost limitations are associated with human capital needed to harvest the plants, which also takes up a lot of farmable space in order for them to walk around the premises and be able to access all the plants.

These cost limitations are also preventing farms from growing the most profitable crops, such as basil or arugula, due to the fact that they require extensive and detailed human care in order to be harvested correctly.

However, the situation of these farms could be greatly improved if automation was to be introduced to the harvesting and planting processes. More than 50% of the operating expenses of indoor farms are related with labor costs, reaching up to 80% in some cases. Automation would help reduce these costs by 35% and increase the utilization capability of the farms greatly, which is currently limited to around a 50% due to the amount of space wasted for workers to move around the farm.

Some automation solutions have been proposed in this project to assess this problem. After performing a financial analysis it has been concluded that farmers would be willing to invest great amounts of money to automate their operations. Any company that designs and sells these machines will have a blue ocean of vertical farmers around the world eager to buy these products to increase their margins.

However, not all farms are suitable for investing in automation. Small farms smaller than 25,000 SF will be better off by maintaining their current operations model or looking for other ways to increase their margins, as an investment in automation won't provide them with the desired returns.

Nonetheless, all the figures shown in this paper have been overestimated, as the information that can be found online is not very extensive and detailed with regard to this business. Therefore, it is very probable that the returns obtained by farms will be much higher than the ones concluded in this paper. When automation is introduced to vertical farms, they will be able to farm more complex harvests with higher margins without increasing labor costs. Also, the utilization capacity will be higher than the ones provided here, as the vertical reach will increase as well. It is also quite reasonable to think that the costs for the machines suggested would be lower than the ones that have been estimated for the purpose of this exercise.

Once vertical farms give this step forward and adapt automation to their operations, this business will have great profit margins. When this moment comes, there will be a massive increase in the number of vertical farms around the world and the business of agriculture will change forever.

FUTURE WORK

In order to make vertical farming a profitable business in the future there are still several things to be done when regarding automation.

First, a more in depth analysis has to be performed when more data is accessible to obtain a more accurate sense of the finances of vertical farms, followed by a similar investment analysis performed in this paper. This analysis will be based on the machine models suggested here and others proposed.

It will also be interesting to obtain a more accurate view on the costs of installing these machines, create a more detailed description of their functioning and characteristics so that prototypes can be designed and quantify the real harvesting potential of these solutions.

Finally, these prototypes will have to be introduced into the operations of an actual vertical farm to measure the real prospective of these machines and their effect in the market of vertical farming.

APPENDIX A

RELEVANT DATA (Agrilyst, 2017)

YIELD (lb/sf)	
Greenhouse hydroponics	
Leafy greens	8.71
Herbs	6.42
Vertical hydroponics	
Leafy greens	5.45

REVENUE - ALL (\$/sf)	Min	Avg	Max
Hydroponics	6.67	21.15	42.86
Aquaponics	5.2	53.89	100
Vertical	2.13	41.16	100

FINANCIALS - Only profitable (\$/sf)	Avg revenue	Av OpEx
Vertical & DWC	51.98	37.1
Hydroponics Leafy Grees	37	20
Leafy greens	37.74	23.91

MARGINS - Only profitable	
Leafy greens	40%
Microgreens	40%

COSTS	Labor	Shipping	Other	Input
Hydroponics	46%	2%	38%	10%
Aquaponics	79%	4%	11%	6%
Vertical	56%	6%	27%	11%

WORKERS	# Full time	# Part time
Large farms (>10sqft)	37	14
Small farms (<10sqft)	3	2

BUDGET (\$/sqft)	Min	Avg	Max
Large farms	0.005	9.34	83.33
Small farms	0.25	7.68	50

Investment:	860,000
Time Horizon:	10 years
Inflation:	2.0%
Increase in Revenue:	
Increase in COGS:	(319,950.00)
Increase in Fixed Costs:	(319,950.00)
Depreciation:	20 years
Salvage Value:	
Taxes:	21%
Selling Price:	
NPV: (2,637.51 €)	
IRR: 29.9%	
Payback: 3.21 years	

