THE VERTICAL FARM INDUSTRY: EXPLORATORY RESEARCH OF A WICKED SITUATION

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EXECUTIVE SUMMARY

Increasing population, global warming, shortage of agricultural land, food security, water shortage, and other challenges are heavily weighing on the current conventional agricultural system. A disrupting new sustainable system is needed to be able to feed 9.5 billion people in 2050. A possible solution for this is vertical farming (VFing), which is growing enormously, parallel with the rise of technological innovation and business opportunities. New VFs are incipient worldwide, with an increasing amount of capital investment. This paper approaches VFing as a wicked situation and develops a theoretical VF business framework to create an overview to better understand the VF industry from a research and business-like perspective. The three main aspects of the framework are the organization (e.g. technology & innovation, geographic location, and product attributes), governance cooperation (e.g. position in the food chain and partnerships), and enabling environment (social aspects, government support, legal aspects, training & education). For this exploratory research, 25 participants, employed at a VF or who are active in the VF industry (e.g. consultancy), mainly from Europe and North America, were interviewed to discuss and validate the various aspects of the framework. All interviews were analyzed using self-determined codes with MAXQDA to identify the importance of the VFBF aspects and to better understand the participants' answers.

The outcome of this study indicates that despite continued energy and labor struggles, the VF industry carries high business potential, which is why larger corporations are investing. Independent of the degree of advanced technology, vertical farms need to produce high-quality products consistently to meet the greater expectations of VF products and their current higher price. The need for more proven systems and standardization is high, although that is common in growing industries. While automation and advanced systems are a way to drastically reduce labor costs, they also demand substantial investments and energy, especially when the technological systems still need development. Participants believe a change in the energy sector from betterment of renewable energy will grant cheaper VF operational costs. Cheap energy will have a large influence on the indoor farm industry because outside of labor, technology, and the building, energy is a major cost of operation.

VFing is a decentralized method of agriculture, that can be disruptive compared to conventional farming. In terms of food security, the current VF models are not disruptive to conventional agriculture because they lack an economy of scale for caloric food. However, VFing is causing changes in the agriculture value chain. Besides selling directly to the consumers, new models are formed (e.g. close collaboration with distribution centers). Partnerships were identified as a key to the success, due to the newness of this emerging innovative industry. Partnerships are usually made where there are gaps of knowledge or expertise. The need for specific local partnerships was often emphasized to better understand the local needs.

During discussion of the enabling environment, community involvement was identified as a way of marketing and educating consumers, and to support local recognition. However, the claimed social value of a VF should be validated for truth, as several organizations make claims that are unsupported. Governments are starting to acknowledge the VF industry, but not enough to create supportive legislation and funding due to VF's low market share in the agriculture sector. Despite the low interest federally, there are greater potentials for local government support. As the industry is still relatively new, specific laws and regulations have not been established. While city farming has more regulations than rural areas, the location was not found to inhibit the start of the business, but rather cause additional time hurdles. As is normal in any food sector, the interviewed participants often noted the strictness of food regulations and cited the importance and need for food quality management.

Additionally, the industry needs more vocationally trained employees to support optimization of the farming process. There is currently a lack of head growers and experts in farming, which is key for providing a consistently high-quality product. The combination of high tech and urban farming attracts younger people towards the industry, which is beneficial because the conventional agriculture industry is aging in some countries. Greenhouses hold an important role in the indoor farm story as it is believed to be more feasible and profitable in certain situation. Greenhouses are often looked over due to the lower technology aspect. However, some interviewed participants believed in hybrid models of VFs and greenhouses, or a change of the current greenhouses by using CEA technologies and robotics.

The developed framework in this research encounters the major aspects of vertical farming and supports a better understanding of the VF industry. This research primarily focused on vertical farms as a business and its potentials rather than a solution for global food security.

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Table of contents

List of tables and figures

Tables

Figures

Abbreviations

Abbreviation	
AVF	Association of Vertical Farming
B2B	Business-to-Business
B2C	Business-to-Consumer
CEA	Controlled environment agriculture
DC	Distribution Center
EPC	Engineering, Procurement, and Management
EU-P	Europe - Industry Participant
EU-VF	Europe - Vertical Farm
G2C	Grow to clean
G2D	Grow to develop
G2H	Grow to heal
G2P	Grow to produce
G2R	Grow to retail
G2S	Grow to share
G2T	Grow to teach
G2W	Grow to wholesale
GAP	Good Agricultural Practices
GMO	Genetic Modified Organisms
HVAC	Heat, Ventilation, and Air Conditioning
LED	Light Emitting Diode
MRQ	Main Research Question
NASA	National Aeronautics and Space Administration
NPD	New Product Development
R&D	Research and Development
ROI	Return Of Investment
RUFS	Resilient Urban Food System
SME	Small and Medium-sized Enterprises
SRQ	Sub Research Question
UFS	Urban Food Systems
US-P	United States - Industry Participant
US-VF	United States - Vertical Farm
VF	Vertical Farm
VFBF	Vertical Farm Business Framework
Zfarming	Zero-acreage farming

1 Introduction

1.1 Background information

Industrialization of food spurred a global food system that made large-scale and widespread food production available year-round, all over the world. Meanwhile by 2050, 9.5 billion people will inhabit the planet, each requiring a minimum of 1.500 calories a day. To produce that amount of calories, an estimated 2.1 billion acres are needed. Additionally, due to the use of fertilizers and pesticides 70% of the world's available freshwater is unusable for drinking as a result of agriculture (Despommier, 2009). However, thanks to scientific and technological advances within the food and agriculture industries, agricultural output and productivity have increased to meet global demands (Rosin, Stock, & Campbell, 2013). Sadly, over the last decades humanity has begun facing climate change and urbanization, both of which directly affect the food industry.

Since the 20th century urbanization has rapidly increased, especially in Europe where urban populations went from 50% in 1950 to 70% in 2009, and it's expected to rise to 80% by 2030 (Heikkilä & Kashinoro, 2009). Urbanization is often associated with highly concentrated populations, high economic activity, increased technological and digital development, greater employment, and acts as important hubs for education, innovation, distribution, consumption, and knowledge-based economies (Madlener & Sunak, 2011). Pairing urbanization with globalization: the average consumer has become increasingly critical of the quality and origin of their food. This trend increased consumer demand for more sustainable food systems, at all levels of the food chain (Vermeir & Verbeke, 2006).

According to de Zeeuw and Drechsel (2015) the combination of urbanization and the need for alternative food systems led to the creation of urban food systems (UFS). The core activity of an UFS is food provisioning in urban areas and encompassing different formats of how food is processed, produced, distributed, and sold within the city. The transition from a global food system to an UFS remains difficult due to the benefits of a well-settled global system. Benefits like constant availability, low prices, and year-round supplies are also the attributes that have created the exhausting demand of the global food system on earth's resources (de Zeeuw & Drechsel, 2015). Fulfilling these attributes has environmental costs. Together, these environmental costs, upcoming trends, and dynamics in our communities cause urban food systems to be shaped and grow according to the needs of urban areas. Some of the community dynamics that influence an UFS are population growth, urbanization, changing diet, scarcity and depletion of resources, climate change, and public health (de Zeeuw & Drechsel, 2015). In this way, UFS's are being developed according to the needs of the urban area.

Mougeot's classification also includes traditional growing systems (e.g. community/home gardens), innovative cropping systems (e.g. soilless cultures, organoponics), and indoor farming systems (e.g. vertical farming). Still Mougeot has concerns with urban agriculture, as it cannot fully replace rural agriculture, and urban contaminants will likely always be around. Overall, he recognizes the need for increased multidisciplinary research and development in order to create a more effective UFS (Mougeot, 2000). Currently, most of the urban agriculture initiatives are still small-scale, labor intensive, and have low-level production (Mougeot, 2000). The population keeps rising and the climate keeps changing

(Despommier, 2009). This suggests that low-scale urban agriculture can't solve human-accelerated problems alone, even with continual research and optimization of agriculture.

With the combined problem of traditional farming and food-related issues in urbanized areas, vertical farming (VFing) has been suggested as one possible UFS solution for metropolises, especially towards 2050 (Besthorn, 2013; Despommier, 2009; Tornaghi, 2017). Vertical farming is defined as "cultivating vegetables vertically by new agricultural methods, which combines the design of building and farm all together in a high-rise building inside the cities" (Al-Chalabi, 2015; Kalantari, Mohd Tahir, Mahmoudi Lahijani, & Kalantari, 2017). Currently VFing is advancing in mega cities like Singapore (e.g. Sky Green) and New York City (e.g. Aerofarms) with growing trends in Europe (Al-Kodmany, 2018), and even a 30% increase of VF product sales in Canada (Sharma & Patil, 2018). The increased interest created multiple types of vertical farm (VF) businesses, distinguished by different types of organization, size, integration, purpose, etc. (AVF, 2017).

