Development of a Vertical Farming System for South Tyrol

Construction of a vertical farming system, backed by vertical farming best practices

less land
less water
less chemicals

Fourth Semester Project

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Synopsis

This project is developing a minimal viable product for South Tyrol's agriculture to help it move closer to its initiative Agriculture 4.0 of 2030.

The thesis starts with a short introduction to give the reader an overview, followed by an explanation of the goal of this work. Then, an empirical and theoretical part discusses the topic of vertical farming and the first steps of a possible vertical farming through the lens of farming management and the creation of a lean business plan.

This is followed by the data collection, analysis and validation parts. This serves as the data basis for this paper. Best practices in vertical farms and an interview with a local agricultural expert strengthen this part.

The solution chapter consists of the proposed minimum viable product, how it is improved, and what a possible vertical farm might look like. Followed by the Future Outlook, which gave a brief overview of how to develop the first steps of the business model.

The last part of the thesis will be the discussion, where the whole approach will be challenged, and some future thinking will be stimulated.

Acknowledgement

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I would like to extend my sincere gratitude to my supervisor Harry Boer for the assistance and guidance throughout the process. Without his feedback and reflections, this work would never have been possible. Another big thank you goes to Michael Klotz, who helped me develop the Minimal Viable Product, which is the essence of this writing and through which it gets its value. Additionally, I would like to express my appreciation to Mr. Felix Hartman from the EURAC Research who took the time to validate my collected and analyzed data. Finally, I would like to thank Nadine Griesser for proofreading parts of the paper and checking it for accuracy.

This thesis revolves around the subject of vertical farming and presents a prototype that makes it possible to save soil, water and chemicals in the South Tyrolean agriculture. Traditional agriculture exclusively uses the horizontal space, while vertical agriculture adds the vertical range, too. Moreover, it is much more controlled and sustainable in its whole process. This could help South Tyrol to get closer to its Agriculture 4.0 initiative for acting in a more environmentally friendly and innovative way.

The complete bibliography is listed in alphabetical order at the end of this report. The Harvard method is used for the listed references, which means that the reference is listed by [Surname,Year]. Furthermore, figures and tables will be numbered.

Stefan Ludwig, 02.06.2022

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Abbreviations

C

CE *Controlled environments*

CO_2 carbon dioxide

K

kg *kilogram*

M

MVP minimal viable Product

S

sq m *square meter*

V

VF *vertical farming*

VFS *vertical farming system*

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1 Introduction

1.1 Background

With the world's population expanding and agriculture occupying about half of all livable land, food security is becoming a more pressing subject to be worried about. Simultaneously, estimations predict that the world's urban areas will grow from roughly 40 to 70 % by 2050, with about 9,7 billion humans. (Orsini, et al., 2020).

Furthermore, pandemics, loss of biodiversity, and extensive fertiliser use are enormous challenges for the food industry. Today's consumer requests locally, mainly plant-based products, which should be healthy, tasty, and fresh. Tragically, 24% of all food never reaches them due to low quality or too long supply chains (Van Delden, et al., 2021).

Looking at a specific place, namely South Tyrol, which is characterized by outdoor agriculture, the first challenges appear on the horizon. According to Eurac Research, from 1968 to the present, 200 hectares of agricultural land have been used each year for the construction of new urban buildings, which is equivalent to the daily land consumption of a soccer field. Viewed from another perspective, 62 % of South Tyrol's land area is still used for farming (Gramm, et al., 2020).
The goal of drastically reducing pesticides and fertilizers, becoming climate neutral, promoting biodiversity and eliminating useless land is putting South Tyrolean agriculture in a difficult position. The rising sustainability thinking, combined with the growing need for more urban areas, prompts South Tyrol to rethink the status quo and investigate the potential for more innovative cultivating methods (Hilpold, et al., 2020).
In order to increase the efficiency and competitiveness of South Tyrolean farms, to facilitate work processes and thus to strengthen the professional attractiveness of agriculture, innovative technology solutions for the production of top quality products on small-structured land could be a key element (Gramm, et al., 2020).

Vertical farming (VF) has the potential to produce food in a climate-resilient way, without releasing pesticides or fertilizers, and using less land and water than traditional agriculture. Vertical growing systems (VFS) can fulfill customers' daily needs for nutrient-rich fresh produce while contributing to resilient food systems.

1.2 The aim of the thesis

This thesis aims to collect the best scientific data, facts, and knowledge about VF to develop both an effective and efficient solution. Therefore, it is structured as follows. A short analysis and the final project outcome will be declared in the Project Objective part, thereby, giving a narrowed scope, which helps the reader understand the purpose behind the writing.
The Empirical Background part consists of section 1 focusing on South Tyrol's current agriculture and its challenges in the next years. Section 2 will introduce VF and its benefits for the environment, the economy, and society. The Theoretical Background contains section 1, which gives a brief insight into the basics of operation management, and section 2 which discusses the establishing of a lean business plan. The goal of these two literature-focused chapters is to introduce the reader to the topic, create awareness of the challenges that agriculture with a focus on South Tyrol will have to face in the upcoming years, and to show how to manage the initial phase of the VF.
The Project Design part will focus on gathering the most accurate data possible, analyzing and validating it by interviewing an expert. The study uses data from representative academic papers to reach the most precise findings possible. Also, "best practices" will be integrated and current methods will be highlighted.

Afterwards, the Solution Chapter is divided into four sections. Section 1 covers the presentation of the MVP, followed by Section 2, which covers the refinement of the prototype. Section 3 explains what a finished VF should look like, and finally the fourth section shows how the vertical farm is made market-ready. The solution chapter gives the reader the possibility to view the potential of a VFS within South Tyrol pragmatically. In addition to the part, the Future Outlook Chapter will provide insights into how the VF business could be developed.

Lastly, Discussion and Conclusion, aim to look at the project from different angles and consider it from a broader perspective. The question of whether vertical farming is the best method for growing food crops in South Tyrol will also be discussed shortly.

2 Project Objective

The following section explains the goal of this work to give a first mental concept in which direction the work is oriented.
Firstly, a short analysis linking to chapter 3 will be presented. Secondly, a specific and measurable objective statement is stated, so that the reader knows what this master's thesis is focused on.

2.1 Analysis

South Tyrol is an agricultural-driven province. It cultivates thousands of tons of vegetables and fruit year, and the cultivation areas are still increasing from year to year. However, some first limitations are arising on the horizon. The climatic conditions are getting extremer each year. From 1960 until today, the temperature has risen by 1,5-3 °C, and rainfall has decreased. Therefore, more watering is required to hydrate and cool the plants.
Moreover, frosty nights are occurring more unexpectedly than before. Even if the temperature is generally on the rise, some days it happens that the temperature suddenly drops. Land scarcity is the next hindrance for the farmers in South Tyrol. Many areas are protected to save the shrinking biodiversity or are too high above the sea level to be used for proper cultivation. Lastly, new species of hazardous insects have been detected in recent years. As temperatures increase, they find it easier to survive during the winter months and therefore reproduce even faster. (Provinz Bozen, 2020).

All of this has prompted the province to develop an Agriculture 4.0 initiative. To increase efficiency and competitiveness, innovative technological solutions for the production of high-value goods on small-scale land could be an important component. Saving resources and minimizing negative environmental and health impacts are important aspects of making agricultural land management more ecological and effective again.
Modern agricultural technologies can offer alternatives to reduce operating costs compared to traditional methods. Technical-mechanical and governance solutions, particularly for application and precision farming techniques, are focus points.

Also, South Tyrol's Agriculture 4.0 initiative is trying to take a more resource-saving approach to agricultural machinery (e-mobility, natural gas, or biodiesel) (Gramm, et al., 2020). Further details on the increased efficiency and reduced environmental and health effects are given in chapter 3.

2.2 Objective

The objective is to address the following points.

- *Reduced water consumption:* Using a VFS, especially an aquaponic closed-loop system, 90-99% of water can be saved compared to traditional farming.
- *Reduced land usage:* As mentioned in the chapter 3, traditional farming cultivates only horizontally, whereas VF also uses vertical space. For instance, growing lettuce vertically brings 20 times more yield than the same space used in traditional agriculture.
- *Reduced chemical usage:* VF is performed indoors, which allows control of the growing environment and reduces insects and other harming bacteria to an irrelevant minimum. In addition, the nutrients needed by the plants are produced entirely by the closed-loop system, where bacteria, earthworms and fish work together (Van Delden, et al., 2021).
- *Decreased import:* South Tyrol is currently importing more vegetables and fruits than it's exporting. Using the same area but converting it to vertical farms should eliminate the need to import certain vegetables and fruits altogether.

The above-mentioned points led to the following project objective.

Establishing the first minimal viable product which reduces water, land and chemical usage and can be scaled up to a VF, brings South Tyrol closer to realizing their Agriculture 4.0 initiative and makes it self-sufficient regarding vegetables and fruit.

The MVP and all its characteristics can be found in section 8.1. This report is primarily aimed at people working in South Tyrolean agriculture. It should help them get comfortable with the idea of switching from outdoor to vertical indoor farming. Furthermore, it is the first step in turning the solution presented later into a company. The exact business model for this could be a starting point for future writings.

2.3 Delimitations

Firstly, the time frame allotted for the development of the final solution was too short. Building a whole new agricultural ecosystem cannot be done in four months. Developing the concept, constructing the MVP, developing the closed-loop aquaponic system, as well as sourcing everything with solar and geothermal energy is not feasible in this short time frame. Simultaneously, the process needs to be designed and operations thought through. Nevertheless, the first MVP will be constructed and presented by the end of this period.
Secondly, South Tyrol's agriculture data sources were limited and not publicly available. Exact numbers about the consumption of vegetables and fruits were not fully accessible, thus making it more difficult to calculate demand accurately. The same applies to import and export data. As declared by the Chamber of Commerce in Bolzano, some data is protected by a statistical secret and therefore, not available for the eyes of the public.
Thirdly, initially only lettuce will be cultivated with this MVP. This could be seen as a limitation, as many other vegetables and fruits could be grown with the presented machines. However, to determine whether MVP works or not, growing time was used as the most important parameter for the plant. With a time of 40 days from seed to harvest, lettuce was best suited option for VF.

The chapter meant to narrow down the scope of the thesis. The analysis of the current agricultural situation in South Tyrol, the objectives of the VF and finally the delimitations should prepare the reader to take a targeted look at the best practices presented in the next chapter.

3 Empirical background

This chapter gathers the empirical fundamentals of the thesis. The first part shows the current situation of South Tyrolean agriculture, which should narrow the reader's view from a worldwide to a regional perspective. The second part focuses on vertical farming and its methods used for cultivation, followed by three sections describing possible environmental, economic, and social benefits. Lastly, the current challenges of VF are listed briefly.

3.1 South Tyrol

South Tyrol's agriculture is facing multiple challenges. The population is growing steadily, with two persons per 1000 inhabitants per year. With dwindling biodiversity and society's expectation of agriculture to produce more sustainably, climate change is putting pressure on South Tyrol. Therefore, Arnold Schuler, the regional councilor for agriculture, plans to make South Tyrol more resource-aware, digital and resilient. To achieve these goals, both consumers and producers need to align their thinking, and society as a whole needs to develop a better understanding of agriculture.

3.1.1 Agriculture in South Tyrol

South Tyrol's agriculture consists of four important pillars: the livestock, the cultivation of fruit, wine and vegetables. The focus of this paper lies on fruits (especially berries) and vegetables growing, as this is of interest to vertical farming. South Tyrol has about 165 hectares filled with different berries, mostly strawberries, blueberries, and raspberries. The cultivation areas are increasing each year by about 2 hectares. In recent years, the temperature during the summer months has been higher compared to previous years, which causes the berries to grow larger. However, some challenges have also arisen. An insect, called the spotted wing drosophila, has been a fundamental problem. Due to the warm weather, its population replicated quickly and caused damage. On the other hand, unexpected frost happens during the summer nights, where the whole farmland freezes and parts of the cultivation area are eliminated.

Most berry producers sell their fruit locally at farmer markets and shops. Only a few companies sell to Austria, Germany and the rest of Italy, too (Provinz Bozen, 2020). Even if the cultivation areas are increasing each year, for many farmers, the space is limited to expand their business and make a living off their berry cultivation. Therefore, many decided to leave the sector as they saw no future.
In addition, South Tyrol's fruit cultivation is supported by provincial funding, which in 2020 paid out more than 30 million euros to farmers due to hail damage to their crops. The unpredictable weather is still a huge risk for many farmers, as their cultivations are mainly outdoor.

Next to the berries, 300 hectares of vegetables are produced consisting mainly of potatoes, lettuce, and cauliflower, but also pack-choy, parsley and arugula. More than 10.000 tons of vegetables are harvested each year, cultivated at an altitude between 600 - 1700 meters. Also, weather conditions in the higher regions are extremely volatile. Furthermore, the cultivation period ranges from April until October, as temperature from mid/end of October until the end of April varieties between 0,5 to 10 °C, which is way too low for cultivation. For instance, lettuce, even though it prefers colder environments, it best grows at 19° C (Provinz Bozen, 2020).

According to the ASTAT[1], the export and import of plants with a cultivation cycle of less or exactly one year count about 52,5 million which refers to 68,5 million euros. Even though South Tyrol is an agricultural province, it surprisingly imports more than it exports. (Provinz Bozen, 2020).

3.1.2 Initiative Agriculture 4.0

As consumer awareness of sustainability grows and prices for traditionally produced agricultural products decline, there is increasing pressure for a competitive business model, especially for small agricultural producers. Furthermore, agriculture and forestry are responsible for 23% of total anthropogenic greenhouse gas emissions, according to the IPCC[2] (2019). South Tyrol is pursuing adaptation techniques toward a more ecologically oriented circular economy (Gramm, et al., 2020).

[1] Provincial Office for Statistics Bolzano
[2] Intergovernmental panel of climate change

Technological advancements will provide opportunities for farmers who are forward-thinking to deal with these issues and effectively lead their farms into the future. Innovative technology solutions for the production of high-quality goods on small-structured land could be a key component in increasing the efficiency and competitiveness of South Tyrolean farms, facilitating work processes, and thereby strengthening the professional appeal of agriculture.