STEPS	Periods	0	1	2	3	4	5	6	7	8	9	10
1	Revenues		319,950.00	326,349.41	332,876.40	339,533.92	346,324.60	353,251.09	360,316.12	367,522.44	374,872.89	382,370.35
1	COGS		(319,950.00)	(326,349.41)	(332,876.40)	(339,533.92)	(346,324.60)	(353,251.09)	(360,316.12)	(367,522.44)	(374,872.89)	(382,370.35)
1	EBITDA		319,950.00	326,349.41	332,876.40	339,533.92	346,324.60	353,251.09	360,316.12	367,522.44	374,872.89	382,370.35
1	Depreciation		43,000.00	43,000.00	43,000.00	43,000.00	43,000.00	43,000.00	43,000.00	43,000.00	43,000.00	43,000.00
1	EBIT		276,950.00	283,349.41	289,876.40	296,533.92	303,324.60	310,251.09	317,316.12	324,522.44	331,872.89	339,370.35
1	Taxes		58,159.58	59,503.38	60,874.04	62,272.12	63,698.17	65,152.73	66,636.38	68,149.31	69,693.31	71,267.77
1	NO PAT		218,790.42	223,846.03	228,999.36	234,261.80	239,632.92	245,108.36	250,679.79	256,373.13	262,179.58	268,102.57
1	Book Value	860,000.00	817,000.00	774,000.00	731,000.00	688,000.00	645,000.00	602,000.00	559,000.00	516,000.00	473,000.00	430,000.00
2	CAPEX	(860,000.00)										
2	NCS	(860,000.00)										(90,300.00)
1	OCF		261,790.82	266,846.03	272,002.35	277,261.80	282,626.44	288,098.36	293,679.73	299,372.73	305,179.58	311,102.57
2	-NCS		(860,000.00)									90,300.00
3	-ANWVC		(860,000.00)	261,790.82	266,846.03	272,002.35	277,261.80	282,626.44	288,098.36	293,679.73	299,372.73	305,179.58
3	FCFFree Cash Flow		(860,000.00)	261,790.82	266,846.03	272,002.35	277,261.80	282,626.44	288,098.36	293,679.73	299,372.73	305,179.58
3	Wired Cash Flow		(860,000.00)	261,790.82	266,846.03	272,002.35	277,261.80	282,626.44	288,098.36	293,679.73	299,372.73	305,179.58
3	CFBA (Cash Flow from Assets)		(860,000.00)	261,790.82	266,846.03	272,002.35	277,261.80	282,626.44	288,098.36	293,679.73	299,372.73	305,179.58
3	Acc CFBA		(860,000.00)	(598,209.18)	(331,363.15)	(59,340.80)	217,891.00	590,527.44	788,625.80	1,082,205.53	1,381,678.26	1,686,987.84
3	Payback		1.00	1.00	1.00	0.21						

Investment:	1,720,000
Time Horizon:	10 years
Inflation:	2.0%
Increase in Revenue:	
Increase in COGS:	(799,876.00)
Increase in Fixed Costs:	(799,876.00)
Depreciation:	20 years
Salvage Value:	
Taxes:	21%
Selling Price:	
NPV: 406,172.83 €	
IRR: 32.3%	
Payback: 4.80 years	