Investing in VFs makes sense given their potential benefits such as shorter supply chain, lower environmental impact, community involvement, educational possibilities, and most importantly to relieve local food stress. However, present VF research is mainly focused on technical, scientific, environmental, and social aspects, with few investigations pertaining to the business of VFs (Banerjee & Adenaeuer, 2014). Two years ago, the investment cost were still seen as too high, with rare reliable ROI (Return Of Investment) calculations, and information regarding the business construct were still missing (Shao, Heath, & Zhu, 2016). Therefore, there should be a framework developed to gain insights and to create a multidimensional overview that enables vertical farm management. The suggested elements of the framework are organization, governance cooperation, and enabling environment (Griffiths & Zammuto, 2005; Waddell, 2016). The organization element is a firm—centric description of the vertical farm project (level of technology, innovation, sustainability, etc.). The second element, governance cooperation includes all aspects of actors in the chain, business arrangements, value chain, etc. The third element is the enabling environment, which includes social coherence, institutional aspects, legitimation, state involvement, etc. Reviewing and describing these three levels of various vertical farm projects may create a better overview of the industry, which is currently hard to analyze due to its wickedness. Wicked problems are described as complex, intractable, open-ended, unpredictable situations (Alford & Head, 2017). This research frames vertical farming in a similar way.

1.2 Problem statement

The need for a resilient urban food system (RUFS) is on the rise due to the negative consequences of urbanization and global problems with agriculture. Cities need sustainable urban farm solutions to solve, or at least reduce the downside of today's issues such as increasing population density and food stress in mega cities (Zasada et al., 2017). Various sources suggest vertical farming (VF) as an urban farm solution to feed citizens locally. Over the years the concept of vertical farming is developed on multidisciplinary levels depending on the location of the vertical farm. This led to a wide variety of vertical farm concepts and businesses, which are influenced by their social, institutional, and economic environment. Investigating the organization behind the VF business became extremely difficult due to the high amount of actors involved. The variety of influences and actors made it difficult to analyze the industry from a

research and business-like perspective. While VFing was originally intended to reduce food stressed regions, nowadays start-ups and businesses globally are investing in the VF industry, even in countries where there are not food stress problems. This is why it can be assumed that the need for a RUFS is not always the drive behind investing in the VF business. Due to the evolution of the dependent and independent factors, in addition to the general complexity of an innovative concept like VF, analyzing this wicked situation will not come easily. It is assumed that creating a Vertical Farm Business Framework (VFBF) will help to develop an overview for VFs and support the VF industry.

1.3 Research objective

Vertical farming became a trending business with multiple actors and influences that made it a wicked situation to create an overview. Therefore, the aim of this research is to create a VFBF in order to gain meaningful insights and to create a multidimensional overview that can support vertical farms. Vertical farm businesses will be analyzed on the various elements of the framework.

1.4 Research questions

Followed by the problem statement and research objective, the main research question (MRQ) of this study is: 'Can the creation of a vertical farm business framework help present an overview for commercial vertical farms?". The MRQ will be answered by sub research questions (SRQ):

SRQ 1: What are the characteristics of the VFBF key terms?

- *SRQ1A: What is the relevant definition of a VF business?*
- *SRQ1B: What does literature say about the organization, governance cooperation, and enabling environment elements?*

SRQ 2: How does the theoretically derived VFBF apply to VF businesses with regards to the three key terms?

SRQ 3: What conclusions can be made about the VFBF based on the information elicited from interviews using the key terms?

1.5 Research design

The research design provides a road map to find the answers of the research questions (Kumar, 2014). The purpose of this study is to create an overview of the wicked situation that vertical farm businesses can cause, by developing a business framework. For this, a qualitative and explorative research design is more appropriate, as VFing from a development perspective is still quite broad and lacks data.

First, the main research question will be answered by three SRQs. The first SRQ will be answered by reviewing relevant literature and will conclude with a suitable VFBF. The gained secondary data will be used for the empirical study by making interviews based on the elements of the framework. Therefore, SRQ 2 and 3 are part of the empirical study and will elucidate information from semi-structured interviews as data collection. Semi-structured interviews are flexible and open but stay pre-determined (Kumar, 2014). In this way, important in-depth, multiple insights of participants' experiences will be collected (Dalal & Priya, 2016). The gained data will be carefully analyzed to frame the wicked situation and discuss

the three elements by themselves. Between 15 and 30 vertical farm businesses and participants in North America and Europe will be selected to apply the VFBF and to gain reliable and valuable data to analyze. All businesses with core activity of producing and selling commercially in the vertical farm industry are qualified for this research, besides their format. However, other VF industry participants (e.g. consultancy, investors) also can be suitable for this research. This study needs a qualitative approach in order to provide a meaningful answer, because quantitative data from commercial operating VFs is still widely unavailable due to the confidentiality of this emerging industry.

A research framework (Figure 1.) is developed in order to provide an overview of the study (Kumar, 2014). It contains 3 steps of the research starting with a theoretical study to make a literature overview of the involved concepts and theories of the study such as vertical farming itself and the literature behind the construction of the VFBF. The theoretical part provides the basis for the empirical study where multiple vertical farm businesses – which operate as case studies – will be contacted to interview. The gained data will be analyzed to end in the last section with conclusions and recommendations.

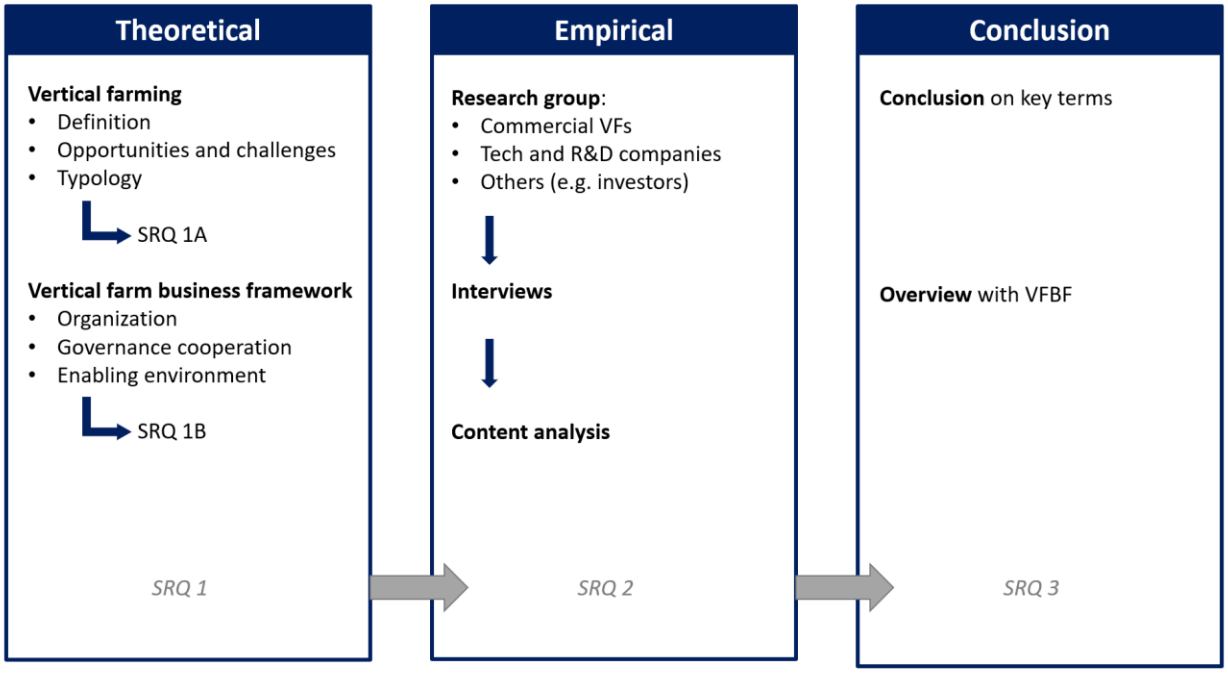

Figure 1. Research Framework

2 Literature study

The literature study investigates the theoretical concepts of vertical farming and the framework to provide the required knowledge for this topic. Section 2.1 will explain and describe what vertical farming is, which challenges and opportunities there are, which typology can be made, and answering SRQ1A. Sub research question 1A will provide insight to the multiple aspects involved in VF management, concluding with the definition of a vertical farm business, for the purpose of this research. Section 2.2 outlines the VFBF by describing the 3 elements (SRQ1B). This framework will then be used in the empirical study.