Saving resources and minimizing the use of damage to the environment and health inputs are important aspects of making agricultural land management more ecological and efficient. As a result, many farmers are attempting to use plant protection products only when necessary or to avoid synthetic chemical herbicides and pesticides entirely. Avoiding major losses in yield and higher production costs, as a result, is a challenging task. Modern agricultural technologies, however, may offer alternatives to reduce operating costs as compared to traditional methods. As a result, there is a strong demand for technical-mechanical but also governance solutions, particularly for application techniques and precision farming techniques (Gramm, et al., 2020).

Also, South Tyrol's Agriculture 4.0 focuses on resource-saving driven technologies for agricultural machinery (e-mobility, natural gas, or biodiesel) and safety aspects to avoid workplace accidents and make work easier, increase efficiency, and reduce the use of environmentally harmful and unhealthy inputs. To promote this initiative, a study was conducted. The results of the Agriculture 4.0 study show that few digital solutions or innovative materials are being used. While farmers recognize the need for improvements in their agricultural technology and the added value of the Agriculture 4.0 project, they are yet not fully convinced of the opportunities that technological innovations can bring to their farms. The reason for this is either the lack of knowledge or too high investment costs. Rather, South Tyrol recognized that farmers increasingly see the need for the further development of already existing machines and equipment and not in the use of new solutions for the management of their farms (Gramm, et al., 2020).

3.2 Vertical Farming

Vertical farming is a cultivation practice which originally organized crops vertically and can be applied indoors and outdoors. The key essence of VF lies in applying the law of minimum – which consists of repeating identifications and optimization of the most limiting factors for growth. But luckily, within VF, nearly every environmental variable is controllable such as humidity, airflow, temperature, nutrients, light quantity & spectrum, and carbon dioxide (CO_2). Moreover, artificial intelligence allows to precisely control the cultivation process and thereby reducing partially the cost of labour (Van Delden, et al., 2021) .

3.2.1 Cultivation Methods & Factors

The most modern way of VF is the so-called plant factory or completely controlled environment (CE). Here, the system is only indoor, solely artificially lightened, and the environment is completely controlled regarding airflow, CO_2, watering, and nutrients (Hallikainen, 2018). However, there are also methods using sunlight conducted in a greenhouse. This is of special interest in regions where the temperature differs not too much between summer and winter and where electricity costs would limit the profitability of the farm.

The growing platforms can be organized in two different ways. One possibility is to build horizontal racks which are stacked vertically above each other. Another way is to grow the plants on a vertical surface, for instance, on a wall (Beacham, et al., 2019).

Commonly, vertical farms apply a soilless growing culture, classifying them according to how the roots are supported. Crops are called aquaponics when their roots are immersed in a substrate and a tank with fishes or other small aquatic animals. Growing methods without substrate, where the roots are directly put into a mineral nutrient solvent, are named hydroponics. Systems and beds where the roots are free in the air and only suspended by a fine mist of nutrient solution, are called aeroponic systems.

Soilless systems also differ in terms of solution management. A closed-loop system recovers the already used water and nutrients repeatedly. In open-loop systems, the nutrient solution is used once and then discarded (Orsini, et al., 2020). Below, figure 1, shows an example of how a closed loop aquaponic VFS works.

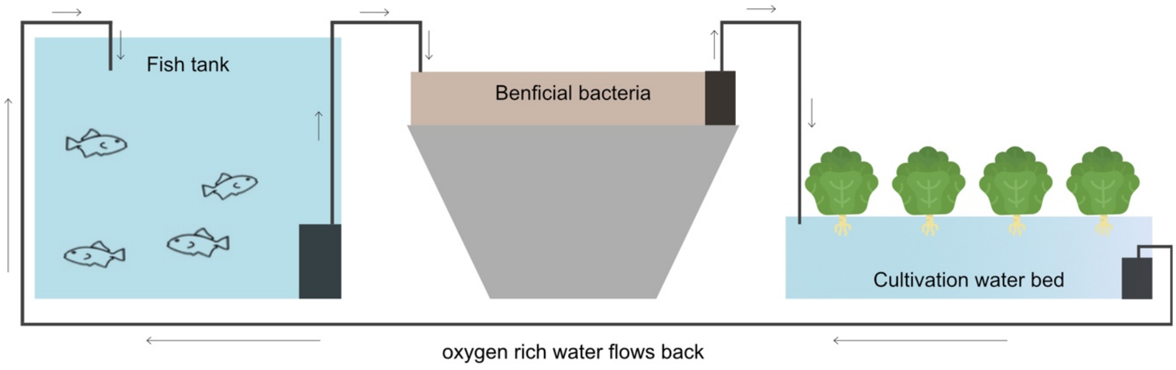

Figure 1: Closed loop aquaponics system

As can be seen in figure 1, three parts play a central role in an aquaponic system. In the fish tank, excrements of the fish are filtered through the pump and brought to the next base. These beneficial bacteria convert ammonia and nitrites from the fish waste to nitrates. Afterwards, the clean and nutrients rich water is pumped into the stage where the vegetables grow. The vegetables take the nutrients from the water and release oxygen. This oxygen-rich water is returned to the fish.

An aquaponics growing culture has many variables to be considered. Two important factors are the number of plants grown and the amount of fish per liter of water. The fish tank size depends on the size of the cultivation beet. A general rule in aquaponics suggests that five kilograms (kg) of fish are enough for each square meter of cultivation area to produce the right amount of nutrients for the plants. The mature weight of tilapia, the most commonly used fish type in aquaponics, is about 0,5 kilograms. One fish needs about 35 liters of water in order to experience a healthy growth (Tyson, et al., 2011).

Plants suitable for vertical farming should not be higher than 30 centimeters to stack multiple racks above each other. Moreover, they need to have a fast-growing cycle (around 40 days) and a high planting density. Leafy vegetables such as arugula, lettuce, parsley, and basil are the most common. In regard to fruits, strawberries or other berries are appropriate (Al-Kodmany, 2018).

This work studies a VFS set up in a greenhouse where plants are grown on a horizontal base, organized vertically and using a closed-loop aquaponics system. The reasoning behind this will be explained in the solution chapter.

3.2.2 Environmental Challenges & Benefits

Regarding the environmental aspects, many variables need to be considered. Energy saving is the first and most critical one, followed by natural light, artificial lightening, temperature control, air circulation, water provision, and nutrient delivery. These can be used in different ways depending on the location and climatic conditions of the vertical farm. Among the mentioned factors, lightening can be the most energy-consuming. Vertical farms can make use of both natural and artificial light. When using solely natural light, energy costs for lightning are zero. However, the need for artificial light during some months or the whole year is given in some regions. Due to extreme heat or cold, plants could never survive outside without only using sunlight. Light emitting diodes are used to consume as little energy as possible and to be able to adapt the light spectrum to the needs of the plant. Nevertheless, the energy consumption is extremely high.
One study shows that if the entire United States took a vertical farming approach, it would require eight times the annual electricity generation of all power plants. Luckily, in most regions, sunlight can be used most throughout the year (Orsini, et al., 2020). Another variable is the required water amount in VF. In Europe, about 3,000 liters of water per person per day are consumed in the production of food. VF could drastically reduce the amount of water used (Orsini, et al., 2020). Some studies mention that VF can save up to 90% water in greenhouses and even up to 99% in modern plant factories compared to outdoor cultivation. The closed-loop system in which water is used again and again contributes especially (Van Delden, et al., 2021).

The last important environmental aspect is land use, where the productivity per unit area and more “land use” can be achieved. If VF is performed all year round, a drastic crop increase can be seen, as traditional agriculture is restricted to external environmental conditions and can only be conducted during certain months. Furthermore, the factor of using the horizontal space and the vertical one is increasing the harvesting amount. When growing lettuce in a VFS, the crop amount can rise 23 times compared to conventional farming. Similarly, one hectare of vertically grown berries substitutes for 30 hectares of traditional cultivated (Richardson, et al., 2021). Also, up to eight crops per year can be achieved by cultivating within vertical farms, while outdoor farming only achieves three a year.

However, there are also some challenges. For an instant, only leafy vegetables with a really short growing cycle, about 30 days, are currently suitable for VF. The same applies to fruit, where only small plants with a short growing cycle, such as strawberries, can be used. By imagining a world relying completely on VF, a wide variety of plants would be omitted (Van Delden, et al., 2021).
VF has 20 times reductions in land use, improving the used area by about 95 % compared to conventional farming. For instance, to supply a population of 100.000 people with fresh vegetables and fruit takes about one square meter per person; thus, a vertical farm which is 100m x 100m x 10 layers high is already enough to feed everyone with fresh vegetables and fruit (Van Delden, et al., 2021).

Regarding environmental aspects, the VF Solution formed throughout this writing will focus on more productivity per unit area and reduction of water use. This leads South Tyrol closer to its Agriculture 4.0 - Initiative, described in section3.2.1

3.2.3 Economic Challenges & Benefits

Currently, countries are moving more toward a highly adaptable and local economy rather than aiming for globalization. One example is Singapore, which noted changes in the world markets and is moving forward to be less or less non-depending on foreign countries. In the following, some economic benefits will be elaborated on.
Firstly, energy costs are initially a lot higher than in traditional farming. Land, light, CO_2, and water in normal farming are provided by nature, in VF need to be established and purchased. However, the cost can be reduced by using a small horizontal area and focusing on going vertical. Moreover, volunteer work could be another way to reduce initial costs. Furthermore, the initial investment can be cut down by using already existing infrastructure and thereby sharing temperature control, electricity, and finances. Also, decreasing heat in cities can be an advantage, which could lead to an overall electrical cost reduction (Van Delden, et al., 2021).
Many locations around the world, particularly Iceland, Italy, and New Zealand, make use of geothermal energy. Other countries with a steady wind, such as Denmark, could use it as a sustainable energy source for VF. And countries with plentiful sunlight could take advantage of solar panels.
The next economic aspect is high-quality food with low prices. As food price is strongly connected to the oil price, fuel is an impacting factor. A rise in the price of oil

will end in an increase in food prices. If food is produced regional, the costs of transport lower strongly.
However, while it is true that putting up vertical farms is expensive at first, once they are up and operating, the price of food will fall. Nevertheless, VF, especially on large scales, is extremal cost-intensive, which makes a start more difficult, and also, the risk of reaching the return on investment (ROI) is higher. Both are factors that hold people back from investing in VF (Van Delden, et al., 2021).
Lastly, land scarcity with a growing population is a central factor. Often is argued that there is not enough space to build new vertical farms within cities or regions. However, it is not always required to build entirely new infrastructure. Old unused buildings or roofs of houses can be used to integrate VFS. Even by building new greenhouses or CE, as already mentioned, an enormous amount of land could be saved. Therefore, creating more space rather than consuming it (Van Delden, et al., 2021).

In this report, the main economic aspects which will be focused on are fighting land scarcity, lowering initial ROI risk and creating low price-high quality food.

3.2.4 Social Benefits & Challenges

Looking at it from a social aspect, VF is also beneficial for bringing people closer to nature, educating them, and creating new job opportunities.
Psychologically nature helps to reduce stress and improves obesity. Multiple studies have shown that closer contact increases a person's focus, stability, and creativity. By installing vertical farms directly in urban buildings within the cities, the direct interaction and communication with nature would increase.
The second advantages of VF for society are new job opportunities. In many big cities, limited jobs are a huge problem. Many new occupations would be created by installing more and more vertical farms in cities. For example, managing seed production, transplanting, managing water and nutrients, supervising artificial lighting, controlling airflow, and harvesting. Also, other jobs, including managing waste, supervising machinery, and analyzing the gathered data from sensors, would offer new vacancies (Van Delden, et al., 2021).
VFS could educate people, especially regarding nutrients, food production, and transport when it comes to education. Today agriculture is still strongly outdoor

driven, and the cultivation fields are located mostly far outside the cities. When vertical farms are created nearer or even in cities, people could closely follow the whole process and understand how their food arrives at their dining table. In numerous vertical farms around the world, innovative methods of growing food are executed. In order to advertise and promote their concepts, the vertical farm owners let people visit their sides, which is also an excellent way to share knowledge, thus enhancing the education aspect. Humans should be made familiar with how their food is made, where it is from, and how it is raised (Van Delden, et al., 2021).
Also, as today's society is multiply hit by pandemics and conflicts worldwide, VF could lead to a greater sense of community. It surely would not solve all world problems. However, it could connect people, for instance, by producing their food in their gardens and thereby creating garden communities that ask each other for advice or exchange their vegetables. As people could grow all year long, less import of goods would be needed, so mostly regional products would be consumed. This leads to greater interaction between inner country parties and offers a possibility for a greater sense of community (Van Delden, et al., 2021)

Lastly, the food security issue in developing countries is still an actual topic. One of the main aims of VF is to provide healthy food in low-income countries. According to studies, a 30-story building could feed 50.000 people. For instance, in Israel, they reported feeding 12,5 % of persons per day with ½ hectare of open-field agriculture, while using the same space in VF could supply 97 % of people a day (Van Delden, et al., 2021).

One important challenge that needs to be mentioned is how people could think about food produced in a controlled environment, similar to a laboratory. As humans associate laboratories with chemicals and artificial products, they could be suspicious about vegetables and fruit produced on vertical farms. A second challenge is the taste of the edible cultivated on a vertical farm that uses artificial light. Sunlight enhances the flavour richness of the vegetables and fruits, but often on vertical farms, the sunlight is replaced by artificial light, which gives a different, tasteless flavour (Van Delden, et al., 2021).

This chapter gave a short overview of South Tyrol's agriculture. Moreover, it should help the reader understand VFS, how they work, and what challenges and benefits they bring. Thereby enhancing the understanding of how a vertical farm could be a possible improvement for South Tyrol's agriculture.

4 Theoretical Background

This chapter is the theoretical backbone of the thesis. It is divided into two main sections. Section 4.1 gives a short inside into the basics of operation management, especially designing the operation. This will help construct a product that could be essential for the South Tyrols agricultural innovation road. Section 4.2 focuses on the initial steps of developing a business model. Consequently, transforming the developed product into a business.

4.1 Operation Management

Firstly, a short overview of directing an operation is given, secondly designing an operation is put focus on and lastly, how to deliver the operations.

4.1.1 Directing the operation

Operation management helps companies to develop and execute products and services. All resources of a company need to be managed and directed in order to achieve the wanted outcome. Generally, OM uses resources in order to suit the market requirements appropriately.
There are three types of input resources involved in a process: Material, Information, and Customers. Which, during the process, should be transformed into an output: product or service. This should lead to value-add for the customer.
To successfully direct operations, a proper strategy is needed. Firstly, broad targets need to be set, which lead the enterprise towards the main objective. Planning how to achieve this goal and stressing long-term rather thinking should be applied. (Slack, et al., 2019).