STEPS	Periods	0	1	2	3	4	5	6	7	8	9	10
1	Revenues		799,876.00	815,873.52	832,190.99	848,834.81	865,811.51	883,127.74	900,790.29	918,806.10	937,182.22	955,925.86
1	COGS		(799,876.00)	(815,873.52)	(832,190.99)	(848,834.81)	(865,811.51)	(883,127.74)	(900,790.29)	(918,806.10)	(937,182.22)	(955,925.86)
1	Fixed Costs		799,876.00	815,873.52	832,190.99	848,834.81	865,811.51	883,127.74	900,790.29	918,806.10	937,182.22	955,925.86
1	EBITDA		799,876.00	815,873.52	832,190.99	848,834.81	865,811.51	883,127.74	900,790.29	918,806.10	937,182.22	955,925.86
1	Depreciation		86,000.00	86,000.00	86,000.00	86,000.00	86,000.00	86,000.00	86,000.00	86,000.00	86,000.00	86,000.00
1	EBIT		713,876.00	729,873.52	746,190.99	762,834.81	779,811.51	797,127.74	814,790.29	832,806.10	851,182.22	869,925.86
1	Taxes		149,913.96	153,273.44	156,700.11	160,195.31	163,760.42	167,396.82	171,105.96	174,889.28	178,748.27	182,684.43
1	NO PAT		563,962.04	576,600.08	589,490.88	602,639.50	616,051.09	629,730.91	643,684.33	657,916.82	672,433.95	687,241.43
1	Book Value	1,720,000.00	1,634,000.00	1,548,000.00	1,462,000.00	1,376,000.00	1,290,000.00	1,204,000.00	1,118,000.00	1,032,000.00	946,000.00	860,000.00
2	CAPEX	(1,720,000.00)										
2	NCS	(1,720,000.00)										(180,600.00)
1	OCF		649,962.04	662,900.08	675,490.88	688,639.50	702,051.09	715,730.91	729,684.33	743,916.82	758,433.95	773,241.43
2	-NCS		(1,720,000.00)									180,600.00
3	-ANWVC		(1,720,000.00)	649,962.04	662,900.08	675,490.88	688,639.50	702,051.09	715,730.91	729,684.33	743,916.82	758,433.95
3	FCFFree Cash Flow		(1,720,000.00)	649,962.04	662,900.08	675,490.88	688,639.50	702,051.09	715,730.91	729,684.33	743,916.82	758,433.95
3	Wired Cash Flow		(1,720,000.00)	649,962.04	662,900.08	675,490.88	688,639.50	702,051.09	715,730.91	729,684.33	743,916.82	758,433.95
3	CFBA (Cash Flow from Assets)		(1,720,000.00)	649,962.04	662,900.08	675,490.88	688,639.50	702,051.09	715,730.91	729,684.33	743,916.82	758,433.95
3	Acc CFBA		(1,720,000.00)	(1,070,037.96)	(410,737.88)	268,053.00	956,892.50	1,638,743.59	2,237,474.51	3,104,158.84	3,386,075.65	4,606,509.61
3	Payback		1.00	1.00	0.00							

APPENDIX C

RAIL-MOVING ROBOT CAPEX

- 1. 5,000 SF
- 2. 40,000 SF
- 3. 100,000 SF

STEPS	Periods	0	1	2	3	4	5	6	7	8	9	10
Investment: 480,000												
Time Horizon: 10 years												
Inflation: 2.0%												
Increase in Revenue: 329,280												
Increase in COGS: 107,738												
Increase in Fixed Costs: 114,758												
Depreciation: 20 years												
Savage Value:												
Taxes: 21%												
Selling Price:												
Book Value												
CAPEX												
Taxes:												
-NCS												
OCF												
-NCS												
-ΔNWC												
FCF (Free Cash Flow)												
Weighted Cash Flow												
FFA (Cash Flow from Assets)												
Acc. CAPEX												
Payback												

F: 30.0%
 NPV: (186,120.16 €)
 IRR: 14.9%
 Payback: 5.16 years

Investment: 1,800,000
Time Horizon: 10 Years

Inflation: 2.0%

Increase in Revenue: 2,634,240
Increase in COGS: 861,907
Increase in Fixed Costs: 318,062

Depreciation: 20 Years
Savage Value:
Taxes: 21%

Selling Price:

STEPS	Periods	0	1	2	3	4	5	6	7	8	9	10
1	Revenues	2,634,240.00	2,686,924.80	2,740,668.30	2,795,476.56	2,851,386.69	2,908,413.82	2,966,582.09	3,025,913.73	3,086,432.01	3,148,160.65	3,211,119.65
2	COGS	861,907.20	879,445.34	896,728.25	914,662.82	933,293.57	952,654.39	972,784.48	993,723.57	1,015,514.37	1,038,205.89	1,061,859.89
3	Fixed Costs	918,051.76	936,423.00	955,151.46	974,254.48	993,729.57	1,013,614.37	1,033,886.65	1,054,564.39	1,075,655.67	1,097,168.79	1,119,129.65
4	EBITDA	854,271.04	871,356.46	888,783.59	906,592.46	924,690.45	943,184.26	962,097.24	981,288.90	1,000,924.68	1,020,932.97	1,041,359.65
5	Depreciation	90,000.00	90,000.00	90,000.00	90,000.00	90,000.00	90,000.00	90,000.00	90,000.00	90,000.00	90,000.00	90,000.00
6	EBIT	764,271.04	781,356.46	798,783.59	816,592.46	834,690.45	853,184.26	872,097.24	891,288.90	910,924.68	930,932.97	951,359.65
7	Taxes	160,466.92	164,084.86	167,744.55	171,477.44	175,284.99	179,168.69	183,130.07	187,170.67	191,292.08	195,495.92	199,781.92
8	NOPAT	603,774.12	617,271.60	631,039.04	645,081.82	659,405.45	674,015.56	688,917.87	704,118.23	719,632.60	735,437.75	751,577.73
9	CAPEX	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)
10	NPV	(1,800,000.00)	1,210,039.04	1,560,000.00	1,850,000.00	2,090,000.00	2,290,000.00	2,450,000.00	2,580,000.00	2,680,000.00	2,750,000.00	2,790,000.00