2.1 The vertical farm business

2.1.1 What is vertical farming

For several years, there has been a need for novel agricultural techniques and improvements. This is evident by the problems the agricultural industry keeps facing. One of the main problems is the scarcity of useable land for crop production, together with the estimated world population of 9.3 billion people in 2050, climate change, water shortage, and other factors (Kozai, Niu, & Takagaki, 2015). Therefore, people started thinking about innovative ways to solve this problem.

The concept of a greenhouse has been around since Roman times. It too has advanced worldwide as a known and familiar way of producing crops. By scaling-up this familiar idea, with up-to-date technology, a new concept is formed that can produce more food within the same area. One of the innovators of this concept is the American professor Dickson Despommier, who came up with the term vertical farming (Despommier, 2010). The core idea of vertical farming is the stacking of surfaces vertically to produce food or medicine, while being integrated into buildings, located in the urban centers of the world. When this VF concept is successfully implemented, it can act as a sustainable urban crop production, which is then hoped to reduce the current pressure on traditional agriculture, and reconnect consumers with their local agriculture (Brin, 2016; Despommier, 2010; Kozai et al., 2015). Since the inception of the VF concept, the idea has transformed from merely stacked greenhouses, to a more modernized concept, strongly focused on indoor and controlled environment agriculture (CEA) technologies. Typically, the facilities can minimally manage the humidity, temperature, and gases required for efficient agriculture production (Brin, 2016). Some sources also refer to this concept as an indoor plant factory with artificial lighting depending on the type of the vertical farm (Goto, 2012; Kozai et al., 2015). In a more green urban architecture perspective is VFing sometimes referred as zero-acreage farming (Zfarming) (Specht et al., 2014; Thomaier et al., 2015).

2.1.2 Opportunities and advantages

Vertical farming is an aspect of urban agriculture which is the production of food – stacked vertically – within an (peri-)urban area. One of the most frequently used arguments for vertical farming is the potential of producing and consuming food locally in the city (Mougeot, 2000; Smit, Nasr, & Ratta, 1996). In this way VFing can play a supporting role in food security for large metropolitan areas and smart cities. Cities with higher quantities of urban agriculture projects indicate a higher economic development of a city. Countries with already existing, well-developed, industrialized, and market-oriented agriculture have

the advantages of the information and transportation network of international cities. These systems can be further used to boost their urban agriculture and interregional trade. Therefore, urban agriculture is becoming an emerging business opportunity in metropolitan areas (Kozai et al., 2015; Thomaier et al., 2015).

Vertical farming can also be a great solution for some of the current social trends, such as the local food movements, increased technical job availability, in addition to the need for food security in urban areas, and the level of food self-sufficiency (Deelstra & Girardet, 2000; Smit et al., 1996; Zasada et al., 2017). There is also a higher consumer demand for transparency in our food system and food safety. Consumers are more aware of what they eat, how it is produced, and where their food originates from. The consumer's social concerns are not unfair considering consistent food scandals that raise food awareness out of the need for consumer safety (Bánáti, 2011). Additionally, obesity is becoming one of the largest health problems in the world. Therefore, the interest in the fight against obesity is increasing among the population. It is suggested that local food production together with food awareness could help alleviate this problem (Oskam, Lange, & Thissen, 2013). Moreover, some cities are faced with empty buildings, resulting in a loss of precious space. It can then be suggested as usable space for vertical farms, which is also mentioned in the core idea of vertical farming. That being said, the social involvement of urban farming can also be applied to VFing. Therefore, a social integration plan within the communities and the commercial VFs is needed. Finally, in addition to the health conscious consumer, there is also an increase of environmentally conscious consumers (Armar-Klemesu, 2000; Golob & Kronegger, 2019). This type of consumer wants sustainably produced food, where all aspects of planet – people – profit are considered. Those considerations also fit within the vertical farming concept. (Oskam et al., 2013)

Within the vertical farm there is the possibility to grow continuous healthy, pesticide/herbicide-free crops all year-round at high rates because of the indoor controlled environment (Despommir & Ellington, 2008). The crops are not directly influenced or damaged due to unpredictable weather-related variations (e.g. storms or prolonged drought). Therefore, vertical farming has higher efficiency than traditional agriculture due to higher production quantities each year, and lower losses. The closed environment fosters the crops free of insects, given the physical barrier between the plants and the outside environment. Indoor vertically farming uses high technology, requiring facilities to have a holistic control over the production (Brin, 2016; Kozai et al., 2015). This makes it possible to optimize the water and waste management and strive for 100% reusable water system. The technical application of aeroponics can further nurture water use reduction by its higher efficiency water usage. VFing is thus seen as climate friendly. Additionally, VFing addresses energy use concerns by opting for indoor automated harvesting systems that eliminate the need for large fossil fuel consuming farm equipment. According to Despommier, VFing can reduce air pollution, CO_2 emissions, and reduce food miles. The latter of which is beneficial for the environment as transportation of goods – sometimes even with cooling – all over the world is second to traditional agriculture in its contribution to climate change. Therefore, Despommier's VF concept in addition to the modernized VF concept could support the reparation of traditional agriculture caused climate change (Birkby, 2016; Brin, 2016).

2.1.3 Challenges and disadvantages

Despite the many perceived advantages of VFs, some experts are still skeptical about the concept. This skepticism starts at the VF's placement and construction. Over the last decade land prices increased enormously, especially in large cities (Gale, Pack, & Potter, 2001). Therefore, the start-up cost of a vertical farm can be expensive, in addition to the already high building costs. This makes it difficult to build large scale vertical farms, as costs are too high and availability of land/buildings in metropolitan areas are limited. Vertical farms also use a lot of technology, automated systems, and artificial light made by LEDs (light-emitting diode)(Gupta, 2017). These factors lead to high energy consumption, which can then reduce the environmental and economic benefits originally perceived of VFing. Additionally, VFs could claim their products are organic because they do not use pesticides and herbicides. But this claim is still unclear, as some experts point out the requirements for the organic certification is not only the non-use of herbicides and pesticides, but also the entire organic soil ecosystem (Birkby, 2016).

Vertical farming would already be in a further stage of development from greater investments if they were capable of growing all types of vegetables, fruits, and even cereal grains – which is the major cash crop. The focus is currently on high-value, rapid-growing, small-footprint crops (e.g. lettuce), which is limiting (Birkby, 2016). In terms of high-density carbohydrates, VF crop production cannot currently provide sufficient calories to meet the standard diet. Vertical farms are enclosed systems, which is mostly seen as a positive aspect, but on the other hand, there are no insects for pollination of the crops. Alternatively, pollination is possible by hand, but requires high amounts of manually labor (Birkby, 2016). Further challenges for the VF industry are the constant need for increased efficiency and profitability. These aspects can only be achieved by improving the multidisciplinary knowledge via support largely by academic and technological research, action research, innovative ideation, and investment in large-scale VFs. Still the required amount of energy conflicts with the principles of sustainable food production (Birkby, 2016; Kalantari, Tahir, Joni, & Fatemi, 2018). One step to combat this problem is the development of new energy-efficient LEDs. Additionally, assembling a qualified team to fully operate a VF can also be a challenge. Successful operations usually requires high requisite knowledge and expertise from multiple disciplines, e.g. plant scientists, microbiologists, mechanical engineers, and electrical engineers, all with even more distinguishable practical knowledge of VFing (Kozai et al., 2015).

2.1.4 Vertical farming business typology (AVF, 2017)

This section discusses and explains all levels of the VF business typology and concludes in the display of the said typology. It is foremost based on the typology of the vertical farm association (AVF, 2017) and it includes 3 major levels: organizational level (organization, business model, size, and production purpose), constructional level (integration and placement), and farm level (exposure and grow mediums). These three levels form the base of a VF business.