4.1.2 Designing the Operation

When starting with a product or service, an initial concept is outspoken. In order to reach a clearer idea outcome, several stages are passed. Figure 1 shows the stages of product/service design innovation.

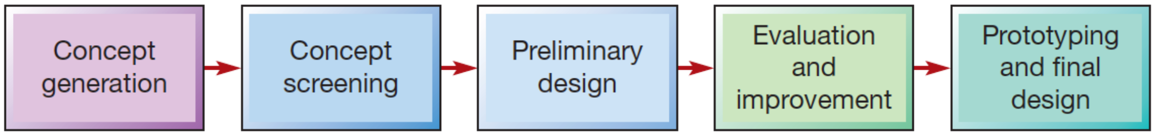

Figure 2: The stages of product/service design innovation, P.119, Slack 2019

The concept generation is the initial point, where the innovative product/service is formed mentally but has no funnelled direction. Afterwards, the concept screening takes place. This stage aims to screen the initial idea and assess if it is doable, if it will be accepted by the market and where possible vulnerabilities lie. Over time, more and more decisions are taken, and the concepts are narrowed down. Importantly, each evaluation screening should be well reflected, as with time, the expenses of changing design options are rising drastically (Slack, et al., 2019).
The next stage is described as preliminary design, where the exact definition of what goes into the product/service. For product-oriented businesses, this phase consists of defining the product's specifications and which components are needed to assemble it. Often a component structure is made to ease the understanding of the interoperation of the parts. A key objective of preliminary design is to achieve simplification through standardization and modularization.
Design evaluation and improvement is the subsequent stage. It is needed to evaluate the preliminary design and improve it before it is released to the market.

The last step of the design innovation model presented in figure 1 is the prototyping and final design. Without properly testing the designed product, entering the market is too speculative. Prototypes decrease this risk by enabling the organization to test the product before it is launched. (Slack, et al., 2019).

4.2 Lean business plan

As described in section 4.1.3, planning is a crucial activity to deliver a product correctly. Moreover, planning is also needed to manage a business. Expectation setting, result tracking and measuring the difference between expectation and effective results are fundamental.
There are many different ways to plan a business. One approach that is especially useful in times with high variability and flexibility is needed is the lean business plan. Small milestones, regular tracking, and frequent course adjustments are part of the lean business planning technique. The plan is minimal, compact, and streamlined for internal usage exclusively, with only enough room for business optimization.
Unlike the traditional formal business plan, the lean plan avoids the professionally prepared summaries and extensive company information for outsiders. It is not a classical document; rather, it is a compilation of bullet points, tables, and lists. (Rose, et al., 2016).

4.2.1 Principles of lean business planning

In order to make a good structured lean business plan, some key principles are needed.

1. **Doing only what is used**: Avoiding things that are not useful at the moment is one key factor of lean business planning. Meaning that there is no big plan needed at the beginning. Rather a gathered document is reviewed and revisioned. It shows which person does what, how much cost it creates and how much money it could make. It's a collection of choices, lists, and projections that don't have to be contained in a single document. It concerns corporate strategy, particular milestones, dates, deadlines, sales and spending estimates. This is not a research paper.
2. **It is a continuous process, not only a plan**: Within lean business planning, you are not performing a plan once, but it is a continuous improvement process. The lean plan is far more beneficial than a static one because it is continuously current, constantly recorded and evaluated, regularly amended, and a valuable management tool.
3. **Assuming constant change**: One of the most common misconceptions regarding planning is that it limits flexibility. When done correctly, it promotes

adaptability. Change is managed through lean business planning. Change poses no threat to it. It's important to pay attention to the minutiae while simultaneously keeping an eye on the big picture. It's a matter of maintaining track of what's going on outside the organization while also keeping track of what's going on inside.

4. **Accountability empowering**: Lean business planning establishes defined goals and monitors progress. It compares the outcomes to the forecast. Only if management undertakes the effort of measuring results and communicating them to those responsible can people on a team be held accountable. The negative feedback is included in the metric itself in good teams. Nobody needs to chastise or lecture because the entire team contributed to the plan's creation and continues to examine it. People are pleased and joyful when they see good performances; they are humiliated when they see terrible ones. It occurs automatically
5. **Planning, not Accounting**: Confusion between planning and accounting is one of the most typical mistakes in corporate planning, which is also true for lean planning. The created projections are merely projections, despite their appearance as accounting statements. They'll always be off, in one way or another. The goal of forecasts is not to accurately predict the future but to establish expectations and then draw the dots between spending and revenue. Accounting goes backwards in time in the minute detail from today. Planning progresses towards the future with increased summarization and aggregation (Rose, et al., 2016).

4.2.2 Establishment of a lean business plan

The creation of a business plan takes place in three steps. Firstly, a strategic summary of your business helps to effectively frame new possibilities without emotion. This strategy summary should be reviewed monthly, and revisions in response to real-world conditions are needed.

Secondly, tactics should be planned to implement the strategy. The lean business plan tactics should be as straightforward as possible. Simple bullet point references are ideal. Until a legitimate business requirement is explained to outsiders, descriptions and explanations or gathering background information are not needed and are seen as unnecessary. However, marketing and product plans should be well-thought-out beforehand. There are three important tactics within lean business planning.

1. *Marketing Tactics*: To perform a successful marketing strategy, it is needed to understand the customer who uses your product perfectly. Choices about pricing, messaging, distribution channels, social media, and sales must be made. For the lean plan, bullet points are enough, as they are only for internal use.
2. *Product/Service Tactics*: Decisions regarding pricing, packaging, new product variants, technology procurement and manufacturing. Also, here bullet points are enough.
3. Other Tactics: Within this set of tactics, all things such as financials, hiring, and logistics are to think off. Important is to focus on happenings that will occur in the near future.

Thirdly, concert specifics need to be made by tracking progress, identifying problems and making changes. Milestones, measurements, assumptions, and a review and revision timeline are all included.
The established plan needs to be reviewed multiple times by all parties involved. Creating a well-recognized and easy to access review schedule is of huge importance. Furthermore, a list of assumptions needs to be created. This helps to manage change, which is crucial in today's world. According to the lean business plan model, no real accountability for the planning process is given without a list of assumptions. Next would be a list of milestones, which should be closely related to the tactics established. Examples are launch dates, review dates, prototype availability, advertising, social media, website development, lead generation campaigns, and traffic. These milestones translate the plan's approaches into real-world terms, complete with budgets, timelines, and management responsibilities. The following table shows an example of how milestones should be addressed.

Milestones Table

Milestone	Due Date	Who's Responsible	Tactics, Details
Reconfigure social media accounts	Completed	Terry	Marketing tactics
Investigate inventory turns	Completed	Garrett and Leslie	Financial review
Meet with Caroline to review market strategy	Completed	Garrett and Terry	
Top 10 customer list	November 13, 2014	Terry	Tactic: focus
Social media program	January 14, 2015	Terry	Let's make sure we're all on the same page with the new year. Social media priorites, context, emphasis, specific plans.
Monthly review	February 19, 2015	Garrett	
Spring promotion plans	March 18, 2015	Terry	Bicycle season coming again. Review general marketing, specific sales and event schedules.
Host bike repair workshop	May 02, 2015	Terry	Tactic: more per customer
Summer marketing programs	May 20, 2015	Terry	Time to establish specific social media content and events for the summer. Participation in community bicycle events.
Summer finance strategy	May 20, 2015	Leslie	Annual financial checkup on cash flow, working capital, and financial needs during the summer slow season.
Review summer inventory plan	June 20, 2015	Garrett	Financial review
Back-to-school programs	August 19, 2015	Garrett	Special sales, promotions, events, and social media spin for the next school year
Annual strategy review session	October 07, 2015	Garrett	SWOT session, strategy and tactics review.

Figure 3: Sample lean plan milestone table, Rose (p.38)

As can be seen, due date, responsibility and the alignment with tactics should be depicted in the milestone table. Lastly, generating performance metrics is an important aspect of developing accountability, one of the lean planning principles. Metrics are an integral aspect of the lean strategy. They are presented to the team as part of the planning process, and the outcomes are subsequently presented to the team at the monthly review meeting. Setting clear expectations and reporting back upon outcomes are often the most important aspects of management. The measurements are those expectations.

The lean business plan is the first part of a planning process that will guide the business and optimize its management to ensure that it achieves its goals.

Initially, the theoretical background gave an inside into operation management to ensure the reader understands steppes taken in a later stage of this thesis. Furthermore, superficial inside into lean business model principles and development was given to ensure the future developed technology, to be able to transform into a valuable business case for South Tyrol.

As will be described in the next section, the objective is to create a vertical farm suited to South Tyrol's agricultural needs and innovation aims. Firstly, the theory part about VF is used for the reader to understand the MVP construction. Secondly, the final concept of the vertical farm will be sustained by the operation management and lean business planning of chapter 4.

5 Data Collection

The VF research database has been growing fast in recent years. Academic papers, professional reports, and best practices are some investigative forms used to explain and understand this innovative topic. This thesis gathers some of this literature to establish a data foundation and fulfil the thesis objective mentioned in chapter 2.

A wide range of literature was reviewed, particularly on best practices and how they might be applied to ST. Cultivation techniques, energy sources, process design, and involved technology were laid in focus. Databases used include Google Scholar, ProQuest, and Scopus.
Ten vertical farming projects worldwide will be presented, highlighting a variety of opportunities, some of which may be beneficial to ST. At the end of this chapter, a summary of the impact of traditional agriculture on ST is provided. Moreover, a link to the concept screening stage of figure 2 is established. This is fundamental in order to move on later to the last three phases of the product design model, which are presented in the solution chapter.

5.1 Sky Green Farm

Sky Green is a Singapore-based company, which was established in 2012 by Ing. Jack Ng. The farm is able to produce one ton of fresh vegetables every day including Chinese cabbage, spinach, lettuce, xiao bai cai, bayam, kang kong, cai xin, gai lan, and nai bai. These vegetables are characterized by a short growth cycle.
The company uses a VFS called “A-Go-Gro” which consists of 9-meter-high, alpha-shaped towers and 38 tiers of growing troughs. On there, vegetables are cultivated in different mediums: soil and hydroponics. The system occupies only 5.6 square meters and produces the tenfold compared to traditional farming. In addition, the trenches rotate slowly around the tower (about three cycles a day) ensuring sufficient light for all plants without the need for a supplemental light source. Sky Green uses an ancient technology to rotate their troughs. Each tower consumes about $3 per month in electricity in the process. With 120 towers in place, they occupy 672 square meters of land, resulting in $360 in monthly electricity consumption. With regard to

water, a closed loop system is used in combination with a floating system. Thus, the water is irrigated for the plants and then flows back into a fish tank where it is supplied with nutrients. In this way, up to 95% more water is saved than in normal agriculture. Furthermore, the company tries to educate the public by offering visits to the farm. They show visitors the power of science and offer them a hands-on experience (Al-Kodmany, 2018).

Figure 4: A-Go-Gro system, Sky Green Farm, Singapore 2021

5.2 Green Spirit Farms

Green Spirit Farms (GSF) is based in New Buffalo, Michigan, where it occupies several old industrial buildings and cultivates pesticide-free and fresh food. The company grows vegetables that meet the local demand, for example lettuce, basil, spinach, kale, arugula, peppers, tomatoes, stevia, strawberries, and brussels sprouts. They use technologies such as the Volksgarden rotatory garden unit to produce a large amount of vegetables in a small space and with few resources. According to the owner of the farm, they use 98 % less water, 96 % less land, and 40% less energy than conventional farming. Green Spirit Farms sell most of its products within a maximum distance of 120 km from its farm and has created over 100 new jobs to support the local labor market. Since they grow their vegetables in a CE, there is a need for artificial lighting, which makes the electricity costs spike compared to a VFS that does not use any artificial lighting. However, they utilize solar panels and wind turbines to lower the cost (Al-Kodmany, 2018).

Figure 5: Volksgarden rotatory system, Green spirit farms 2020

5.3 La Tour Vivante

Another project concept within the VF area is the La Tour Vivante Building, which is planned in Paris, France. It combines living and agriculture as well as urban farming with VF technology. The main goal is to feed at least the inhabitants of the building. Tomatoes, lettuce, and strawberries will be cultivated in the building. The "greenhouse" is 7300 square meters and if evenly distributed can produce an estimated 63000 kg of tomatoes, 37333 kg of lettuce, and 9324 kg of strawberries each year. The tower itself is 112 meters high and has a ground floor of 48x25 meters. Furthermore, the tower is divided into 13 apartments with a total of 11045 square meter (sq m): an office area of 8675 sq m, a planting area of 7000 sq m, a shopping space of around 6750 sq m, and a nursery plus media library with about 650 sq m. The energy for the whole tower is produced by two wind turbines on the top, 3000 sq m of solar panels on the façade, and 900 sq m of solar hot water on the rooftop. People who live and work in the tower can enjoy fresh, preservative-free products. In addition, the facility is economically supported by the tower tenants, part of whose rent is used for this purpose. It is also possible to hire tower residents to reduce travel time from home to work. In addition, the combination of farm, living and office space brings residents closer to traditionally distant agricultural experiences and reconnects them with nature (SOA, 2017).

5.4 FarmedHere

FarmedHere was founded in 2011 and is located in Illinois. The farm covers a land area of about 9960 sq m and contains three facilities. The first and largest one is located 24 km from Chicago downtown and is able to produce 6% of Chicago’s vegetable demand. It is housed in an old two-story and windowless warehouse and is operated entirely by artificial light. The system used in this vertical farm consists of aquaponics and aeroponics, which together have a cultivation area of 13935 sq m. Compared to outdoor farming, they save up to ten times the space. This area produces about 136 tons of leafy vegetables, mainly lettuce, basil, watercress and arugula, but also peppers, tomatoes and other vegetables in demand will be grown there in the future. The fish are tilapia, which are commonly used in vertical farming due to their fast growth and easy breeding. Compared to outdoor farming, the closed-loop system reduces water consumption by about 97%.
Moreover, the practice of "on-demand growing" drastically reduces food waste. Within 14-28 days, FarmedHere is able to adjust the amount and type of cultivation to the demand of the population. Nevertheless, some of their farms have already been shot down due to the high electricity consumption. The fact that energy is the main obstacle within the VF sector is stressed. Even when using solar, wind, and water energy, artificial lightening is still extremely costly (Al-Kodmany, 2018). Indeed, FarmedHere closed its facilities in 2018.