Investment: 4,860,000
Time Horizon: 10 Years

Inflation: 2.0%

Increase in Revenue: 6,585,600
Increase in COGS: 2,154,768
Increase in Fixed Costs: 2,295,134

Depreciation: 20 Years
Savage Value:
Taxes: 21%

Selling Price:

STEPS	Periods	0	1	2	3	4	5	6	7	8	9	10
1	Revenues	6,585,600.00	6,717,312.00	6,851,658.24	6,988,651.40	7,128,465.23	7,271,034.54	7,416,455.23	7,564,784.33	7,716,089.02	7,870,401.62	8,027,779.65
2	COGS	2,154,768.00	2,197,087.36	2,241,820.63	2,288,657.26	2,337,028.64	2,387,035.93	2,438,596.21	2,491,348.93	2,545,110.96	2,600,139.18	2,656,482.22
3	Fixed Costs	2,295,134.00	2,341,067.49	2,387,878.64	2,435,596.21	2,484,348.93	2,534,035.91	2,584,116.63	2,635,110.96	2,687,139.18	2,740,248.69	2,794,392.43
4	EBITDA	2,135,697.60	2,179,391.15	2,224,958.98	2,272,407.93	2,321,051.66	2,370,000.00	2,419,348.93	2,469,110.96	2,519,312.25	2,570,000.00	2,621,222.25
5	Depreciation	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00
6	EBIT	1,892,697.60	1,936,391.15	1,979,958.98	2,023,398.15	2,068,726.12	2,114,960.64	2,162,119.85	2,210,222.25	2,259,286.69	2,309,338.43	2,360,432.43
7	Taxes	397,463.30	406,432.14	415,581.38	424,913.61	434,432.48	444,141.73	454,045.12	464,146.67	474,450.21	484,959.81	495,677.29
8	NOPIAT	1,495,234.30	1,529,959.01	1,564,377.60	1,599,484.54	1,634,293.64	1,668,818.51	1,703,073.49	1,737,071.52	1,770,821.42	1,804,371.62	1,837,754.92
9	CAPEX	(4,860,000.00)	(4,860,000.00)	(4,860,000.00)	(4,860,000.00)	(4,860,000.00)	(4,860,000.00)	(4,860,000.00)	(4,860,000.00)	(4,860,000.00)	(4,860,000.00)	(4,860,000.00)
10	NPV	(4,860,000.00)	4,637,800.00	4,571,000.00	4,131,000.00	3,898,000.00	3,645,000.00	3,400,000.00	3,159,000.00	2,916,000.00	2,673,000.00	2,430,000.00

Investment: 1,800,000 €
Time Horizon: 10 Years

Inflation: 2.0%

Increase in Revenue: 6,585,600
Increase in COGS: 2,154,768
Increase in Fixed Costs: 2,295,134

Depreciation: 20 Years
Savage Value:
Taxes: 21%

Selling Price:

STEPS	Periods	0	1	2	3	4	5	6	7	8	9	10
1	Revenues	6,585,600.00	6,717,312.00	6,851,658.24	6,988,651.40	7,128,465.23	7,271,034.54	7,416,455.23	7,564,784.33	7,716,089.02	7,870,401.62	8,027,779.65
2	COGS	2,154,768.00	2,197,087.36	2,241,820.63	2,288,657.26	2,337,028.64	2,387,035.93	2,438,596.21	2,491,348.93	2,545,110.96	2,600,139.18	2,656,482.22
3	Fixed Costs	2,295,134.00	2,341,067.49	2,387,878.64	2,435,596.21	2,484,348.93	2,534,035.91	2,584,116.63	2,635,110.96	2,687,139.18	2,740,248.69	2,794,392.43
4	EBITDA	2,135,697.60	2,179,391.15	2,224,958.98	2,272,407.93	2,321,051.66	2,370,000.00	2,419,348.93	2,469,110.96	2,519,312.25	2,570,000.00	2,621,222.25
5	Depreciation	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00
6	EBIT	1,892,697.60	1,936,391.15	1,979,958.98	2,023,398.15	2,068,726.12	2,114,960.64	2,162,119.85	2,210,222.25	2,259,286.69	2,309,338.43	2,360,432.43
7	Taxes	397,463.30	406,432.14	415,581.38	424,913.61	434,432.48	444,141.73	454,045.12	464,146.67	474,450.21	484,959.81	495,677.29
8	NOPIAT	1,495,234.30	1,529,959.01	1,564,377.60	1,599,484.54	1,634,293.64	1,668,818.51	1,703,073.49	1,737,071.52	1,770,821.42	1,804,371.62	1,837,754.92
9	CAPEX	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)
10	NPV	(1,800,000.00)	4,637,800.00	4,571,000.00	4,131,000.00	3,898,000.00	3,645,000.00	3,400,000.00	3,159,000.00	2,916,000.00	2,673,000.00	2,430,000.00

Investment: 1,800,000 €
Time Horizon: 10 Years

Inflation: 2.0%

Increase in Revenue: 6,585,600
Increase in COGS: 2,154,768
Increase in Fixed Costs: 2,295,134

Depreciation: 20 Years
Savage Value:
Taxes: 21%

Selling Price:

STEPS	Periods	0	1	2	3	4	5	6	7	8	9	10
1	Revenues	6,585,600.00	6,717,312.00	6,851,658.24	6,988,651.40	7,128,465.23	7,271,034.54	7,416,455.23	7,564,784.33	7,716,089.02	7,870,401.62	8,027,779.65
2	COGS	2,154,768.00	2,197,087.36	2,241,820.63	2,288,657.26	2,337,028.64	2,387,035.93	2,438,596.21	2,491,348.93	2,545,110.96	2,600,139.18	2,656,482.22
3	Fixed Costs	2,295,134.00	2,341,067.49	2,387,878.64	2,435,596.21	2,484,348.93	2,534,035.91	2,584,116.63	2,635,110.96	2,687,139.18	2,740,248.69	2,794,392.43
4	EBITDA	2,135,697.60	2,179,391.15	2,224,958.98	2,272,407.93	2,321,051.66	2,370,000.00	2,419,348.93	2,469,110.96	2,519,312.25	2,570,000.00	2,621,222.25
5	Depreciation	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00	243,000.00
6	EBIT	1,892,697.60	1,936,391.15	1,979,958.98	2,023,398.15	2,068,726.12	2,114,960.64	2,162,119.85	2,210,222.25	2,259,286.69	2,309,338.43	2,360,432.43
7	Taxes	397,463.30	406,432.14	415,581.38	424,913.61	434,432.48	444,141.73	454,045.12	464,146.67	474,450.21	484,959.81	495,677.29
8	NOPIAT	1,495,234.30	1,529,959.01	1,564,377.60	1,599,484.54	1,634,293.64	1,668,818.51	1,703,073.49	1,737,071.52	1,770,821.42	1,804,371.62	1,837,754.92
9	CAPEX	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)	(1,800,000.00)
10	NPV	(1,800,000.00)	4,637,800.00	4,571,000.00	4,131,000.00	3,898,000.00	3,645,000.00	3,400,000.00	3,159,000.00	2,916,000.00	2,673,000.00	2,430,000.00