2.1.4.1 Organizational level

Organization

The organizational level of a VF business is a key factor in the determination of the business's purpose. There are four types of VF organizations, thus creating deviations within the VF typology. The first

organizational type is the grower organization who has the main purpose to produce food for retail, food establishments, and/or directly for the end consumer. The main focus is producing high-quality products that meet the demands of their consumers. Grower VF businesses are referred to as commercial VFs. The second type is the technology organization who's focus is on the technology behind the VF. Here, technology refers to any of the applicable concepts such as light systems, automation systems, and water circulation systems, etc. This level of organization develops and supplies all products required for running any type of VF. Vertical farm technology companies typically have a (semi) operating VF as a proof of concept, in addition to showcasing the production capabilities to potential buyers. The third type of organization is the institutional organization who focus on the research of VFing, development of the VF concepts, and teaching about VFing. The institution can be a private research center, university, government organization, or a non-profit organization. Similar to the protype-VFs used by the technology organizations, the institutional organizations usually have small systems—the difference being that these VFs are used for the purpose of research instead of for sale. The fourth and final type is the consultancy organization, with the focus on advising and helping other organizations who are involved in vertical farming. The consultancy can be in- or ex-situ according to the situation, question, or level of complexity. Therefore, it is important to identify the purpose of the intended VF business, to select the correct organization (AVF, 2017).

Business model

As mentioned before there are several VF business types, which determines the purpose of each VF project and its business model. A research VF will have different main objectives, economics, and required facilities compared to a commercial VF (Banerjee & Adenaeuer, 2014; Liaros, Botsis, & Xydis, 2016; Spruijt, Jansma, Vermeulen, de Haan, & Sukkel, 2015). The finance behind the VF depends on the quantification of capital expenditures to build the site, together with the choice of the growing system, used technologies, and level of automation (Brin, 2016). Brin (2016) also estimated the price of a production unit to range approximately between $ 1.000 and 4.000 /m^2.

The commercial VFs can be split up in three business model categories: (1) Turn-key farm solutions and services, (2) sales of vegetables and fish, and (3) sales of systems. Turn-key farm solutions and services act in two fold through business-to-business (B2B) and business-to-consumer (B2C) transactions. Business to business sales structure provides a total package of commercial systems and small farm systems. Business to consumers sales structure provides home appliances and to some extent, small kitchen devices. Turn-key solutions can refer to not only the engineering, but also procurement and construction service (EPC), which provide solutions for design construction, installation, maintenance, and management of VFs. The second type of business model of sales of vegetables and fish focus on selling end products to retailers or even the consumer. Selling directly to the consumer can be done through e-commerce or the business's own selling point. Sales to retail or wholesale can be done via a distribution center. Finally, the sales of systems business model typically have VFs to demonstrate, promote, sell their products, and occasionally offer their facilities for the purpose of research (Brin, 2016).

Due to the lack of fully operational sites, it is difficult to predict the gross profits of VFs. According to Brin (2016), the estimated ROI should be between 8 and 12 years. Still there are a couple of products and technique developments that can enhance a grower's business model (Brin, 2016).

Table 1. Vertical farm business models (Brin, 2016).

VF Business models		
Turn-key farms solutions & service	*B2B*	providing VF systems + EPC service
	B2C	providing home appliance + EPC service
Sales of vegetables and/or fish	*B2B*	sales to retail
	B2C	direct sales to consumer (own selling point, e-commerce/delivery)
Sales of systems	*B2B*	showrooms for systems
	B2R	offer facilities for research

Size of vertical farm

Vertical farm businesses can be divided by size, depending on the number of employees, locations, and buildings. The three groups are start-ups, small and medium-sized enterprises (SME), and large enterprises. Start-up VFs are incipient businesses, with small single buildings and less than 6 employees per location. Start-ups are mostly characterized as technology driven businesses and are supported by funding from investors. A SME is characterized as businesses with one or more building/locations and/or more than six employees. Mostly, SME are developed from start-ups after reaching a certain level of maturity. When a business is established and has more than 40 employees and multiple sites, it is in the group of large enterprises.

Production purpose

The last aspect of the organizational level is the purpose of production. This aspect is strongly related to the organization and business model. Production purpose tells why the VF business is producing particular goods or using specific systems (Bocken, Short, Rana, & Evans, 2014; Kozai et al., 2015). Not all production purposes fit with the organization types and business models listed above. For example an institution is not growing vegetables for wholesale, but rather grow to teach and research. Of course multiple production purposes are possible for a single organization. There are eight types of purposes: grow to share (G2S), grow to teach (G2T), grow to produce (G2P), grow to retail (G2R), grow to wholesale (G2W), grow to clean (G2C), grow to heal (G2H), and grow to develop (G2D). G2S is a community-based purpose where sharing is central. G2T is an educational purpose where the VF is used to teach students and people who are involved or interested in the VF industry. G2P, G2R, and G2W have more commercial purpose, where the core activity is growing and selling crops in high quantities. G2C has a more unique purpose that is used to clean or threat water and air. G2H has a bio-pharmaceutical purpose to produce plants, which are used in the pharma industry as components for medicine. G2D has a main role in R&D (research and development) and NPD (new product development), where the VF is used to develop new ideas, techniques, and products (AVF, 2017).

2.1.4.2 Constructional level

Integration of unit

The way that the VF is integrated in a building is the first aspect of the constructional level of a VF business. To meet the original VF concept, the location of the VF should be within a skyscraper or otherwise unused building within city limits. While this idea is out-of-the-box and creative, it is also rather utopian as its technical and financial feasibility comes into question. Transforming a building into a high-tech VF can

bring high costs. Same for the incredibly high land prices in large cities, which can be a stumbling block for starting companies (Birkby, 2016). The total surface land surface doesn't necessarily matter, as long as the building is high or wide enough to support enough crop production to run a profitable VF (Brin, 2016). Transforming buildings and selection of land surface are of higher concern for VF businesses with the purpose of G2S, G2R, and G2W. Alternatively, if a company has the business model of selling systems, there is low necessity to be in the core of a city.

There are 3 possible levels to integrate a VF into a building. The first way is termed holistic integration, which basically means building a new factory where the components are integrated at the beginning of the building design. The second integration is retrofitting where the food production units are placed into an existing building, but where the building is not fully converted into a VF. An example being the basement of a mall is transformed into a VF. The last integration form is conversion, which means that an existing building is fully transformed to a VF.

Placement of vertical farm

With regards to building integration types, there are also 5 possible VFs placements for any given building (AVF, 2017; Ellingsen & Despommier, 2008; Kozai, 2018). These 5 placement types are as follows: rooftops, interior, façade, underground, and ground level. Rooftop placement is the simple concept of placing the vertical farm on top of an existing building. Interior placement is when the VF is placed inside of a building. The third type is facade placement where the vertical farm is attached to the facade of the building, this type can be placed on the building's interior or exterior facade. Underground placement is when the VF is in a basement, or anywhere below the ground level. The last placement type is ground level placement which seems redundant, however this type is usually characterized by a single-story VF unit that can be placed outside a building on the ground.

2.1.4.3 Farm level

Exposure of the crop

The decision of exposing the crops to sunlight and other natural elements has a large influence on the design, construction, and selection of technology when building a VF. The first crop exposure type is full exposure. This exposure type eliminates or decreases the use of artificial light, but also limits the integration and placement types at the constructional level, to crop production where only sunlight can reach—i.e. not in a basement or within the center of a traditional building. This exposure type is more useful when VF placement is on a rooftop or in an open-air farm. The second type – enclosed exposure – is similar to the full exposure type, as it utilizes sunlight as the main light source. The difference here is that the crops are fully protected against other elements of nature and therefore only require some adjusted technologies. The third type of exposure is closed exposure which mean there is no sunlight or other natural elements involved. The plants will use fully artificial light to grow, mostly provided by light-emitting diode (LED) lighting technologies. Other light technologies are also possible (e.g. TL and HPS).

Growing medium I

Aeroponic

Aeroponics is a growth method where plants are cultivated in an air (mist) environment without the use of soil, requiring little water. This idea was originally invented by National Aeronautics and Space Administration (NASA) to grow plants in space. Compared to other grow mediums, it is the most water efficient systems and can use 90% less water than hydroponics. Plants are fed by the nutrient rich mist with minerals and vitamins in order to grow (Birkby, 2016).

Hydroponic

Hydroponics is a growth method where plants are cultivated without the use of soil, instead the crop roots are submerged and grown in a mineral nutrient water solution. Hydroponic systems have two frequently used techniques, the deep-flow technique and the nutrient-film technique. The system behind the deep-flow technique uses a senor to measure the water level of the hydroponics. When the water level becomes lower than the set level, the plants gets extra nutrient enriched water. The solution is recirculated to the bare roots of the plant at a constant time interval. The second technique – nutrient-film technique – uses an ebb-and-flow system that adds water mechanically. Both systems make it easy to measure the loss of the nutrient solutions and are easily managed (Diver, 2000; Oskam et al., 2013).