5.5 Roof top farming

Rooftop farming could lead to a more sustainable way of urbanization, as nature and the city would be reunited. Moreover, it can reduce the space used for conventional agriculture and diminish food transportation miles, therefore also CO_2 emission. To make this statement more evident, an experiment was conducted by the University of

Bologna. For two years, lettuce, black cabbage, chicory, tomatoes, eggplant, chili peppers, melons and watermelons were cultivated on the roofs of two buildings in the city. Some vegetables were planted in wooden boxes in commercial soil and compost, while others were placed in PVC tubes by simply cutting a hole in the tub every 30 centimeters. Lastly, a floating system was also tested, where the vegetables swim in the water. For all systems, a type of closed-loop system called Nutrient Film Technique (NFT) was used, which ensures 90% less water consumption and reduces nutrient waste.

After the experiment was conducted for two years, calculations were carried out to determine how efficient RTF would be. The demand for fresh vegetables for the entire city would be 16,169 tons per year. Bologna counts 3500 flat roofs with an area of about 82 hectares. This means that RTF could produce 12505 tons of vegetables each year, which would account for 77% of the fresh vegetables consumed in the city.

Lastly, by applying this type of cultivation on roofs throughout northern Italy, CO_2 emissions could be reduced significantly. Currently, North Italy procures its vegetables mainly from the South (Emilia Romagna, Sicily and Puglia) and partly also from Spain and Holland. By adopting RTF and thus limiting imports, CO_2 emissions could be reduced from 0.70 kg CO_2 to 0.26 kg CO_2 (Orsini, et al., 2014).

5.6 YASAI

YASAI is an ETH spin-off, which is located in La Sarraz, Switzerland. There, in the Swiss mountains, a farm was created on an old mining site that was unusable for traditional farming methods. The old limestone mine counts a space of more than 100.000 sq m and today cultivates basil, mint, coriander, rosemary, rocket, chives, shiso green, and mizuna. The farmers not only filled and used the completely destroyed land, but also developed a system to restore flora and fauna in this nutrient-poor area. The farm can potentially produce about 3.525 tons of vegetables a year, avoiding 614 kg of CO_2 per annum. It offers the possibility of creating more than 300 new jobs as well as reducing imports of vegetables into Switzerland, which could lead to a reduction in CO_2 emissions from transport of around 40,000 tons per year.

In addition, rainwater is collected on the roofs, which is then used for watering the plants in the closed-loop system. This saves 90% more land and water compared to

traditional agriculture. Geothermal pumps are used to heat the building, which offsets 3150 tons of CO_2 per year.
Their vision is to grow more with less, and so they have also started to offer VF as a service. Together with the tech company IFarms, they have developed the YASAI-Block, a modular, artificially intelligent driven vertical frams that can grow plants in every circumstance. In addition to the “growing block” they also offer a “service block” to help customers with software, operations, and marketing (Ceaser, et al., 2021).

5.7 SPREAD

SPREAD is a Japanese vertical farm, located in Kyoto and was founded in 2007. The farm is 2828 sq m large and produces 7,7 million heads of lettuce a year. The sole lettuce producing farm is equipped with vertical racks with artificial lighting creating a cultivation area of 25,200 sq m. Compared to traditional farming, this method is 90% more land-use efficient. The farmers use a hydroponic system and control all important variables, such as temperature, CO_2, liquid nutrients, humidity, and light. Groundwater in the closed-loop system irrigates the plants resulting into a water-saving of 98% compared to outdoor agriculture. They sell their lettuce in more than 4000 stores in Japan and work all year round, as they are completely independent of the weather. This leads to a reduction in food miles and thus a strong reduction in CO_2. In addition, zero pesticide use has been achieved, which has a positive impact on the global environment and people' health[3].
From a social perspective, they also offer VF study tours and agriculture-related educational programs. They show children how their farm works, giving them the opportunity to start thinking about Japan and the world's food problem at an early age, in the hope of raising their awareness of how this problem can be solved (SPREAD CO., 2022).

5.8 Infarm

One vertical farming based in Europe is Infarm. It is based in Berlin and aims to revolutionize food production by bringing it close to cities. It cultivates 75 varieties of vegetables and fruit, ranging from strawberries to lettuce, herbs and mushrooms. The company possesses more than 1400 farms around the world and harvests one

[3] Pesticide can cause many short- and long-term health effects, acute and chronic diseases.

million plants a day. Its main facility produces about 400 tons of vegetables and fruit are annually. By trying to cultivate as close as possible to where the vegetables are sold, they are moving toward becoming a carbon-neutral business.
Working with artificial intelligence to monitor the plants helps increase their growth and quality of nutrients. For each plant, the cultivators collect more than 50.000 growth, color, and spectral points delivering them an enormous amount of data. They solely use artificial lightening and hydroponics to grow their plants. Moreover, Infarm is able to produce the same annual amount of vegetables on 40 sq m as traditional outdoor farmers on 10,000 square meter. As far as water consumption is concerned, ten million liters of water are saved every year compared to conventional agriculture. In this vertical farm, both water and land are optimized by 95%. In addition to that, supply chain shortages are minimized, as weather independence allows them to produce 365 days a year, adapting to the demand of the population. Lastly, they are employing more than 1000 people in their vertical farm facilities (Infarm, 2022).

5.9 Johns Food Company (JFC)

Located in the United Kingdom JFC produces about 3000 kg of fruit, vegetables, and herbs each week. The company grows four types of berries, ten types of herbs, eight different sorts of salads, mushrooms, tomatoes, peppers, and tulips. All plants are cultivated indoors on ten-meter-high racks and are grown entirely with artificial lighting (LED). The current total size of the farm is 13,750 sq m.
JFC uses robotics to make its planting and harvesting processes even more efficient and accurate, and collects data to adjust its entire production process. To finance the electricity consumed by the vertical farm, it mainly uses renewable energy such as solar panels and wind turbines. By the summer of 2022 they plan to be completely powered by renewable energy. They also use a closed-loop system and capture rainwater so they can reuse every liter of water 30 times which is 90 % more efficient compared to traditional agriculture. The United Kingdom grows about 50% of its vegetable and 20% of its fruit consumption itself. JFC increases this amount each year as they are able to grow all year long, leading to a food mile reduction of 95% (Johns Food Comapny, 2022).

5.10 Badia Farms

This vertical farm is located in Dubai and is specialized in herbs and microgreens for high cuisine restaurants. Due to the harsh climate in Dubai, the plants are grown exclusively indoors with artificial lighting. Sun, soil or pesticides are not used in the process. In traditional agriculture, where in some cases more than 300 different pesticides are used, Badia, like many other vertical farms, does not need any.
Saudi Arabia uses 80% of its water resources for agriculture. Badia Farm's hydroponic system consists of a closed loop system and is able to use water 90% more efficiently than traditional agriculture. Reducing water consumption is very important for Saudi Arabia as water availability is drastically decreasing. In 1974, the amount of water per person was about 555 cubic meters, in 2014 it dropped to 74 cubic meters per person.
Also, with regard to land, Dubai cannot use 90% of the available land for traditional cultivation and is therefore forced to import 80% of its fresh vegetables. Badia farms consumes 90% less land than classical farming does. It operates on an area of about 4645 sq m where it produces 1277 tons of fresh food each year. Moreover, it is able to use any kind of land surface, as indoor growing allows to adjust any parameter of the plant needs (Badia, 2022).

5.11 South Tyrol agriculture

In the following part, a compact overview of the technologies and cultivation methods of traditional agriculture in South Tyrol and their impact on the region is given. 62% of the region is used for agriculture, and only 28% of the entire region can be used for conventional vegetable and fruit production. The rest of the land is too steep, so only livestock and grazing are practiced. ST is located in the middle of the Alps and therefore has a continental climate. Temperatures range from -15 °C in the winter to +38 °C in the summer months. However, climate change is affecting the Alpine region significantly. Worldwide, the temperature has risen by about 0.85 °C since 1880, while in the Alpine region there has been an increase of about 2 °C, which will continue to rise over the next 100 years. In this case, this can also bring a positive effect. The warmer climate makes the area above 1500 meters in South Tyrol more suitable for cultivation, thus there will be more space for cultivation. The type and intensity of land use have a strong influence on biodiversity. As numerous studies show, biodiversity generally decreases with increasing intensity of agricultural use. For South Tyrol, its monotonous cultivation of apples and grapes is the main reason for that.

Nearly all plants are grown by the same method, called “no dig”. With this method, the empty parts of the beds, where no plants grow, are covered with straw. This prevents the growth of unwanted herbs, and thus saves a lot of time, because the beds do not need to be cleaned throughout the year. Moreover, a lot of organic material is mixed into the soil to create a nutrient- and oxygen-rich growing space for the plants.

Irrigation is an integral part of many areas of South Tyrolean agriculture. Due to the dry location in the inner Alps, the mostly south-facing slopes and water-intensive crops have always depended on supplemental irrigation. Due to climate change, more and more areas have been affected by longer periods of drought in recent years. Basically, South Tyrol, as all regions of the Alps, receives much more precipitation than is lost through evaporation, which leads to a positive climatic water balance. However, ST uses 62% of its yearly water consumption for agriculture which corresponds to an annual water volume of 170 million m3 (Hilpold, et al., 2020).

Experts assume that conflicts over water resources will also intensify in South Tyrol in the future. On the one hand, global warming means that less water will be stored in the form of ice and snow for the summer months, and on the other hand, evaporation on agricultural land may increase by up to 15% over the next 70 years. In terms of direct pollutant emissions, agriculture plays a minor role compared to sectors such as transport or industry. However, fine dust is produced by ammonia losses during fertilization.

After transport and heating, agriculture is the third-largest emitter of greenhouse gases in South Tyrol. According to data from ISPRA and the Provincial Agency for the Environment and Climate Protection, agriculture accounts for 17.4% (489 kt CO_2 equivalent) of South Tyrol's total emissions. About 7% of these agricultural emissions come from the use of fossil fuels for machinery and vehicles. The remaining 93 % are methane and nitrous oxide emissions from livestock farms. Agriculture, especially grassland farming, is responsible for 67 % of methane emissions and for 75 % of nitrous oxide emissions in South Tyrol (Gramm, et al., 2020).

South Tyrol needs to fertilize its agricultural land because the nutrients provided by nature are not sufficient. Animal excreta, which contains a high proportion of nitrates, is often used for this purpose. These seep into the groundwater and thus, increase the nitrate concentration to a level that is unhealthy for humans.

This chapter provided a concise overview of the VFSs that exist worldwide. As one could read, buildings can be transformed into vertical farm and coexist with the people living in them. Furthermore, regardless of the system chosen, land and water are saved and pesticides and fertilizers can be reduced to zero. Compared to traditional agriculture, where water is irrigated without a control mechanism, soil is only used horizontally, and over 150 different fertilizers and pesticides are used, it seems like a possible option for ST to consider VF.

6 Data analysis

The following chapter gives a schematic overview of the vertical farms mentioned in [chapter 5](). It provides the reader with a comprehensive understanding of the individual concepts of farms and their benefits for the economy, the environment and the society of the country. Finally, data on traditional agriculture in South Tyrol is collected to show differences.

Vertical Farms

The following table is a depiction of all vertical farms presented in Chapter 4, providing a detailed overview and facilitating comparison.

Vertical Farms	Growing Methode	Plants	Amount of Production*	Amount of land**	Source of light	Economic benefit	Environemental benefit	Social benefit
Sky Green Fram ***(Singapore)***	vertical/horizontal A-Go-Gro aquponics	chinese cabbage, spinach, lettuce, xiao bai cai, bayam, kang kong, cai xin, gai lan and nai bai	365.000	672	sun light	reducing import costs. using minimal space.	95% less land 90% less water 0 chemicals reduction CO2 emission	Public Farm visits. Creating new healthy jobs.
Green Spirit Farm ***(USA)***	vertical/vertical volksgarden rotatory garden hydroponics	lettuce, basil, spinach, kale, arugula, peppers, tomatoes, stevia, strawberries, and brussel sprouts	N.A.	N.A.	artificial light	reducing import costs. reusing abandoned buildings.	96% less land 98% less water 0 chemicals reduction CO2 emission	Creating healthy job environment. supplying local population with fresh vegetables.
La Tour Vivante ***(France)***	vertical/horizontal urban agriculture hydroponics	tomato's, salt and strawberries	109.000	1200	sun light, artificial light	reducing import costs. decreases heat in the cities.	N.A.	supplying all habbitants of the buliding with fresh vegetables & Fruit
FarmedHere ***(USA)***	horizontal/ horizontal horizonrtal water beds aquaponics	lettuce, basil, watercress and arugula, peppers, tomatoes, and other demanded vegetables	shot down	9960	artificial light	reducing import costs. reducing transportation costs.	90% less land 97% less water 0 chemicals reduction CO2 emission	creating healthy job environment. supplying local population with fresh vegetables.
Roof top farming ***(Italy)***	horizontal/horizontal urban agriculture hydroponics	lettuce, black cabbage, chicory, tomato, eggplant, chili pepper, melon and water melon	12.505.000	820.000	sun light	reducing import costs. decreases head in the city.	90% less water 0 chemicals reduction CO2 emission	supplying whole population with fresh vegetables.

YASAI ***(Swizz)***	vertical/horizontal vertical racks aquaponics	basil, mint, coriander, rosemary, rocket, chives, shiso green, and mizuna.	3.525.000	100.000	artificial light	reducing import costs. reusing unusable land.	90% less land 90% less water 0 chemicals reduction CO2 emission	growing block for private households.
SPREAD ***(Japan)***	vertical/horizontal vertical racks hydroponics	lettuce	145.000	2.828	artificial light	reducing import costs.	95% less land 98% less water 0 chemicals reduction CO2 emission	VF study tours. agriculture related education programs
InFarm ***(Germany)***	vertical/horizontal vertical racks Hydroponics	cultivate 75 different varieties of vegetables, herbs, mushrooms and fruit	400.000	N.A.	artificial light	reducing import costs.	99% less land 95% less water 0 chemicals reduction CO2 emission	creating healthy job environment. supplying local population with fresh vegetables.
Johnson Food Company ***(UK)***	vertical/horizontal vertical racks hydroponics	berries,herbs, salads, mushrooms, tomatoes, peppers & tulips	144.000	13.750	artificial light	reducing import costs. use of renewable energy.	90% less land 90% less water 0 chemicals reduction CO2 emission	creating healthy job environment. supplying local population with fresh vegetables.
Badia Farms	vertical/horizontal vertical racks hydroponics	herbs and microgreens	1.277.000	4.645	artificial light	reducing import costs.	90% less land 90% less water 0 chemicals reduction CO2 emission	creating healthy job environment. supplying local population with fresh vegetables.