APPENDIX D

WHOLE AUTOMATION CAPEX

- 1. 5,000 SF
- 2. 40,000 SF
- 3. 100,000 SF

STEPS	Periods	0	1	2	3	4	5	6	7	8	9	10																																																																																																																																															
Investment: \$70,000																																																																																																																																																											
Time Horizon: 10 Years																																																																																																																																																											
Inflation: 2.0%																																																																																																																																																											
Increase in Revenue: 391,020																																																																																																																																																											
Increase in COGS: 127,939																																																																																																																																																											
Increase in Fixed Costs: 143,774																																																																																																																																																											
Depreciation: 20 Years																																																																																																																																																											
Salvage Value:																																																																																																																																																											
Taxes: 21%																																																																																																																																																											
Selling Price:																																																																																																																																																											
<div style="border: 1px solid black; padding: 5px; margin-top: 10px;"> FC: 31.0% NPV: (528,281.01 €) IRR: 6.0% Payback: 7.29 Years </div>																																																																																																																																																											
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 10%;">NOPAT</td> <td style="width: 10%;">75,807.02</td> <td style="width: 10%;">16,420.56</td> <td style="width: 10%;">16,931.67</td> <td style="width: 10%;">17,453.01</td> <td style="width: 10%;">17,984.77</td> <td style="width: 10%;">18,527.16</td> <td style="width: 10%;">19,080.41</td> <td style="width: 10%;">19,644.72</td> <td style="width: 10%;">20,220.31</td> <td style="width: 10%;">20,807.42</td> <td style="width: 10%;">21,406.52</td> <td style="width: 10%;">22,028.20</td> </tr> <tr> <td colspan="13"> <div style="border: 1px dashed black; padding: 5px;"> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 10%;">Book Value</td> <td style="width: 10%;">(870,000.00)</td> <td style="width: 10%;">826,500.00</td> <td style="width: 10%;">783,000.00</td> <td style="width: 10%;">739,500.00</td> <td style="width: 10%;">696,000.00</td> <td style="width: 10%;">652,500.00</td> <td style="width: 10%;">609,000.00</td> <td style="width: 10%;">565,500.00</td> <td style="width: 10%;">522,000.00</td> <td style="width: 10%;">478,500.00</td> <td style="width: 10%;">435,000.00</td> <td style="width: 10%;">391,500.00</td> </tr> <tr> <td colspan="13"> <div style="border: 1px dashed black; padding: 5px;"> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 10%;">NCS</td> <td style="width: 10%;">(970,000.00)</td> </tr> </table> </div> </td> </tr> </table> </div></td> </tr> </table>													NOPAT	75,807.02	16,420.56	16,931.67	17,453.01	17,984.77	18,527.16	19,080.41	19,644.72	20,220.31	20,807.42	21,406.52	22,028.20	<div style="border: 1px dashed black; padding: 5px;"> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 10%;">Book Value</td> <td style="width: 10%;">(870,000.00)</td> <td style="width: 10%;">826,500.00</td> <td style="width: 10%;">783,000.00</td> <td style="width: 10%;">739,500.00</td> <td style="width: 10%;">696,000.00</td> <td style="width: 10%;">652,500.00</td> <td style="width: 10%;">609,000.00</td> <td style="width: 10%;">565,500.00</td> <td style="width: 10%;">522,000.00</td> <td style="width: 10%;">478,500.00</td> <td style="width: 10%;">435,000.00</td> <td style="width: 10%;">391,500.00</td> </tr> <tr> <td colspan="13"> <div style="border: 1px dashed black; padding: 5px;"> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 10%;">NCS</td> <td style="width: 10%;">(970,000.00)</td> </tr> </table> </div> </td> </tr> </table> </div>													Book Value	(870,000.00)	826,500.00	783,000.00	739,500.00	696,000.00	652,500.00	609,000.00	565,500.00	522,000.00	478,500.00	435,000.00	391,500.00	<div style="border: 1px dashed black; padding: 5px;"> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 10%;">NCS</td> <td style="width: 10%;">(970,000.00)</td> </tr> </table> </div>													NCS	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)																																																																														
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NCS	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)	(970,000.00)																																																																																																																																															
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STEPS	Periods	0	1	2	3	4	5	6	7	8	9	10
Investment: 2,410,000												
Time Horizon: 10 Years												
Inflation: 2.0%												
1	Revenues	3,128,160.00	3,190,723.20	3,254,537.66	3,319,628.42	3,386,020.99	3,453,741.41	3,522,816.23	3,593,272.56	3,665,138.01	3,738,440.77	3,813,229.14
1	COGS	1,023,514.80	1,043,885.10	1,064,864.80	1,086,162.09	1,107,885.34	1,130,043.04	1,152,643.90	1,175,696.78	1,199,210.72	1,223,194.93	1,247,662.37
1	Fixed Costs	1,150,189.04	1,173,192.82	1,196,656.68	1,220,589.81	1,245,001.61	1,269,901.64	1,295,299.67	1,321,205.67	1,347,629.78	1,374,582.37	1,402,074.66
1	EBITDA	954,956.16	973,545.28	993,016.19	1,012,896.51	1,033,134.04	1,053,796.72	1,074,872.66	1,096,370.11	1,118,297.51	1,140,663.46	1,163,974.51
1	Depreciation	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00
1	EBIT	834,956.16	853,045.28	872,516.19	892,376.51	912,634.04	933,296.72	954,372.66	975,870.11	997,797.51	1,020,163.46	1,043,004.51
1	Taxes	175,130.79	179,139.51	183,228.40	187,399.07	191,653.15	195,992.31	200,418.26	204,932.72	209,537.48	214,234.33	219,024.14
1	NPAT	659,825.37	673,905.77	689,287.79	704,977.44	720,980.89	737,304.41	753,954.40	770,937.29	788,260.04	805,929.14	823,980.37
2	Book Value	2,410,000.00	2,169,900.00	2,048,500.00	1,938,000.00	1,837,500.00	1,746,000.00	1,662,500.00	1,587,000.00	1,519,500.00	1,459,000.00	1,405,500.00
2	CAPEX	(2,410,000.00)										
2	Taxes:											
2	NCS	(2,410,000.00)										(253,050.00)
1	OCF		779,325.37	794,405.77	809,787.79	825,477.44	841,480.89	857,804.41	874,454.40	891,437.29	908,760.04	926,429.14
2	NCS		(2,410,000.00)									253,050.00
3	-ΔNWC											
3	FCF/Free Cash Flow		779,325.37	794,405.77	809,787.79	825,477.44	841,480.89	857,804.41	874,454.40	891,437.29	908,760.04	1,179,279.14
3	Worl'd Cash Flow											
3	CFPA (Cash Flow From Assets)		779,325.37	794,405.77	809,787.79	825,477.44	841,480.89	857,804.41	874,454.40	891,437.29	908,760.04	1,179,279.14
3	ACF/CFPA		(2,410,000.00)	(1,630,674.63)	(836,886.89)	(68,481.07)	796,596.37	1,080,477.27	2,498,281.68	3,372,796.08	4,284,173.47	5,177,253.50
3	Payback		1.00	1.00	1.00	0.93						