Aquaponic

Aquaponics is a growth method that uses the hydroponic system combined with a recirculating aquaculture to create a bio-integrated food production (ecosystem) to produce fish, vegetables, and/or herbs. The nutrient enriched effluent from the indoor fishponds are used in the hydroponic system. The idea behind the system is the generated nutrients from fish manure, algae, and fish feed can be used as nutrients for the plants. These nutrients would otherwise be considered contaminants in a purely fish farm system, instead they can be used as liquid fertilizer for the plants. The rhizobacteria in the plant roots take up those contaminants. Additionally, the hydroponics serve as a bio-filter to keep the water fresh for the fish in the pond (Diver, 2000). Successful aquaponics requires special training, skills, management, and following the key elements to operate: hydroponics, nutrients in aquaculture effluent, plant adaptation, specific fish species, specific water quality characteristics, bio-filtration and suspended solids, and matching component ratio (Birkby, 2016; Diver, 2000).

Growing medium II

The difference between growing medium I and II is the use of soil, with grow medium I pertaining to soil-free growth methods. Growing medium II includes all types of soil-based growth methods, which includes the use or combination of the following: raised permanent or mobile planters, with soil depths above or below 6 inches. The permanent planter growth type is justly named ‘planter,’ while the mobile planter method type is called ‘containerized’. The depth of the plant in and on the soil also warrants categorization, with the term ‘extensive’ referring to plant root depth up to 6 inches in the soil and the term ‘intensive’ referring to plant root depth over 6 inches in the soil.

The VF typology

The vertical farm typology (Table 2.) gathers all aspects of the previous discussion, which are the building blocks of a vertical farm business.

Table 2. Typology vertical farms (AVF, 2017).

Vertical farm typology	**Organization level**	Organization	Grower	*Producing food*		
			Technology	*Developing and testing technologies*		
			Institution	*Focus on research*		
			Consultancy	*Providing and support*		
		Business model	Turn-key	*Selling systems and providing service*		
			Sales of food	*Selling food products*		
			Sales of systems	*Showing and offering facilities*		
		Size	Start-up	*Single location/building, <6 employees*		
			SME	*Possible more locations/buildings, 6 – 40 employees*		
			Large enterprise	*Multiple locations/buildings, >40 employees*		
		Production purpose	G2S	*Grow to share*	G2W	*Grow to wholesale*
			G2T	*Grow to teach*	G2C	*Grow to clean*
			G2P	*Grow to produce*	G2H	*Grow to heal*
			G2R	*Grow to retail*	G2D	*Grow to develop*
	Constructional level	Integration	Holistic	*New building design*		
			Retrofitted	*Partly transforming existing building to VF*		
			Converted	*Total transforming existing building to VF*		
		Placement	Rooftop	*On top of the building*		
			Interior	*Inside the building*		
			Facade	*To the inside or outside facade of the building*		
			Underground	*Basement VF*		
			On ground	*Next to a building*		
	Farm Level	Exposure	Full	*Plants are exposed to sunlight and other weather elements*		
			Enclosed	*Plants are exposed to sunlight but are enclosed from other weather elements*		
			Closed	*No exposure to sunlight and other weather elements, use of artificial light*		
		Growing medium I	Aeroponic	*Nutrient rich mist/air as grow medium, without soil*		
			Hydroponic	*Nutrient rich water as grow medium, without soil*		
			Aquaponic	*Nutrient rich water with fish culture as grow medium, without soil*		
		Growing medium II	Planter	*Crops planted in large container*		
			Containerized	*Single crop planted in container*		
			Intensive	*Crop planted into ground with a depth of >6 inch*		
			Extensive	*Crop planted into ground with a depth of <6 inch*		

As can be seen, there is a wide variety of possible options for the creation of a vertical farm business. Each business brings different managerial challenges and issues with them, so for the continuation of this research one type of business will be selected. There are plenty of companies who provide consultancy, research, or provision of turn-key systems, but the actual grower business seems to be the most challenging evident by the relatively low existing full crop production businesses.

SRQ1A: What is the relevant definition of a VF business?

The VF with the organizational level: grower, providing food, all sizes, and G2P/G2R/G2W, with the constructional level: all possible varieties of integration and placement, and with the farm level: all possible exposures and growing mediums will be selected as the definition for a commercial VF business in this research **(SRQ1A**).

2.2 The vertical farm business framework

This section elaborates on the three elements of the VF business framework to answers SRQ1B. Pervious section defined what a VF business and the possible VF formats are for this research. However, the vertical farm industry is a wicked situation. The situation can be dissembled in the organization of VF, the governance cooperation, and the enabling environment to gain a more holistic overview of the industry.

2.2.1 The organization

The first element of the framework is 'the organization' and consists of the core competencies and the operational aspects of the company. It includes the discussion and the decision making in terms of how the company will create its product, with the consideration of how advanced and innovative **technology** systems will be used. The second aspect is the various **positioning and location** possibilities of a VF**.** This aspect is believed to be important to considerate and is one of the core elements of a VF ideology. Additionally, VF vegetables and herbs have higher prices per kilogram due to the still high production costs (Birkby, 2016). Therefore, the **product attributes** are also a key element for commercial VF businesses. Product characteristics are important to consider in terms of product acceptance, product placement, and product marketing, in order to have a proper willingness to buy.

2.2.1.1 Technology

The technological aspects behind a VF system is a key element for commercial VFs. There is a wide variety of possible technology that can be selected to create an advanced plant factory. The use of innovative technologies is the drive behind the sustainable agricultural system, VFing represents. Over the past 10 years, the availability of technologies increased and created more advanced applications, from automation to computer-assisted tools used for production, management, quality, and scientific data (Kozai et al., 2015; Zeidler, Schubert, & Vrakking, 2013).

VF and greenhouse technology companies are investing in research to optimize their products in the best possible way. Procuring innovative systems for a commercial VF requires high capital and can influence the economic and technical feasibility of the operation. This makes it an important factor for the VF business and requires thoughtful reasoning to decide which technologies will be used, and how advanced the VF will be or need to be. The selection of the technology systems involves various factors, which can be approached in different ways. A first option is to think about which product the company wants to produce. Depending on the production goal, the appropriate technology is selected, followed by modifications to the building to fit the wanted technological systems. The second option a vertical farm manager has is to look the other way around, by analyzing the environment and selecting which building is available for the VF. After the selection of the building, the possible technologies can then be chosen,

followed by determining which products are possible to produce in that specific VF setting. In terms of cost, the level of technology (simple – advanced systems) will affect the building cost price, power cost, and water expenses.

To further analyze technological aspects, the purpose of the VF should be known. The VF purpose can influence how advanced the farm will or can be depending also on the available capital. Currently, the possible technological systems are: nutrient delivery system, water management system, light and power system, plant cultivation system, environment control system, fish farming system, food process system, germination system, and cleaning system (Kozai et al., 2015; Zeidler et al., 2013). The listed systems are not always present in a VF, but in short it can be said that a high advanced VF will have all systems, including the optional systems which require higher amounts of technical skill and expertise. In the Table 3. below are the various possible systems shown.

Table 3. Possible present technological systems in a vertical farm (Kozai et al., 2015).

System	Function	Standard	Optional
Nutrient delivery system	• Nutrient provisioning at specific quantity and time • Storing water and nutrients • Mix water and nutrients (ratio)	X	
Water management system	• Recycle and process: water, by-products, and used resources • Processing collected products • Deliver collected products to subsystems	X	Reusing of water
Light and power system	• Lighting: various spectra, intensity, and day/night cycle	X	Use of 100% artificial light
Plant cultivation system	• Ensuring optimal conditions for crop production • Structure for crops • Monitoring diseases	X	
Environment control system	• Monitoring air quality, temperature, humidity, CO2 level, and removal of unwanted gases		X
Fish farming system	• Monitoring water conditions, feed, and diseases		X
Food process system	• Process food, harvest fish and crops, separation of (in)edible biomass, and packaging		X

Germination system	• Monitoring seed growth, grow conditions, and transport of germinated seeds		X
Cleaning system	• Clean and sterilize equipment, recover re-useable equipment	X	Closed system

In addition to the decision making of which systems will be implemented in the VF, other operational aspects need to be considered for the VF production strategy. A VF can opt for multi-crop cultivation, which enables them to provide a wider variety of products and create more possibilities. Alternatively, opting for a mono-crop strategy allows the company to optimize and maximize the production efficiency using an upscaling principle. Today's technologies enable VFing to create closed-loop-recycle systems to boost the sustainable drive of the business, which can then be used in the branding of the company. However, implementing environmentally sustainable systems also increases the cost of the business, while there are suitable less advanced systems—open-loop-recycling—that can be used at much lower costs. For example, the institute of space systems conducted a feasibility study that calculated the required average edible biomass price for a break-even operation of a 37-floor VF-design. This specific study scenario concluded that the required sales price for edible biomass would need to be 9.88 euro/kilogram. Compared to the baseline used in that study – which had a price of 12.54 euro/kilogram – the study scenario had a lower operational cost (due to a significant decrease in power costs) when not using a fully closed-loop-recycle system (no waste management and no water recovery) (Zeidler et al., 2013). However, this conclusion is only an estimate because it hasn't been proven in practice. Granted, the conclusion of that study brings additional considerations to the overall decision making and reasoning for how innovated and sustainable a VF can be, given costs. Similarly, other studies calculated feasibility costs of vertical farms designs, all also only resulting in rough estimations, thus creating the need for further—action based—research (Al-Chalabi, 2015; Banerjee & Adenaeuer, 2014; Sharma & Patil, 2018).