*Table 1: Overview of 10 vertical farms; *in kg; **in square meters*

As can be seen, the table is divided into location, growing method, plants, amount of production, amount of land, source of light, economic benefits, environmental benefits, and social benefits of the farm. These nine factors should reveal differences or similarities between the vertical farms that lead to a clear explanation of the reasons for which the solution presented later was developed.

- **Location**: The above-presented farms are scattered all over the world. Two are located in the USA, five in Europe and four in Asian countries. The reasoning behind choosing farms around the globe lies in getting the best possible overview of methods used. Still, five of the chosen farms are located in Europe, close to or in Italy. This offers the possibility to make a more feasible comparison for the construction of a vertical farm in South Tyrol. Importantly, eight of the above farms are in operation. La Tour Vivante in France is still under construction and FarmedHere has closed its facilities.
- **Growing Methods**: In order to find the most adequate growing method for South Tyrol, different variants are included in the table. Each farm was given three parameters, the first one being the growing direction. Some farms cultivate vertically, layer above layer, where plants are grown on a horizontal

surface. Others cultivate vertically and plants grow alongside a wall, meaning they are also vertically set. Lastly, there is one farm, FarmedHere, which grows its plants solely horizontally.

The second parameter is the technical construction on which the plants are grown. Most farms use vertical racks, where the vegetables and fruits grow on shelves. A few cultivate on horizontal waterbeds, where the plants grow on styrofoam, which is completely submerged in the water.

Furthermore, two farms have adopted special growing techniques. Sky Green utilizes the A-Gro-Go method which consists of a vertically directed, alpha-shaped tower with horizontal racks on it. These racks are constantly moving up and down in a circle along the tower. The advantage of this system is that it combines space and electricity savings. Rotation allows each plant compartment to receive the same amount of sun during the day, and eliminates the need for artificial lighting. The whole construction consumes $ 3 of electricity per month. In figure 5, the system is depicted for better understanding.

Green Spirit Farms works with the Volksgarden rotatory systems. This method uses a closed circle, on the inner surface of which the plants grow. It saves space by using all 360 ° within the ring. Figure 6 depicts the system.

The third parameter shows whether the farm uses aquaponics or hydroponics. The difference between the methods is explained in chapter 3 of the thesis.

- **Plants:** For VF small, fast-growing plants are ideal. As can be seen in the table, each farm grows different fruit, vegetables, mushrooms, or herbs. A few farms specialize more on one type of plant, whereas most of them try to cultivate as many species of plants as possible. The only similarity they show is that all focus on plants with a short growing cycle, flat roots, and a small height.
- **Amount of production to amount of land**: This variable indicates how many kilograms the farms grow per square meter. One advantage of vertical farming is land saving. In areas such as South Tyrol, where usable land for farming and living is limited, this factor plays an important role.
- **Source of light**: One crucial factor in vertical farming is how to get enough light for the plants. The table shows whether the projects use artificial lighting, sunlight, or a combination of both.

- **Economic benefits**: The analyzed firms have similar benefits. Reducing the cost of importing goods, CO_2 emissions, transportation costs, and land use are the most evident benefits. Precise economic benefits, such as financial data, are not published and are therefore not available for the data collection part.
- **Environmental benefits**: Environmental benefits are one of the main marketing points used by companies to advertise. Due to efficient water and land use, no pesticides, and fewer miles of transportation, vertical farming is considered very valuable to the environment. How efficiently the electricity is used compared to traditional agriculture could not be determined from the data found. It was also difficult to accurately track the reduction in food miles across all farms.
- **Social benefits**: The social benefits deriving from a healthy environment are primarily in creating new jobs and educating people about the origins and cultivation of the food they eat. Moreover, employees work surrounded by fresh plants, which creates an oxygen-rich environment. Compared to traditional farming, they are also less exposed to extreme weather conditions, which can lead to fewer health problems.

6.1 Traditional farming

In order to provide a viable means of comparison between the two types of cultivation, the following table shows the results produced by traditional agriculture.

Location	Growing Methode	Plants	Amount of Production*	Amount of land**	Source of light	Economic challenges	Environemental challenges	Social challenges
South Tyrol, Italy	horizontal/horizontal horizontal groundfloor beds. no dig methode, soil based.	berries, vegetables	13.572.000	4.650.000	Sunlight	high insurance payments due to unstable weather. not enough space for cultivation. higher Import costs Not enough production amount for export	high land consumption. 170 mio. m3 water per year. 150 different chemicals. destroying bio diversity.	health risks (fertilizer) urban buildings

*Table 2: South Tyrol's agriculture overview; *in kg; **in square meter*

The structure of table 2 is similar to the one of table 1. The only difference is that instead of listing the economic, environmental and social benefits, it points out the challenges in all three areas.

- **Location**: The only location here is South Tyrol. The reason for choosing only one place is that the vertical farm should be built in there. Moreover, it should directly show the advantages for South Tyrol's agriculture when changing from conventional to vertical farming.

- **Growing Method**: All plants are grown in soil on a horizontal surface. The most commonly used method, especially for vegetables, is the "no dig method", explained in section 5.11 of the thesis.
- **Plants**: Vertical farming, at the time of this writing, is only suited for fast and small growing plants. The above table mentions only the production of berries and vegetables. Other cultivations such as vineyards and apples, which make up a large part of South Tyrol's agriculture, are no included.
- **Amount of production to amount of land**: The amount of production is about 13.752 tones a year on a space of 4.650.000 square meters.
- **Economic challenges**: As stated in section 5.11, each year, a large amount of money must be spent on insurance to compensate farmers for their losses. Weather conditions are fast changing, and therefore hard to predict. Another challenge mentioned in the table is the limited space. Both urban and agricultural land is increasingly constrained by mountains, forests and nature reserves.
- **Environmental challenges**: As can be seen in the table, a lot of water, land, and pesticides are used to ensure a stable yearly cultivation and harvest. This has damaging effects on the biodiversity, as areas are completely cleared for agriculture and subsequently irrigated with an uncontrolled amount of water containing many chemicals. In Fact, up to 150 different types of fertilizer are being used.
- **Social challenges**: Social changes are rising on the horizon. All chemicals used to fertilize fresh food pollute the air. Many people live next to the cultivation areas and are directly affected. Also, due to the growing population, a lot of new urban buildings are being constructed which again makes it difficult to create new agricultural land.

6.2 Advantages of vertical farming and South Tyrol's agriculture

This section provides an overview of the potential benefits of VF compared to traditional agriculture. The focus is on the production quantity in relation to the area used for it, the light source, the economic, the social and the ecological benefits. To facilitate the comparison, table 3 helps.

Point of interest	Traditional Farming in South Tyrol	Vertical farming*
Amount of production / Used land for production	2,918 kg/sq m	145 kg/sq m
Source of light	Sun light	Sun light/artificial light
Economic factors	high insurance payments due to unstable weather, not enough space for cultivation, higher Import costs, not enough production amount for export	reducing import costs, reusing unusable land, reusing abounded buildings, decreases head in the city, reducing transportation costs
Environmental factors	high land consumption, 170 mln m3 water per year, 150 different chemicals, destroying bio diversity	90-99% less land, 90-98% less water, 0 chemicals, reduction CO_2 emission
Social factors	health risks due fertilizer and air pollution, urban buildings	educational content (farm visits), creating new healthy jobs, growing block for private households

*Table 3: comparison between traditional & vertical farms; *average value of a vertical farm*

The amount of production per square meter in a vertical farm increases significantly. It is important to mention, that the 145 kg/sq m are the average harvesting amount of all vertical farm in chapter 5. Some, such as Sky Green produce 543 kg/sq m, and others such as Johnson Food Company are way below with 10 kg/sq m. The big difference between the farms can be related to different points of focus. For example, Singapore has a shortage of land and therefore Sky Green tries to use as least surface as possible by going as high as possible.

The source of light is one factor which, together with labor, causes high costs in vertical farming. Even though LED technology has been increasing the efficiency, many farms, such as FarmedHere (presented in Section 4.3), still had to stop production due to high electricity costs.

As far as economic factors are concerned, it is difficult to be more precise. The assumption that imports decrease, and exports increase when moving to vertical farming is due to the high amount of production per square meter. South Tyrol is already able to produce a big part of people's consumption, but still, they have a quite high import rate when looking at fruit and vegetables. According to Chamber of Commerce of Bolzano, the region imports 68,5 million euros and exports 52,5 million of goods. The establishment of vertical farms could lead to less land usage and at the same time higher output. This should put South Tyrol in a position to reduce imports and possibly export more of its goods in a second step.

Environmental factors are probably the most valuable. First, water use would be controlled, as both aquaculture and hydroponics are systems in which water plays a central role and is therefore closely monitored. Second, the surface compensation is decreased. Buildings or land that are unusable for conventional agriculture could be reactivated with VF. Third, reducing, and often eliminating, chemicals has major environmental benefits, such as the enhancement of the diminishing biodiversity.

Next, the emission of CO_2 would be reduced. There are multiple reasons why CO_2 is reduced in VF. One factor is the reduction of agricultural machinery for transportation, as the spaces of the vertical farms are more compact. Another factor is the decline in imports. If more goods were produced in the region, there would be fewer vehicles importing food for South Tyrol, which would have a positive impact on CO_2 emissions.

Last, there is the social impact, mainly through the creation of new job opportunities where people work in a healthy environment. Of course, traditional agriculture is also close to nature, but exposure to direct sunlight, highly volatile weather and chemicals make the working environment harmful to the health of the human body.

Additionally, since a vertical farm needs little space, there is the possibility of creating ‘private growing blocks’ for each household. This would enable people to grow the most necessary vegetables and fruits on their own, which would lead to more savings regarding food spending. This could be a starting point for future writing.

This chapter has provided an overview of what factors are different in vertical farming than in traditional farming. Above all, the reduction of land, water and chemical consumption plays a major role. In addition, factors such as the creation of new healthy jobs and more kg/sq m indicate that South Tyrol should change its agricultural behavior to achieve the goal of their Agriculture 4.0 initiative. In the next chapter, a possible first step in the field of VF is presented.

7 Data Validation

This chapter ensures that the collected and analyzed data is accurate and that VF could help South Tyrol within its Agriculture 4.0 – Initiative. This is conducted by interviewing one of South Tyrol's local agricultural experts and researchers at the EURAC centre in Bolzano, Felix Hartmann.

Hartmann read the whole data collection and analysis prior to the interview. His background as Agrology and founder of HACCP Assistance[4] gave him a good understanding of the agricultural situation in South Tyrol and the topic of VF.
At the beginning of the interview, the general situation of agriculture in South Tyrol was focused on, which relates to section 5.11 of the thesis. He talked about the monocultural agriculture the region is currently having. For the last 50 years, South Tyrol focused firmly on establishing apple and vineyard plantations, as they saw it as the most profitable and climatically advantageous for the area. However, he mentioned that a trend forwards mixed culture is recognizable.
Today problems arose, such as shrinking biodiversity and the overload of the soil through fertilization and constant cultivation. Therefore, some farmers try to shift to a mixed culture, which uses antique techniques such as three-field farming, where the soil can rest every two years and regenerate oxygen.

Nevertheless, the boundaries of switching from monoculture to more innovative agriculture are high, as the costs and risks from changing to different growing methods are high. Also, as farmers specialize in these two cultivation techniques, vineyards and apples, the source and transfer of knowledge are missing entirely. However, the EURAC currently makes a study where they research how agriculture in South Tyrol could be changed and which factors are needed to convince farmers to think differently.

Regarding fertilizing, South Tyrol plans to conduct integral agriculture, which uses natural fertilizers and pheromones, leading to less pesticide and chemical use. He

[4] Hazard analysis and Critical Control Points (HACCP). South Tyrolean enterprise with assists in business planning, innovation management, funding and food law.

cannot imagine that a monoculture, as it currently is in South Tyrol, would work without fertilizer. But it could be possibly achieved by shifting to mix culture and more innovative indoor cultivation. For example, legumes corps can generate nitrogen for the soil, and cereals can produce carbon. Yet, in his option, this would not be profitable, as the maintenance cost and the amount of space consumed are too high, and therefore the need for changing to more innovative ways of using cultivation areas is given. Apart from the harmful environmental aspect of chemicals used in agriculture, the resources for producing elements of these fertilizers will be difficult in future. For instance, according to studies, phosphors won't be able to be produced 30 years from now.

Later he spoke about land consumption and if South Tyrol will face a shortage soon. As written in chapter 3, South Tyrol consumes two football fields of land each day. Combining this with the growing demand for food for the population, Hartmann thinks land shortages will soon arise. He would start going vertical in both agriculture and urban building to diminish the land consumption.

Regarding water, he thinks the at the moment, South Tyrol has enough water resources. Glaciers deliver an extreme amount of freshwater each year. However, they are shrinking, and they will be wholly consumed within the next 30 years. Moreover, rain should fall less often, and therefore water resources could become more negligible. He mentions that South Tyrol should start controlling irrigation amounts more precise. At the moment, two different systems for watering the plantations are used. Top crown and drip irrigation. The latter is the more sustainable one, better controlling the water flow. He pointed out that many farmers use both systems cotemporally, and especially the top crown method consumes a lot of water. The most wasted water is the one used for frost protection. Farmers often need to irrigate their plants to save from damages which occur on frosty nights, as mentioned in section 3.1.

South Tyrol uses 70% of its water consumption for agriculture, and he thinks reducing that amount could be possible with a circular system in greenhouses. He visited many farms all over the world that are cultivated in greenhouses and recognized how little water they consume by tracking the exact amount a plant needs and refilter the redundant water to reuse it.

Later in the interview, he mentioned also that the problem with vertical farming could be that the communes are rarely allowed to build new greenhouses, as they think it would damage the touristic value of South Tyrol. Moreover, a building license is needed above a particular high of construction, and as South Tyrol does not appreciate new Greenhouses, this could be difficult to get.
The last challenge he mentioned was the initial cost. Agricultural land in South Tirol is costly. For one hectare, 10.000 sq m, 700.000 € should be calculated.