STEPS	Periods	0	1	2	3	4	5	6	7	8	9	10
Investment: 5,050,000												
Time Horizon: 10 Years												
Inflation: 2.0%												
1	Revenues	7,820,000.00	7,976,808.00	8,136,344.16	8,299,071.04	8,465,052.46	8,634,353.51	8,807,040.58	8,983,181.40	9,162,845.02	9,346,101.92	9,533,000.00
1	COGS	2,588,887.00	2,609,962.74	2,652,161.99	2,715,405.23	2,782,107.61	2,851,269.76	2,881,609.76	2,998,026.79	3,057,887.33	3,121,887.33	3,190,152.94
1	Fixed Costs	2,875,472.60	2,932,983.05	2,991,641.69	3,051,474.53	3,112,504.02	3,174,754.10	3,238,249.18	3,303,014.16	3,369,074.45	3,436,452.94	3,505,152.94
1	EBITDA	2,366,140.40	2,443,863.21	2,482,540.47	2,532,191.28	2,582,483.11	2,634,491.81	2,687,181.65	2,740,925.28	2,795,743.78	2,851,658.66	2,908,747.02
1	Depreciation	252,500.00	252,500.00	252,500.00	252,500.00	252,500.00	252,500.00	252,500.00	252,500.00	252,500.00	252,500.00	252,500.00
1	EBIT	2,113,640.40	2,181,363.21	2,230,040.47	2,279,691.28	2,330,335.11	2,384,991.81	2,434,681.65	2,488,423.28	2,546,243.78	2,599,158.66	2,656,247.02
1	Taxes	448,064.48	458,086.27	468,308.50	478,735.17	489,370.37	500,218.28	511,283.15	522,569.31	534,081.19	545,823.32	557,794.66
1	NPAT	1,665,575.92	1,723,276.93	1,761,731.97	1,800,956.11	1,840,964.73	1,881,773.53	1,923,398.50	1,965,855.97	2,009,162.59	2,053,334.34	2,098,452.36
2	Book Value	5,050,000.00	4,797,500.00	4,545,000.00	4,292,500.00	4,040,000.00	3,787,500.00	3,535,000.00	3,282,500.00	3,030,000.00	2,777,500.00	2,525,000.00
2	CAPEX	(5,050,000.00)										
2	Taxes:											
2	NCS	(5,050,000.00)										(530,250.00)
1	OCF		1,998,075.93	1,975,776.93	2,014,231.97	2,053,456.11	2,093,464.73	2,134,273.53	2,175,898.50	2,218,355.97	2,261,662.59	2,305,893.34
2	NCS		(5,050,000.00)									530,250.00
3	-ΔNWC											
3	FCF/Free Cash Flow		1,998,075.93	1,975,776.93	2,014,231.97	2,053,456.11	2,093,464.73	2,134,273.53	2,175,898.50	2,218,355.97	2,261,662.59	2,305,893.34
3	Worl'd Cash Flow											
3	CFPA (Cash Flow From Assets)		1,998,075.93	1,975,776.93	2,014,231.97	2,053,456.11	2,093,464.73	2,134,273.53	2,175,898.50	2,218,355.97	2,261,662.59	2,305,893.34
3	ACF/CFPA		(5,050,000.00)	(3,111,924.08)	(1,136,147.15)	878,084.82	2,931,540.94	5,025,005.67	7,159,279.20	9,333,177.70	11,553,533.67	13,815,196.26
3	Payback		1.00	1.00	0.56							