Another technological consideration is the use of artificial light, a technology commonly use in greenhouses and VFs. However artificial light has the downside of raising power costs and creates additional heat. Natural light in combination with artificial light can reduce the amount of power needed, but this setup also introduces less controlled factors. The VF then becomes more dependent on sunlight. The ideology of VFing, using artificial lighting – mostly LED – creates the possibility of full control of the grow process. This is done by selecting only the specific light spectra, per crop species necessary for ideal growth (Gupta, 2017; Zeidler et al., 2013). In this way the yield can be maximized by shortening the plant growth cycle and eliminates weather variation, when compared to the use of natural lightning in conventional agriculture. The same feasibility study of Zeidler (2013), assumes the combination of natural and LED lighting is economically more feasible than a fully artificially lit system, especially when there is an option for the use of additional green energy (e.g. windmills, solar panels) to decrease the power costs (Oskam et al., 2013; Zeidler et al., 2013).

All the aforementioned possible production process options will affect the construction and the design of the VF building, in addition to increase or decrease the initial cost of the building. Outside of the cost of physically building and designing a VF, there is the cost of finding skilled employees to work the

technology. Implementation of advanced food systems and technology requires high levels of knowledge and expertise (BRON) that are nearly always provided by well trained and educated individuals. As result of the increased use of advanced technologies and systems, there is also an increase of agricultural development and AgTech movement. Additionally, further developments in technology and education created a variety of agricultural degree programs around the globe to provide highly skilled recruits for traditional agriculture (Sharma & Patil, 2018). With that in mind, VFs do have a higher need for skilled and talented recruits with specific knowledge of agricultural technology—even more so than in conventional agriculture. Ideally, VFs should have staff from multiple disciplines including mechanical, biological, and electrical engineers, horticulturists, data scientists, plant scientists and more, all with experience in controlled environment agriculture. Besides the technology and agricultural knowledge, there is also a high need for specific logistic and distribution practice. It is recommended that agricultural education focus on the current and future concerns of agriculture: disease-stricken corps, droughts, harsh winters, natural disasters, and climate change (Brin, 2016). This could be further fostered by schools and universities working in agriculture, horticulture, and forestry to stimulate their students to pursue an agricultural career, in addition to pushing new idea creation during school projects, in cooperation with industries. It is important for schools and governments to keep investing in these programs and projects to fulfil the need for specific skilled recruits (Brin, 2016).

The scheme below provides an overview of the discussed points from the 'technology' aspect of the organization element. It concludes that technology is at the core of decisions regarding both the building and the product of the VF, in addition to requiring the support of people who provides knowledge, maintenance, and expertise.

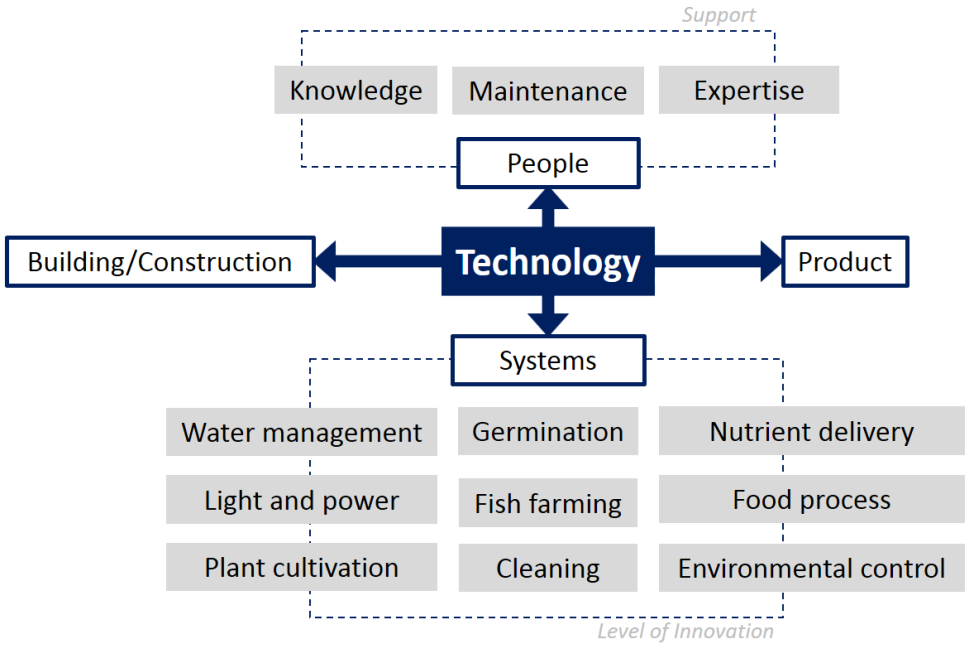

Figure 2. Systematic overview of technology in a VF (Author).

2.2.1.2 Geographic location

Despite the original intention of being placed in the core of an urban area, the VF concept now reaches beyond that scope and is seen in peri-urban areas as well (Specht et al., 2014). A vertical farm has the advantage of using a smaller area of land for the stacked cultivation of crops compared to conventional farming. This doesn't mean it has to be located on a building in city but has various possibilities, regardless location (Despommier, 2011).

The decision making for the specific location of the VF has an influence on the business model. Vertical farms have also been suggested as a solution for areas where the weather conditions, certain altitudes, and climate do not support agriculture, in addition to food deserts whether urban or rural, and of course metropolitan areas (Gentry, 2019; Molin & Martin, 2018). While these locations are considered opportune areas for VF placement, other locations might also be suitable. Opportunistic weather conditions should also be considered in the construction of a VF. For example, in areas with sufficient sun, a greenhouse-like VF with the addition of solar panels could reduce energy costs, by utilizing the sun as a natural resource. Another possibility is in areas with sufficient water resources, a water recycling system does not need to be used—as discussed in technology section—saving operational costs (Graamans, Baeza, Van Den Dobbelsteen, Tsafaras, & Stanghellini, 2018; Kozai, 2016).

Therefore, when building a VF, the location environment should be carefully analyzed to reduce operational costs as much as possible. Other considerations for picking an ideal location for the VF are availability of land and feasible building options. In the case of renovating a building into an advanced VF (retrofitted/converted), there are several aspects to meet those requirements. Aspects to consider include accessibility of electricity and water, constructional feasibilities, distribution opportunities, and building regulations. To conclude this section on positioning and location, considerations must be made in terms of what the intended product is, to what level of vertical integration is needed, and what can be done in the selected location's environment?

2.2.1.3 The product

Vertical farming can provide a wide variety of products with multiple possible attributes for its targeted consumers. The technology used in VFing is still unknown for most consumers, but it plays on today's environmental, health, and food safety conscious consumers (Kozai, 2016; Oskam et al., 2013). Therefore, products of VFing require additional marketing in such a certain way that the consumer brand/product awareness increases, as to provide consumers with knowledge of the technology, in order to gain their trust and appreciation of the innovative agriculture. Further reason for proper marketing of VF produce is due to the higher price per kilogram caused by the high production costs of VF products compared to conventional products. Therefore, VF products need to display their added value, so consumers have greater willingness to buy the higher priced product (Birkby, 2016; Hu, Woods, Bastin, Cox, & You, 2011).

There will always be consumer groups who are suspicious of products produced in high-tech, factory settings, in spite of conventional agriculture. However, in addition to being related to proper marketing, location selecting, and population group, process transparency can reduce consumer suspicions. Brin also

noted that as long as the price of VF produce is higher than the conventional vegetables prices, there is a high need for decent and informed marketing with a focus on gaining familiarity with the concept of indoor vertical farming (Brin, 2016). A study in Japan and Hong Kong found individual's impressions of the indoor VFing concept to be overall positive, with the only anxieties being related to the product itself. However, their study population showed some understanding in terms of the safety of VFing and its controlled environment, but soilless cultivation was not understood (Kozai, 2016). Similar research was conducted by Al-chalabi (2015), among stakeholder perceptions of hydroponics. That study had results that posed a possible social barrier for VFing. When asked about their impressions of hydroponics, the interviewees answered with comments of it being 'not natural' and 'chemicals,' giving off an overall negative perception (Al-Chalabi, 2015). Therefore, it is suggested that further promotion and education will help improve the acceptance of VFing, in addition to adapting a business model according to future consumers in each intended country (Kozai, 2016).