However, he sees an enormous advantage in building greenhouses with closed-loop systems.

- The water-saving would be much higher due to the circular system.
- It could be cultivated all year long, as it is indoor, thereby creating a CE.
- By combining greenhouses with vertical agriculture, mixed cultivation would be easier and more profitable, as all year long could be grown, and with small space, a significant amount would be harvested.

He also mentioned that South Tyrol is currently trying to convince the hospitality sector to act more regional[5]. If successful, it would lead them to buy more vegetables and fruit locally, which would lead to more farms switching to other forms of cultivation, besides apples and vine, as they see the huger demand and profit chances.

In conclusion, he thinks that South Tyrol will face land scarcity and a water and fertilizer problem soon. Therefore, vertical farming, mainly focusing on saving land, would be an excellent and most urgent first step to achieving innovative and more sustainable agriculture. The next chapter will describe the MVP and how it is developed.

[5] This initiative is called **NES** (**Nachhatlige** (sustainable) **Ernährung** (allimenation) **Südtirol** (South Tyrol)

8 Solution

The created Minimal viable product (MVP) will be presented in the first part of this chapter. Followed by the improvement of the MVP for an issueless running and finally the explanation of the completed vertical farm. Each step will be explained in detail, from the small MVP to the 100 sq m Greenhouse. Lastly, the solution will also describe how to deliver this vertical farm to the market by establishing a short, lean business plan relating to section 4.2.

As described in section 4.1.2. to initialise a product, an initial concept needs to be outspoken. As decelerate in chapter 2, this solution aims to help South Tyrol reach its goal of 2030: Innovating agricultural work by reducing land, water and pesticides consumption.

8.1 Preliminary Design – Minimal Viable Product

As depicted in figure 2, the preliminary design is the third stage of product design innovation. The first two stages, concept generation and concept screen, were performed in chapters 2 and 5 to 7. This section should explain the exact concept and all its components to create a ready to use the first MVP.

8.1.1 Objective

As will be seen in this section, it was decided to develop a similar solution to the machinery Sky Green uses, presented in section 5.1. The reasoning behind this is the following:

- *Reducing land usage*: As written in chapter 3 and 5, South Tyrol faces a space problem. Mountains, nature reserves, and the high above sea level altitude lead to a natural hindrance to a broader agricultural and urban development. As could be read in chapter 5, there are multiple ways to save space and still produce the same if not more amount of fresh food. Firstly, living and growing can be united, urban farming, or instead of using only the horizontal surface, the vertical direction is utilized too.

- *Reducing water usage*: By using a closed-loop system, water-saving is maximized. As could be read over and over in chapter 5, within VF, water is saved up to 98% compared to classical farming.

Other objectives, such as reducing electricity costs, will be tackled in sections 8.2.

8.1.2 Technical details

After the research was completed, the first drawings and construction/material plans were made to build the MVP. The following picture shows the MVP to ease the imagination.

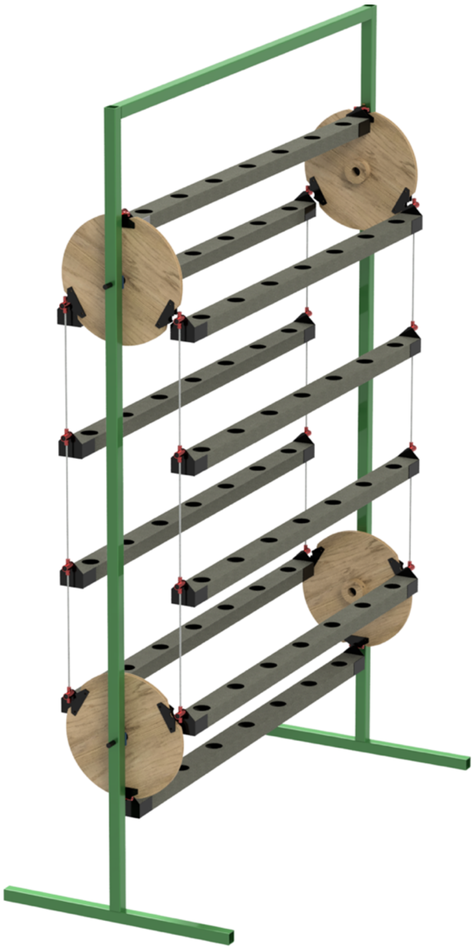

Figure 6: First minimal viable product

The prototype is two meters long, one meter wide, and about two meters & eighty centimetres high.

The most used material is steel, followed by PVC and wood. Aluminium would be lighter and make the MVP easier to transportable. However, as transport of the machine is not the main concern, steel is cheaper and its production more environmentally friendly, it was decided not to utilize aluminium at this stage. PVC tubes were used as they are light, water floats easily through them, and there is nearly no loss when it comes to condensation of water as they are closed. The wooden wheels were made of a triple wood alloy, which can resist a weight of 500 kg per cubic meter. The PVC tubes are fastened on a 5 mm thick steel rope.

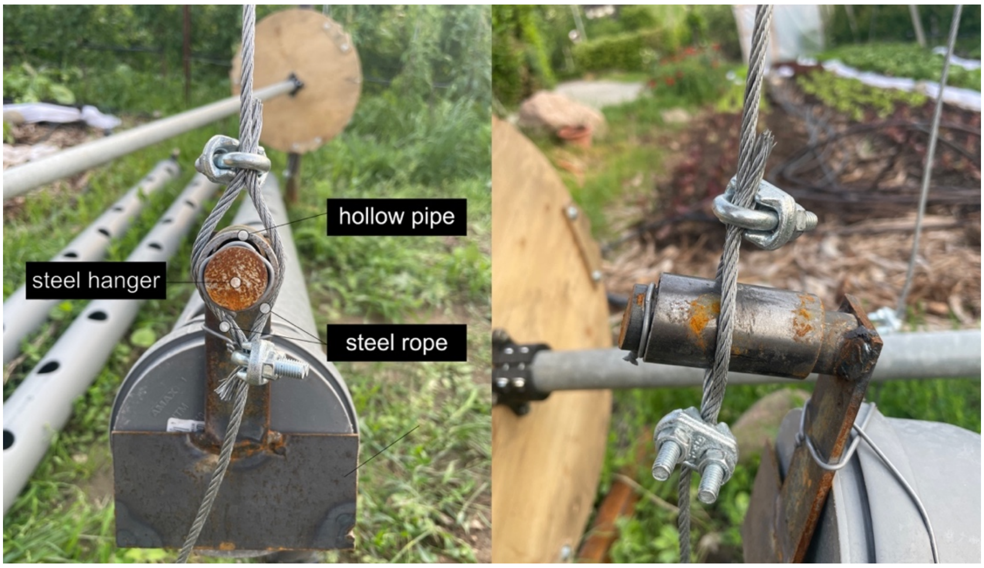

Figure 7: Steel construction to stabilize PVC tubes.

As can be seen in figure 8, close-up picture of the bracket, the PVC tubes are connected to a steel hanger. The upper part of the steel hanger is placed within a hollow pipe, which allows the PVC tube to freely move around its axis and ensures the plants stay in balance. At the same time, the hollow pipe is pressed within the steel rope, which hinders it from moving and keeps the tube on both sides at the same height.

One part of the MVP, the stepper motor, enables the 10 PVC tubes to turn around the whole steel construction. This allows the same amount of sunlight for all the plants during the day. Normally, a vertical structure is always disadvantageous regarding direct sunlight distribution on all plants, but this argument is null and void with this method.

The motor consumes 15 watts, and the electrical power used for it will initially be taken from a normal socket. In order to make the motor work and exactly move in a

predefined rhythm, a program needed to be coded. The coding can be found in the appendix of the report.
The construction of the MVP cost about 700 €, worktime excluded. The weight is about 150 kg. The following table lists all material resources used to build the MVP.

Part	Amount/pieces	Size	Material
Drive disk	4	500mm x 10mm	wood
Water tank	1	1000 liter	PVC
Motor	1	N.A.	metal
Arduino	1	N.A.	metal
Relais	2	N.A.	metal
Pump	1	N.A.	PVC
Electricity cable	1	N.A.	metal
Ball bearing with flange	4	20 mm diameter	metal
Chain	1	1500 mm	metal
Control box for electricity	1	300x100x50mm	PVC
Steel rope	10	5 mm diameter 523 mm length	metal
Axis	2	20 mm diameter 2200 mm length	metal
Steel rope for stabilization	2	5 mm dimension 3500 mm length	metal
Tubes for irrigation	1	10 mm diameter 8000 mm length	
Vertical Side bar	2	50x50 mm 4 mm thickness 3200 mm length	metal
Horizontal top bar	1	50x50 mm 4 mm thickness 2200 mm length	metal
Horizontal ground floor bar	2	50x50 mm 4 mm thickness 1000 mm length	metal
Tubes for cultivation	10	100 mm diameter 2000 mm length	PVC
Gear wheel big	1	700 mm diameter	PVC 3D printed
Gear wheel small	1	70 mm diameter	PVC 3D printed
Bolts with nuts	N.A.		metal
Funnel	1		PVC

Table 1: List of materials for the first MVP

Lastly, the machine, once placed on their final spot, will be fixed with steel cable on the floor, in order to prevent unexpected falling.

8.1.3 Agricultural details

The machine is capable of producing 100 heads of lettuce. Lettuce will be used as the first plant for testing the machine. The reasoning behind this lies in its high demand, short growing period of 30 days, and uncomplex cultivation process (Alsanius, et al., 2021). All salads are put into one of the ten holes on each PVC tube. In order to make the root development process easier, the hole of the tubes is filled with a net cup and coconut fibre. The empty cups were the lettuce will grow are shown in figure 8 below.

Figure 8: PVC tubes with empty net cups for the lettuce

During the growing period, water is floating through each tube. The water is provided by a hose placed on the top of the steel structure. Each time a tube is below the hose, a certain amount of seconds water is irrigated into the PVC tube floats through, the ten salad heads take the amount of water they need, and on the other side of the steel structure, a plastic funnel is placed, where the water is collected and automatically brought back to the water tank. The irrigation water with the tank is brought to the plants using a pump, which consumes about 20 watts and is sourced by a socket. This ensures water is used multiple times and not irrigated with our control or saving mechanism.

The whole machine consumes 2 square meters of land and, as stated previously, it produces 100 heads of lettuce a month. This is approximately 35 times more salad than South Tyrol can produce in one square meter. According to the official data of IRE, 2.5 kg of salad is grown on one square meter per year. With this MVP, 90 kg per square meter can be grown. Calculations of how this value is achieved are found below.

Amount of lettuce currently produced in traditional farming : 2,5 kg/sq m/year Amount of lettuce produced with the MVP: 90 kg/sq m/year

For the above calculation, a lettuce weight of 150 g was assumed. One hundred heads of lettuce x 12 months x 150 grams equals 180.000 grams a year. 180.000 grams a year are 180 kg per machine. One machine occupies two square meters, leading to the 90 kg/sq m.
Notably, the machine is placed in a greenhouse, which allows growing all year long, whereas outdoor agriculture can only grow from mid of April to the beginning of October.

The presented MVP is the preliminary design and first step toward a possible vertical farm in South Tyrol. However, there are still many things that could be optimized, and one machine is far from the objective of leading South Tyrol into an innovative agricultural area. The next section will provide the insides of the first improvements.

8.2 Evaluation & improvement of the MVP

To lead South Tyrol near its goal of reaching the initiative Agriculture 4.0 in 2030, the MVP needs to be tested, adjusted, and improved. This relates to stage four of the product design innovation model, depicted in figure 2.

8.2.1 Objective

The goal of the refined version is to ensure the faultless running of the MVP and the reduction of the electricity costs. Thereby creating a machine which is ready to be produced multiple and therefore creates the first infrastructural piece for the vertical farm.

- *Faultless running*: Some additional part was needed to ensure that the machine was running with no issues. Details about the adjustments are given in section 8.2.2.
- *Reducing electricity costs*: The Installation of a small solar panel in order to remove the electricity costs which the pump and step motor are creating in the first MVP design.

8.2.2 Technical details

During the first MVP test phase, some issues occur that need to be optimized and grow the first lettuces. Firstly, the steel rope had difficulty staying in place and often dropped out of the wooden wheel. In order to prevent this, a 3D printed piece, depicted in figure 9, was added.

Figure 9: 3D printed PVC triangle to hold the steel rope within the wooden rail

As the figure 9 visualizes these PVC triangles force the steel rope to stay with the wanted area and ensure a smooth running. Secondly, the small hollow steel tubes, which were in the first design of the MVP were squeezed between the steel rope and served as a hanger for the large PVC tubes, do not perfectly hit the three eyelets of the wooden wheels. Figure 10 will help to understand this part better.

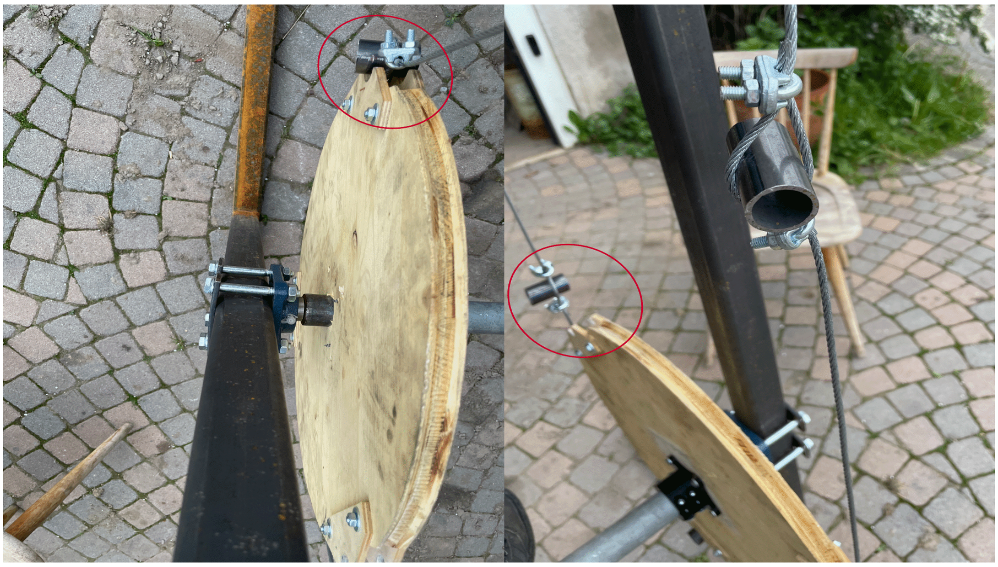

Figure 10: Depiction of how the hollow steel stubes hit the grove.