FC: 30.0%

NPV: 1,289,420.55 €

IRR: 38.7%

Payback: 2.8 Years

STEPS	Periods	0	1	2	3	4	5	6	7	8	9	10
1	Revenues	3,128,160.00	3,190,723.20	3,254,537.66	3,319,628.42	3,386,020.99	3,453,741.41	3,522,816.23	3,593,272.56	3,665,138.01	3,738,440.77	3,813,229.14
1	COGS	1,023,514.80	1,043,885.10	1,064,864.80	1,086,162.09	1,107,885.34	1,130,043.04	1,152,643.90	1,175,696.78	1,199,210.72	1,223,194.93	1,247,662.37
1	Fixed Costs	1,150,189.04	1,173,192.82	1,196,656.68	1,220,589.81	1,245,001.61	1,269,901.64	1,295,299.67	1,321,205.67	1,347,629.78	1,374,582.37	1,402,074.66
1	EBITDA	954,956.16	973,545.28	993,016.19	1,012,896.51	1,033,134.04	1,053,796.72	1,074,872.66	1,096,370.11	1,118,297.51	1,140,663.46	1,163,974.51
1	Depreciation	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00	120,500.00
1	EBIT	834,956.16	853,045.28	872,516.19	892,376.51	912,634.04	933,296.72	954,372.66	975,870.11	997,797.51	1,020,163.46	1,043,004.51
1	Taxes	175,130.79	179,139.51	183,228.40	187,399.07	191,653.15	195,992.31	200,418.26	204,932.72	209,537.48	214,234.33	219,024.14
1	NPAT	659,825.37	673,905.77	689,287.79	704,977.44	720,980.89	737,304.41	753,954.40	770,937.29	788,260.04	805,929.14	823,980.37
2	Book Value	2,410,000.00	2,169,900.00	2,048,500.00	1,938,000.00	1,837,500.00	1,746,000.00	1,662,500.00	1,587,000.00	1,519,500.00	1,459,000.00	1,405,500.00
2	CAPEX	(2,410,000.00)										
2	Taxes:											
2	NCS	(2,410,000.00)										(253,050.00)
1	OCF		779,325.37	794,405.77	809,787.79	825,477.44	841,480.89	857,804.41	874,454.40	891,437.29	908,760.04	926,429.14
2	NCS		(2,410,000.00)									253,050.00
3	-ΔNWC											
3	FCF/Free Cash Flow		779,325.37	794,405.77	809,787.79	825,477.44	841,480.89	857,804.41	874,454.40	891,437.29	908,760.04	1,179,279.14
3	Worl'd Cash Flow											
3	CFPA (Cash Flow From Assets)		779,325.37	794,405.77	809,787.79	825,477.44	841,480.89	857,804.41	874,454.40	891,437.29	908,760.04	1,179,279.14
3	ACF/CFPA		(2,410,000.00)	(1,630,674.63)	(836,886.89)	(68,481.07)	796,596.37	1,080,477.27	2,498,281.68	3,372,796.08	4,284,173.47	5,177,253.50
3	Payback		1.00	1.00	1.00	0.93						

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