Most VF products will have a similar range of product attributes like freshness, traceability, year-round production, pesticide- and herbicide-free, and finally product consistency. However, the degree to which these attributes can be used depends often on the location, placement, and purpose of the VF business. For example, a VF that is within a city that delivers directly to a retailer can claim that their products are ultra-fresh, due to the reduced supply chain to the consumer. Additionally, because of the reduced supply chain, the ultra-freshness can also be linked to added health benefits, as the stored nutrients have not degraded over timeline of a traditional supply chain (Brin, 2016). Another main attribute is traceability and localness of the product. Depending on the level of marketing, the consumer can more easily know where the product came from. Fully enclosed VFs can provide year-round products, which can be convenience for their buyers and consumers (Sharma & Patil, 2018). Another common VF product attribute is the possibility of not using pesticides and herbicides, which is a huge selling point by certain consumer groups. Lastly, the way the product is processed can be much of the same, in that the most common concepts is the delivery of untouched products, or products that have been size reduced, or even combined into prepared salads or mixed bags as is the case of many vegetables and herbs. The aforementioned attributes are possible for most VFs, but it is still the responsibility of the VF manager to decide in which form the products will be brought to the buyer or consumer.

2.2.2 Governance cooperation

The second element of the framework is governance cooperation. This element involves the strategic task and collaboration between the **position in the food chain** and **partners** of the VF. A graphical overview of the key actors and partners in a VFs chain is provided in Figure 4. below. Vertical farming requires various actors and partners to sustain a successful business. Because farming crops indoors is an innovative, technological, and agricultural business, partnerships are needed to support investment in its research and development. Problems associated with VF – such as high production costs – are continually improved through new developments and research breakthroughs. These improvements thereby increase the

sustainability and profitability of the VFing business. Through these collaborations, an appropriate marketing strategy and marketing plan can be designed, triggering the sale of the VF's uniquely produced products. Therefore, it is crucial that the VF manager select the most beneficial actors and partners to create a strong value chain. In doing so, the business can deliver its high-valued VF products to the market and to its consumers with ease.

2.2.2.1 Positioning in the food chain

A supply chain consists out of various actors, who work individually or in aggregates, to turn raw materials into an appreciated end-product for its desired consumers (Omta, Trienekens, & Beers, 2001). Vertical farm food chains have a similar structure to the conventional food chain with actors like specific input deliverers, primary producers (the VFers), food processors, wholesalers, retailers, and at the end of the chain—the consumer. In the case of a VF, the number of intermediates varies depending on the positioning in the chain and what the level of vertical integration is selected. Vertical integration can create complexities in the supply chain, but it can also provide more transparency and traceability. According to Aakkula (2006) alternative food chains should focus more on transparency, traceability, and a good relationship between the actors within the chain to create added value for non-conventional products (Aakkula et al., 2006). Good collaboration and knowledge exchange are required to create a value chain. A value chain is a managerial tool to analyze and map all primary and supporting activities, both technological and economically distinguished, in order to add value to its products and create a competitive advantage. In this way the potential willingness to buy can increase, thereby covering the overall cost of the chain to gain profit (Kaplinsky & Morris, 2000).

Having an advanced plant factory, creates the possibility of processing and packaging the end-products for direct delivery to consumer or distribution centers (Sharma & Patil, 2018). This results in a shorter chain distance and reduced chain actors, more possibilities for vertical integration, and having a higher farm value share in consumer prices compared to conventional farmers.

A conventional agribusiness food chain can be mapped as a series of linked segments: a primary producer followed by food process/packaging, distribution center, retail (and wholesale or food services), and ends with the consumer, as shown in the Figure 3., value chain 1. In theory, VFing has 4 possible positions of disrupting the current standard food chain, as shown in value chain 2 – 5. Because a VF is not attached to a specific location—unlike conventional farms, which are typically situated in rural areas—VF can act more robustly, by taking on multiple hats under one roof. As the positioning of the VF get closer to the placement in option 5, the acting role of the VF consolidates the activities typically done by middlemen, downstream. This sort of consolidation of roles is called vertical integration, and has both advantages and disadvantages (Perry, 1989).

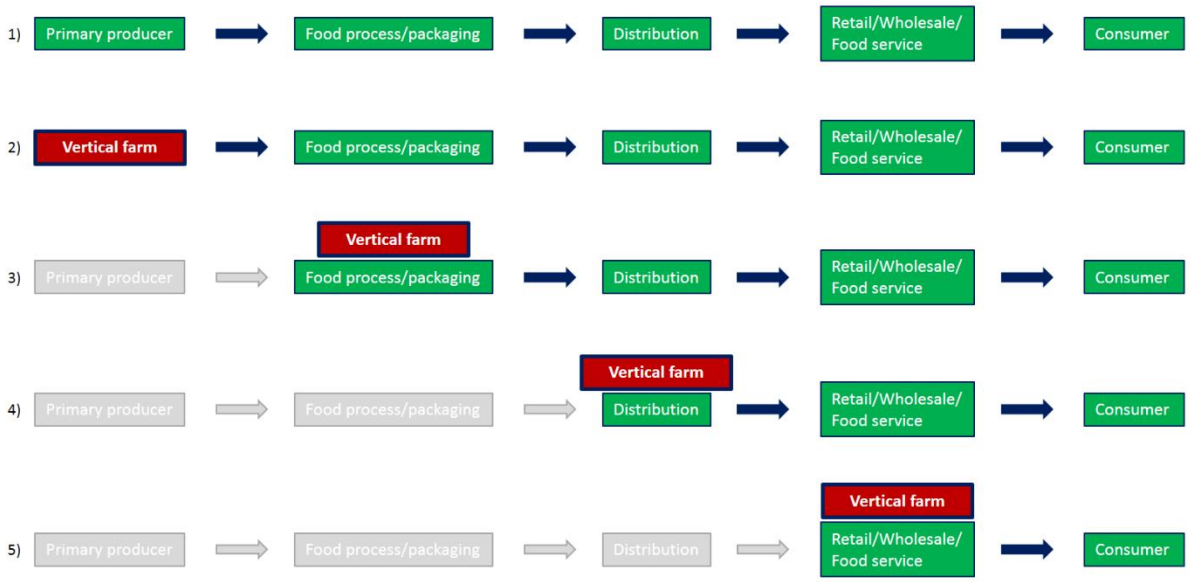

Figure 3. Suggested vertical integration formats for vertical farms (Author).

Depending on the positioning and purpose of a VF business, vertical integration can be a benefit or a stumbling block. At full vertical integration—as is the case in option 5—higher amounts of information are generated within the operating system, which increases the predictability and provides the leverage, of control within the supply chain. To sustain this level of integration, there will also be higher investment needs for equipment, construction, and specialized skills. Despite the higher costs, this level of vertical integration also promotes greater investment for internal assets to deliver value proposition and strengthen the core competences of the firm. With less chains in the food supply chain, there is a possibility for less transactions costs, which allows the VF to create its own scope, and size of the supply chain—with higher quality assurance (Kneafsey et al., 2013; Loertscher & Riordan, 2019). Still, full integration is not suitable for all VF businesses, as this level of integration creates even more complexities to the business itself. Therefore, it is sometimes better to outsource some of the activities depending on the capabilities—but also overarching purpose of the VF (McCarthy & Anagnostou, 2004).