As can be seen in figure 10, the small steel tubes need to hit the wheel eyelets exactly. In the refined version of the MVP, on the bottom and the top of the hollow steel tube, a steel stick was welded, and then connected with steel rope. Figure 11 below shows the construction before and after.

Figure 11: Old vs new version of the bracket for the PVC tubes

This new construction allows adjusting the hollow steel tube and placing it in the exact position to hit the wooden eyelets.

Lastly, the wooden wheels had difficulties staying in the same place on the big steel tube. They started to turn around their axis. Therefore a second 3D printed piece, shown in figure 11, was developed to ensure stable hold of the wheels.

Figure 12: 3D printed lock for wooden-wheel fixation

The 3D printed piece is fixed around the big steel tube and screwed into the wooden wheel.

Regarding the electricity consumption, the refined version of the MVP uses a small solar plate, which is the first step toward using renewable energy for the vertical farm. The solar plant procures enough energy for both the pump and step motor. Together they consume about 35 Watt.

8.2.3 Agricultural details

On the agricultural side, there were no significant changes. Once lettuce growing is tested, the aim is to cultivate other vertical farming suitable plants such as basil, strawberries, parsley, arugula, and pack choy.

Regarding the irrigation water, deriving from a fish tank will be postponed as the time was simply too short to prepare and configure the tank with the fish. Meaning, that water will be supplied from the 1000-litre PVC tank, but without fish. Besides time, the second reason for postponing it was the recognition that a fish tank would make more sense as soon as more machines are in place and a specific tank for the cultivation fishes is made. Led to cost and time savings, as the standard irrigation tank was freely available and no special design was needed.

It seems ready to be multiplied after refining the MVP with the PVC triangles, the welded piece of steel, and the solar plate. However, this can't be assured without proper testing for several months. Parts could still break or not work as wanted. Time will be needed to see if the refined MVP will be a final one for scaling the project up.

8.3 Vertical Farm – final design

The following part will describe the end product, a South Tyrolian Vertical Farm. Importantly, all below described things are not realized yet but will be, once the MVP is properly tested.
The final version of the farm should be an "A-Go-Gro" system, as described in section 5.1, combined with aquaponics and growing in a greenhouse.

On a space of about 100 square meters a greenhouse, consisting of a wooden farm, covered with polycarbonate plastic would be built. The length is about 20 meters, the width five meters, and the height four meters. Figure 8 shows a simple ground plan of the greenhouse.

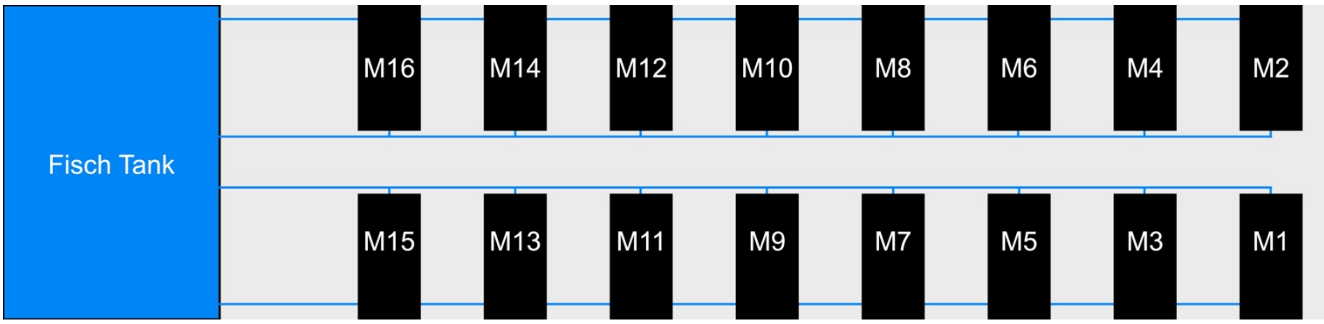

Figure 13: Vertical farm ground plan

16 machines, M1 to M16, are placed in the Greenhouse. Between each machine, there is a space of about a meter, which allows to check and harvest the plants. Moreover, sunlight can reach the plant, also when they are on the lower part of the machine, which promotes faster growth.
As written in section 3.2.1, the construction of the fish tank consists of many variables. Firstly, it needs to be decided which type of fish is utilized. Tilapia will be used, as it is one of the simplest for bearded and most applied in aquaponics. One tilapia grows to about 0,5 kilogram and needs a volume of 35 litres of water. Secondly, the amount of nutrient-rich water the plants need during their life cycle needs to be estimated to decide about the size of the fish tank and, thereby, the amount of fish that need to be placed in the tank.

As described in section 3.2.1, generally, five kg of fish is enough for one square meter of cultivation area in aquaponics. Each machine has a cultivation area of about 2 square meters. Summing up all 16 machines, it equals 32 square meters of cultivation space. As each square meter needs five kg of fish to receive enough nutrients deriving from the fish excrements, 160 kg of fish are required, which equals 320 tilapias. Each fish water necessity is 35 liters, meaning the tank must have a volume of 11.200 liters.

If all 16 machines are fully utilized, the farm will produce an amount of about 1.600 heads of lettuce a month or nearly 20.000 heads of lettuce a year.

8.4 Deliver the Solution to the market

Section 8.3 shows a possible scenario of how the first vertical farm could be constructed. By following the lean business approach, this section will declare the strategy, tactics, and milestones of the farm.

8.4.1 Strategy summary

The first step when laying out a lean business plan is a strategic summary of the product or service a business is intended to do. Moreover, it should be written in a list form and only contain the most important points.

1. *Where is the business at the moment*: Currently, the business is at a testing stage, where technical things need to be constructed issueless in order to be able to build multiple machines, and the whole vertical farm is presented in section 8.3.
2. *What were achievements until this current stage*: The first MVP is improved and runs faultless, meaning that lettuce can be grown on it. Nevertheless, technical issues could still occur, leading to the decision of first proper testing this first machine for two months before starting to build the next ones.
3. *Vison of the business*: The vision is to supply the whole of South Tyrol with fresh vegetables and fruit all year round to reduce water, land, and chemical use, leading to less import need and thereby reducing the CO_2 emission produced by the transport.

8.4.2 Tactics

According to the lean business plan, three important tactics need to be planned initially. The following list will describe those three for the vertical farm.

1. *Marketing tactic*: Two crucial steps need to be achieved. One is the image the business depicts once people start to know the company, and the other is how to sell the product, in this case, vegetables and fruit.
   The image needs to be built by proper storytelling and declaring the values of the business in order that people can start identifying with the product they see on the shelves and start preferring it.
   Initializing it by building a website and an Instagram channel where people can stay up to date with the happenings. Bringing the product on the shelf will be prompted to local stores, such as Spar, GastroFresh, COOP, and Poly.
2. *Product tactics*: The salad head will be sold with the whole root and prompted as "still living". They are. When buying a salad with the roots not cut off, it stays longer fresh, and the probability of withering diminishes. There will be no packaging, sold completely "necked". This is one more sign of sustainability and enhances people's likelihood of buying it.
   It will be sold for the same price as salat grown in traditional farming, making it more interesting for people to buy, as the way it is produced more environmentally friendly. With ongoing time, the farm will be extended to other vegetables and fruit suitable for vertical farming.
3. *Other tactics*: Other things to think of in this early stage are financials. As mentioned in section 8.1, the construction of one MVP costs about 700 €. Meaning that the construction of 16 MVPs cost about 11.200 €. The costs for the greenhouse, the fish tank, and the ongoing cultivation costs are not yet calculated and will be determined once the prototype is ready to be multiplied.

8.4.3 Milestones

The most important milestone will be shown in the table below, which is following the example of the lean business milestone table present in chapter 4.

Milestone	Date	Tactic details
Issueless running of the machine	*August 2022*	Collecting data and improving technology
Getting funding to build multiple machines	*October 2022*	Convincing NOI-Tech Park of Bolzano of the usefulness of this machine.
Detailed paling of the vertical farm	*November – December 2022*	Sustained by experts of the NOI-Tech Park.
Building of the vertical farm	*January – April 2023*	Getting market ready
Creating Marketing infrastructure	*January – April 2023*	Company image, social media & website
Reaching the market	*April 2023*	Marketing & Sales are going live.

Table 4: Millstone table for one year

Table 4 shows the millstones which need to be achieved to make the vertical farm run. Firstly, the assurance that the MVP is ready to be worked issueless and therefore can be replicated multiple times is to be taken care of, which is done by letting it run for serval weeks and trying to improve its construction.

Secondly, funding to construct the whole farm will be organized. At Bolzano, there is an innovation contest each year, where people can present their ideas. The farm will be presented there, and if successful, funding will be revised.

Thirdly, if the funding is successfully received, the planning of the farm presented in section 8.3 needs to be done. Together with experts from the NOI-Tech Park of Bolzano, every technical and financial detail of the farm can be elaborated on.

Thirdly, from January - to April 2023, the construction of the farm would take place. If this time farm is enough, it depends on the number of workforces and the time spent constructing each day. This millstone would be the starting point for the vertical farming business and the entry into the vegetable market of South Tyrol. During this time, also marketing and sales infrastructure will be built. Company image, social media channels and a website should be prepared. The last milestone on the table, delivering the marketing strategy, aims to make the farm known. Leading people to buy the product in the supermarket.

The solution chapter presented the MVP and its refined version. Moreover, it gave an outlook of how the final farm could be constructed and which steps would be needed to transform the farm into a market-ready business.

9 Future Outlook

This chapter provides the reader with an understanding of how a business could be developed out of the technology-focused Solution. A business establishment process was described superficially in section 8.4 by showing the lean business approach. However, in this chapter, a more profound and different way will be presented by following the business model innovation process of Taran, Boer and Nielsen. The chapter will combine theory and the theory applied to the possible developed vertical farming business.

9.1 Business model innovation space of the vertical farm

Business model innovation can be approached in many ways, spanning from enterprises which innovate their current business model to companies which establish a new business model to its existing and lastly, companies which are completely new and need to build their business structure from scratch. According to Schumpeter, there are five types of innovation: product/service innovation, process innovation, market or position innovation, supply/demand chain/network innovation and organizational innovation (Taran, et al., 2021).

The biggest innovation takes place on the process side by looking at the vertical farming business. It would be established from scratch, where an existing product, lettuce, would be delivered to an existing market, South Tyrol's vegetable market, but with a new way of producing it, vertical farming.

There are different forms of "from scratch" established business models. Firstly the "spin-offs" result from employees of an established business who decide to launch their firm. Also, students who start a new business in collaboration with their university are known as spin-off companies.

Secondly, "garage firms" are started as a hobby in private homes and develop into a business (Taran, et al., 2021).

The vertical farm would be the second of the two establishment forms, developing the MVP and idea of the vertical farm privately in a garage.

However, the question how innovative the business is, still needs to be determined. Following the approach of Taran et al., three factors need to be considered.

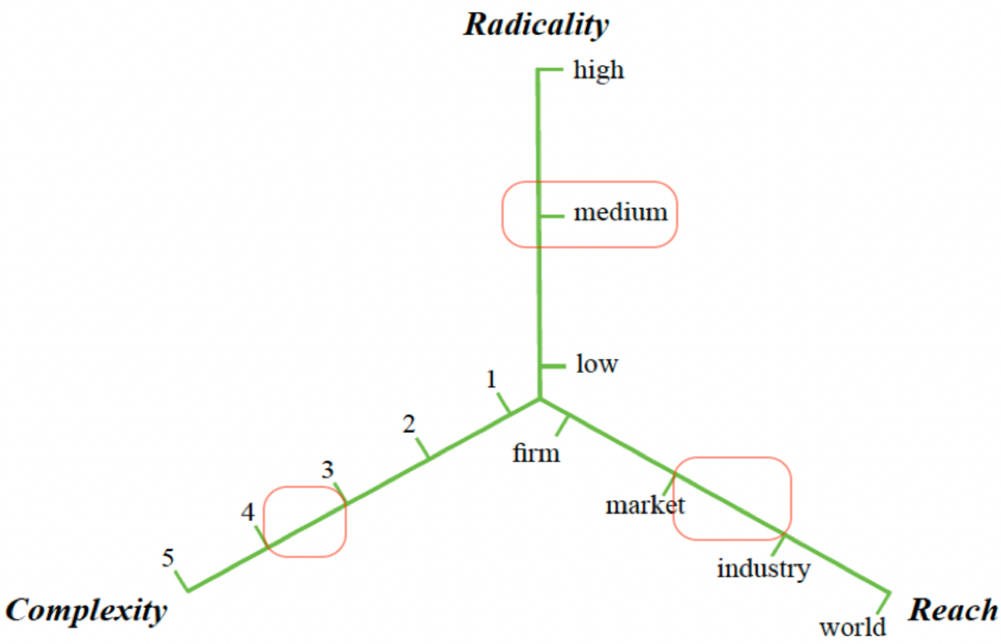

Figure 14: The business model innovation space by Taran. Red squares are showing were the vertical farming business is located.

Firstly, how radical the innovation is can be classified. Low would be an incremental innovation, were as high as a radical innovation process. Secondly, the reach of the new business is of importance. Does it affect only the firm itself, or is it influencing the whole world? For instance, Tesla's business models affect the whole world, whereas a firm-culture innovation may only affect the enterprise itself.
Thirdly, the complexity of the business innovation closes the three-dimensional space of these three factors (Taran, et al., 2021).

Regarding the VF business, the reach would be probably between market and industry-wide. It would not affect the world , as the presented vertical farm exists already, and it is not a completely new idea. However, for South Tyrol, it is. In the last 50 years, their agriculture-focused on apples and grapes, and vertical farming, focusing on smaller fruit and vegetable plants, will require new ways of approaching cultivation.

The radicality of the vertical farming business could be described by using the example of radical and incremental innovation of the 5V's, described by Taran et. al.

Value drivers	Description	Incremental innovation	Radical innovation
		What do we provide?	
Value Proposition	A company's offering of products and services.	Offering 'more of the same'.	Offering something different (at least to the company).
		Who do we serve?	
Value Segment	Customer segments a company aims to serve.	Existing market.	New market.
		How do we provide it? Who are our partners?	
Value Configuration	Involving both the primary and support activities needed for a company to develop, produce and deliver its offerings.	Exploitation (e.g. internal, lean, continuous improvement).	Exploration (e.g. open, flexible, diversified).
Value Network	Partners who engage in different kinds of cooperation with a company, with the goal of achieving economies of scale, reduction of risks (e.g. joint venture) or tapping into new knowledge or resources.	Familiar (fixed) supply chain and network partners.	New (dynamic) supply chains and network partners (e.g. alliance, joint-venture).
		How do we make money?	
Value Capture	Including revenue model, cost structure, margin model, and resource velocity.	Incremental cost cutting in existing processes.	New processes to generate revenues, or disruptive cost cutting in existing processes.

Table 5: Examples of incremental and radical innovations of the 5 Vs, by Taran et. al

The green highlighted areas in table 5 show the degree of radical innovation of the vertical farm. By referencing back to figure 11, this business model would be categorized as medium radical. The product, vegetables, and the market, South Tyrol's vegetable market, are already in place, which makes the value proposition and segment incremental. However, the way money is created by adapting new processes, and cost-cutting in existing processes makes it more radical. Regarding Value Configuration and Network, it is a mix of radical and incremental, as some partners and ways of providing the product will stay the same, whereas others change completely. For instance, local vegetables provided all year round will require a new partner network during the winter months, as it didn´t exist until now.
Lastly, the complexity of the vertical farming business model is determined. If one or two value drivers are radically innovated, it could result in incremental innovation in two or three other value drivers (Taran, et al., 2021).

As shown in table 5, radical innovation is given in some of the value drivers of the vertical farming business, which could probably lead to other unforeseen incremental innovations in the other value drivers.
By locating the vertical farming business on the business model innovation space in figure 11, it would be between 3-4. As the market and customers to sell vegetables are already in place. However, the cultivation process is different and new, the enterprise is built from scratch, and it is not guaranteed that people will accept the vegetables produced in this new manner.

9.2 Value drivers of the vertical farming business

As written in section 9.1 and depicted in table 11, a business model needs five key values according. The following will superficially touch the five values for the vertical farm in South Tyrol.

- *Value proposition*: Consisting of the enterprise’s products and service offering (Taran, et al., 2021). Compared to traditional agriculture, the vertical farm would offer vegetables and fruit grown on a minimum of space. For instance, the current MVP would produce 35 times more lettuce than classical methods. Furthermore, as explained in the solution chapter, the product would be grown in an environment where no chemicals are used, and water is reused multiple times. Lastly, the vegetables could be grown all year long, making South Tyrol more sustainable in its agriculture and less dependent on imports.
- *Value segment:* Determining the Customer to whom the company wants to offer their product or service (Taran, et al., 2021). The market for the produced product is already in place. The lettuce will be sold to wholesalers, then sell it to local stores and restaurants. This is the fastest way to access the market and create revenue. Simultaneously, the business's branding and online marketing infrastructure will be built to be well known in South Tyrol.
  This should facilitate the selling to stores and gastronomy without the need of the wholesaler.
- *Value configuration*: Including both the primary and supporting tasks required for a corporation to design, produce, and distribute its products (Taran, et al., 2021). In the beginning, the farm should occupy an area of about 100 sq. m. and 16 MVPs will be produced to grow vegetables. The entire design of the farm is not jet

precisely developed and will be determined once the MVP is tested. As mentioned, the distribution of the product, the grown vegetables, will initially take place through one wholesaler. This creates immediate revenue and simultaneously time to develop a logistic structure.

- *Value network:* Consisting of partners who execute different types of cooperation and gather new knowledge resources (Taran, et al., 2021). Initially, the partner network would consist of familiar participants. Established wholesalers would deliver the vegetables to the market. However, the more the farm grows, the newer the supply chain would become, shifting from an incremental to a radical innovation regarding this key value. For instance, an own network will be built, where the regional gastronomy is supplied with vegetables.
- *Value capture: Containing revenue model, cost structure, margin model, and resource velocity* (Taran, et al., 2021)*. The vertical farm will take a quite radical approach. As written in section 8.1, the amount of lettuce produced per sq. m. per year is 35-fold to traditional cultivation in South Tyrol. Also, water consumption will be reduced to a minimum, as the closed cycle will lead each excessive drop of water back to the irrigation tank. Moreover, chemicals will be reduced to zero, which is one more cost-saving factor. In a later stage, a webshop will be built where people can order their weekly fresh vegetables and receive them at certain pickup points, which would lead to new revenue streams besides the wholesaler market*.

These are only the first steps in creating a business model for the prototype developed in chapter 8. By determining the radicality, reach and complexity of the business model and developing the five key values, a good starting point for establishing the complete business model is given. However, managing a business today is getting increasingly challenging. Future economic trends are very unclear, and market shifts are unexpected. Product lifecycles, skills, strategic decisions, and job assignments are becoming shorter. Therefore continuous adjustment will be needed.

10 Discussion

This part looks deeper into some of the other chapters of this paper and addresses possible weaknesses. It shows which approaches within the thesis could be done differently and discusses their outcomes.

Firstly, the empirical and theoretical part of this paper is discussed. As the aim of the thesis was to "develop a first minimal viable product which reduces water, land and chemical usage and can be scaled up to a vertical farm, which brings South Tyrol closer to its achievement of their Agriculture 4.0 – Initiative", the most important things to address were vertical farming and the agricultural situation in South Tyrol. This led to the understanding of why the prototype was developed.
Literature about operational management and the basic steps of developing a lean business plan are described in chapter 4. Moreover, chapter 9 provided a future outlook on how the vertical farming business could be developed by using the business model innovation process of Taran, Boer and Nielsen. Both chapters were needed to describe how the MVP could be transformed into a vertical farm and delivered to the market.
Since the main focus was the MVP development, the part of construction and business planning of the vertical farm was only touched on. It could have been discussed deeper by adding other theoretical literature. For instance, quality management would have helped to see how the vertical farm and its cultivated vegetables should be presented to people. As mentioned in section 3.2.4, people often connect food produced in vertical farms as "laboratory-made". By creating a knowledge base in quality management, the risk of failure would be diminished.

Secondly, the data collection method was conducted by presenting ten vertical farms, placed worldwide, and traditional farming, which takes place in South Tyrol. This part led to a broad overview of which possible cultivation methods exist, which advantages they bring and how constructing a vertical farm in South Tyrol could be directed. An additional approach could have been to create a questionnaire. Subsequently, it would have been handed out to local agricultural experts and farmers to see what they think about the current agricultural situation and which possible approaches they would take to help South Tyrol achieve its Agriculture 4.0 – Initiative.

Thirdly, the data validation consists of one interview with an expert from the EURAC research center in Bolzano. His insides gave the data more value, as it showed that South Tyrol faces multiple problems within agriculture. The monoculture of apples and grapes could have a negative longer-term effect on the whole nature in South Tyrol. However, conducting interviews with multiple experts would have given the data even more reliability.

Lastly, the solution chapter is discussed. The design and construction of the first and refined MVP was the main target of the solution. However, it could have also been taken another pathway. Instead of building a machine that would then be used to grow vatable and fruit for wholesale, the prototype could be adjusted for private households. This would have enabled private households to grow their fresh vegetables on their balconies or urban gardens.
Moreover, the focus also could have lied on developing a vertical farm business model for South Tyrol and afterwards developing a prototype. This could have led to more assurance that the farm would fit the need of the South Tyrolean market. Also, sections 8.3 and 8.4 of the solution could have been further elaborated.

The development of the prototype could open a new pathway of agriculture for South Tyrol. Even if this exact method would not be successful, the sign that people have started to develop new cultivating methods reinforces South Tyrol's belief that it is time to rethink and work forward a more sustainable way of agriculture.

11 Conclusion

Before writing this thesis, the initial thought was to check if South Tyrol would be suited for vertical farming and how beneficial it could be. After investigating and going through research, the aim shifted over to developing an MVP to bring South Tyrol closer to its target of the Agriculture 4.0 initiative.

This was the recognition that South Tyrol has started to face a land scarcity within agriculture. Main parts of the region are protected or simply too high above the sea level for cultivating vegetables and fruit. This leads to the need to save the land. Moreover, also water and chemical usage in farming are causing problems. Biodiversity diminishes, and health risks rise, as described throughout the writing.

After declaring the aim of the thesis, an empirical and theoretical background was formed. Within the empirical background, vertical farming and South Tyrol agriculture were explained to the reader. A basic understanding of VF was given by describing growing methods, benefits and challenges. Additionally, deeper insight into the current agriculture of South Tyrol and the initiative Agriculture 4.0 zero were made.

Data from 10 different vertical farms and South Tyrol agriculture were collected during the project design phase. These served as a base for the data analysis, where the presented data was structured and compared. Lastly, within the data validation phase, an interview with a research expert of the EURAC center in Bolzano was conducted. This gave the data its validity and showed if the findings were relevant.

The solution part presented the MVP, which was designed and developed during this thesis's four months. Also, after testing the prototype, a refined version of it could be conducted, which led to the second testing phase. Followed by the Future Outlook, which delivered a possible way of how the initial steps for the business model of the vertical farm could look.

Lastly, in the discussion, the parts of the thesis were challenged by mentioning different approaches to how the topic could have been addressed.

This writing presented the first step forward to a new agricultural future for South Tyrol. It needs more than one prototype to achieve the Agriculture 4.0 – Initiative. Still, it is a first step, which could be the starting point for agriculture that uses less land, water and chemicals.

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12 Appendix

12.1 Code for the step motor

```
#include <AccelStepperWithDistance.h>
#include <Wire.h>
//RTClib installieren
#include "RTClib.h"
RTC_DS1307 rtc;

//stepper----------------------------
#define STEPPER 37
#define enablePin 22
#define stepPin 23
#define dirPin 24

AccelStepper stepper1(1, stepPin, dirPin);
int maximumSpeed = 1000;
int normalSpeed = 10;
int acceleration = 1000;
//homeButton------------------------
#define homePin 28
//pump------------------------------
#define PUMP 36
void setup() {
  //homeButton
  pinMode(homePin, INPUT_PULLUP);
  //pump
  pinMode(PUMP, OUTPUT);
  //Stepper
  pinMode(STEPPER, OUTPUT);
  pinMode(enablePin, OUTPUT);
  digitalWrite(enablePin, HIGH);
```

```
  stepper1.setMaxSpeed(maximumSpeed);
  stepper1.setSpeed(normalSpeed);
  stepper1.setAcceleration(acceleration);

  Serial.begin(9600);
  delay(500);
  if (!rtc.begin()) {
    Serial.println("Error! Verify Connection!");
    return;
  }
  if (!rtc.isrunning()) {
    Serial.println("Configuring Time...");
    rtc.adjust(DateTime(F(__DATE__), F(__TIME__))); //adjusting time to Computer
Time when Compiling
  }
}

char settimana[7][4] = {"dom", "lun", "mar", "mer", "gio", "ven", "sab"};
void loop() {
  DateTime now = rtc.now(); //ask time
  Serial.print(now.year(), DEC);
  Serial.print('/');
  Serial.print(now.month(), DEC);
  Serial.print('/');
  Serial.print(now.day(), DEC);
  Serial.print(" (");
  Serial.print(settimana[now.dayOfTheWeek()]);
  Serial.print(") ");
  Serial.print(now.hour(), DEC);
  Serial.print(':');
  Serial.print(now.minute(), DEC);
  Serial.print(':');
  Serial.print(now.second(), DEC);
  Serial.println();
```

```
delay(1000);
Serial.println("Enter Command: ");
Serial.println("- home");
Serial.println("- test pump");
Serial.println("- machine ready");
while (Serial.available() == 0) {}
String cmd = Serial.readString();

//home---------------------------------
if (cmd == "home") {
  stepper1.setCurrentPosition(0);
  stepper1.moveTo(10000);
  Serial.println("Homing...");
  Serial.println("Press button when on Home");
  digitalWrite(enablePin, LOW);
  while (digitalRead(homePin) == HIGH) {
    stepper1.run();   //move slowly
    delay(3);
  }
  stepper1.setCurrentPosition(0);
  stepper1.setMaxSpeed(maximumSpeed);
  stepper1.setSpeed(normalSpeed);
  stepper1.setAcceleration(acceleration);
  digitalWrite(enablePin, HIGH);
  Serial.println("Machine in home-position");
}
//test pump-----------------------------
if (cmd == "test pump") {
  digitalWrite(PUMP, HIGH);
  Serial.println("Water should flow...");
  delay(2000);
  digitalWrite(PUMP, LOW);
  Serial.println("Pump tested.");
}
```

```
//machine ready--------------------------
if (cmd == "machine ready") {
  Serial.println("Machine is now ready to start! Do you want to start?");
  Serial.println("Enter Command:");
  Serial.println("- yes");
  Serial.println("- no");
  while (Serial.available() == 0) {}
  String cmd1 = Serial.readString();
  if (cmd1 == "yes") {
    while (1 == 1) {
      if (now.hour() >= 5 && now.hour() <= 22) {
        Serial.println("Machine working...");
        DateTime now = rtc.now();
        Serial.print(now.year(), DEC);
        Serial.print('/');
        Serial.print(now.month(), DEC);
        Serial.print('/');
        Serial.print(now.day(), DEC);
        Serial.print(" (");
        Serial.print(settimana[now.dayOfTheWeek()]);
        Serial.print(") ");
        Serial.print(now.hour(), DEC);
        Serial.print(':');
        Serial.print(now.minute(), DEC);
        Serial.print(':');
        Serial.print(now.second(), DEC);
        Serial.println();
        delay(1000);
        if (now.minute() % 1 == 0) {
          digitalWrite(STEPPER, HIGH);
          digitalWrite(enablePin, LOW);
          stepper1.moveTo(100);
          while (stepper1.distanceToGo() != 0) {
            stepper1.run();
```

```
          }
          digitalWrite(enablePin, HIGH);
          digitalWrite(STEPPER, LOW);
          stepper1.setCurrentPosition(0);
          Serial.println("Machine stopped.");
          Serial.println("");
          delay(3000);
          digitalWrite(PUMP, HIGH);
          Serial.println("Water flowing...");
          delay(10000);
          digitalWrite(PUMP, LOW);
          Serial.println("Water stopped.");
          delay(47000);
        }
      }
    }
  }
  if (cmd1 == "no") {
    Serial.println("Returning to main menu....");
    delay(2000);
  }
 }
}
```