2.2.2.2 Partnerships in the VF chain

Actors can be internal intermediates in the chain, but also external actors, which are the partners of cooperation. Possible key partners for VFs are technology providers, key-turn system companies, consultancies, and institutional organizations (Despommier, 2009). In the case for advanced VFs, it is important to be up to date with the use of highly advanced technologies. This is required to solve today's energy problems that are present in some VFs, but as well for improving the overall efficiency of the crop production (Kozai et al., 2015). Other key partners can be public or private depending on the needs and which business support services are necessary for running a VF. There are two key partnerships for vertical farms; those who support the VF and those who provide research-oriented knowledge. Finding the right partners is an important aspect to run an efficient, profitable VF (Brin, 2016). The first aspect of a partnership for VFs has the main focus on delivering support on a technological level, farming level, and operational level. Vertical farms require a lot of skilled people; there is a need for collaboration with

supportive partnerships, to bring the knowledge and expertise to the VF (Brin, 2016; Takeshima & Joshi, 2019). Mostly companies who provide VF turn-keys systems also provide consultancy and services to optimize the production or help with software issues. When knowledge or skill is lacking on a farm level, there are organizations available to supplement the gap in information. Support at this level is typically provided by the technology providers who offer full support packages with the purchase and use of their product. VFs can use highly advanced systems that are difficult to manage on a technical level. This can be solved by plenty of possible partnerships with operational optimization companies, depending on the need of the VF. A second aspect is the need for research and development. This aspect requires a lot of resources, which are not always accessible for the VF itself. Strong connections between universities, private, and public research centers can supplement a VFs lack of resources by providing valuable knowlegde (Brin, 2016). As VFing keeps rises beyond the concept it once was, a new sector within crop production has been born, bringing with it new businesses and departments to support the multifaceted needs of a progressing and competative VF business.

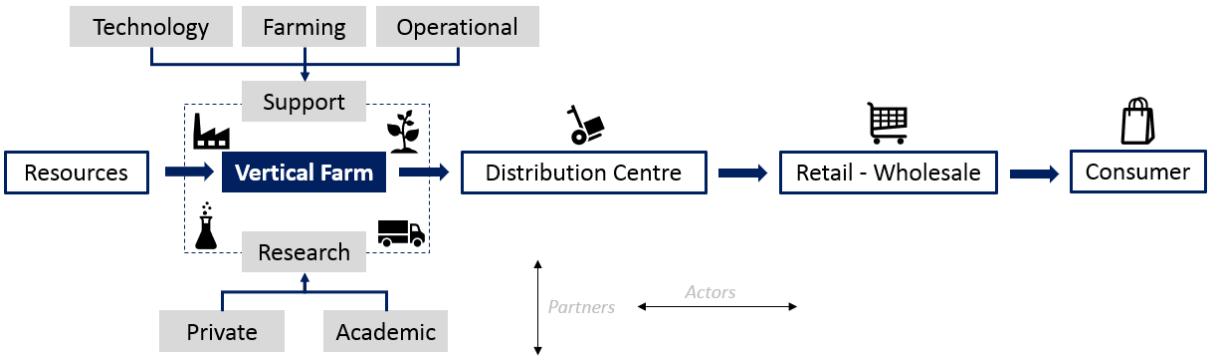

Figure 4. Overview of VFs key partners and actors (Author).

2.2.3 Enabling environment

The third and last element of the framework is the enabling environment. This element involves the interrelated conditions surrounding the VF including but not limited to regulations, laws, bureaucratic, politics, and culture (Brinkerhoff, 2004). The positive enabling environment is needed for vertical farming to empower the business and stimulate the movement of its product. Within this element, it is believed that the **legal aspects, governmental support** and **community** aspects are the key conditions for vertical farms, as to enable the creation of the specific environment vertical farms need (Bruce, 2019). In this case, enabling environment is sometimes also referred to as a business-enabling environment, based on its ability to empower an industry rather than a social community.

2.2.3.1 Legal aspects

Agricultural industries and businesses are subject to abide by regulations, laws, and codes throughout the supply chain, with particular enforcements in food regulations and operational rules (Deloitte, 2017; Sharma & Patil, 2018). Regulations and laws are location specific and vary around the globe.

VFs are different from conventional farms, they require additional government support to modify specific regulations and laws to enable the integration of a VF into a given environment and surrounding community (Brin, 2016; White, 2010). Currently – in some regions – urban regulations prevent the entrance and opportunities of VFs. For example, sometimes VF developers cannot obtain business loans and operation improvements due to complications in the regulations. Meanwhile many cities are also starting local projects to foster urban agriculture to promote heathier local food, with aim to build a resilient food system within the city (Brin, 2016). But due to local regulations, actually implementing the vision of these project proved harder than expected. Sometimes a reformulation is need for expansion and modification of the current regulations due to VFs not being able to use vacant industrial lands. Urban regulations for indoor farms reusing empty buildings, is still unclear and needs revision by the regional government (Brin, 2016; Thomaier et al., 2015). This needs to be fixed in order to foster industry development.

Tailoring the conventional farm regulations and laws for vertical farm adaption presents a wicked situation. This is not only because of the already settled regulations, but also because it requires additional safety and security assurances regarding building a farm on or in a building, thus creating potential infrastructural issues. Regulations also exist for the access of goods required for the building and operational aspects of the VF, bringing forth complications of codes specific to urban regulations (Al-Kodmany, 2018; Brin, 2016). Besides locational and constructional regulations, there are also food regulations (e.g. Good Agricultural Practices (GAP), local food safety regulations), equipment/production regulations, and non-production related codes (e.g. elevator systems, security, pest control) (Brin, 2016; Oskam et al., 2013; Zeidler et al., 2013). Still VF businesses have complications with laws and regulations (e.g. zoning), even when local governments make some changes in the regulations to support businesses (Besthorn, 2013; Brin, 2016).

Other regulation issues can be in the strictness of genetic modified organisms (GMO). The GMO regulation in several countries still follows zero-tolerance contamination with very restricted rules. This regulation in particular is sometimes hard to follow by certain VFs and their related businesses. The restriction of GMOs can exclude some players who try to enter the VF market by increasing the already high production costs. While most regulation changes start on a government level, many have suggested that regulations regarding VFs should be viewed on regional and local levels, often even on a case-by-case basis. This suggestion was made, in addition to a need for international regulations to create more collaboration within the entire VF industry (Brin, 2016; Slingerland, Ruben, Nijhof, & Zuurbier, 2006). Only then can the VF industry be fostered to help build a sustainable city—preluding a more sustainable planet. Regulatory reforms are required to stimulate VFing as an innovative business, to enhance the possibility of market entry, optimization, and up-scaling of the commercial farms. Despite several published works and investigations into the building of a high-tech VF, the situation remains a wicked problem due to city regulations, constructional codes, and laws (Brin, 2016).

2.2.3.2 Community involvement

Community involvement is the second aspect of the enabling environment. This particular aspect has been listed in literature as a key factor for resilient urban agriculture. Community involvement is often associated with socialness, however there are various reasons for communities to form aside from just location. These other type of communities can be focused on developing knowledge in the sciences, farming, business, investments, spaces, or even to promote social change (Besthorn, 2013; Brin, 2016). For vertical farming, community involvement comes in two forms, namely the people who are involved in the company's activities directly, and those in the community that help facilitate the knowledge and appreciation of the VF concept (Thomaier et al., 2015).

By spreading knowledge and appreciate of VFing to the location-based communities of a VF venture, new VF businesses can be better supported by their local population. In doing so a VF business within a city community can foster the distribution of their products more easily because the added value of VF produce will be understood. This in turn enables the VF and their business to thrive (Besthorn, 2013; Brin, 2016). Additionally, when the community is involved, the populous are more likely to support the creation of green procurement policies, which not only helps the involvement of the community by creating discussions about urban agricultural policies and agendas, but also ensues closer access to healthy food options. Getting the community involved with the VF business can also help develop a better added value chain by creating specialized ordering and delivery systems of the produced goods.

While these specialized systems can create additional costs, they may also help develop a more sustainable ordering model that allows competition or even collaboration with communities around the globe who've continue to develop, the exchange of information and experience (Kozai et al., 2015). As such, creating a transparent company image towards the consumers can incite the community's willingness to become involved with a new business, which can result in more appreciation towards VF products. Additionally, depending on the level of sustainability held by a VF, environmentally conscious communities can be garnished for support, in addition to help boost the green image of the city that the VF is in. These associations can bolster relations between the VF farmers and the citizens (Al-Kodmany, 2018). Building VFs within a city creates economic boosts and job opportunities for local citizens, which benefits the community by contributing to its overall welfare (Al-Kodmany, 2018).A key factor and a helpful promotor of VF community involvement is the introduction of the term vertical farming into school and university programs. In this way young people are aware of the concept, and instead of being faced with suspicion, they can be excited about potential opportunities to come out of this innovation. In some Japanese elementary school programs, vertical farming has been included in the teaching and textbooks on food production, familiarizing children with the VF concept at a young age (Brin, 2016). Similar inclusion of the VF concept is being integrated into US school curriculums, with applications towards science, technology, engineering and mathematics programs. This not only increases students' willingness to accept VF products for their own consumption, but it also peaks their interests in being involved with creating innovative solutions and new ideas that could help VFs.

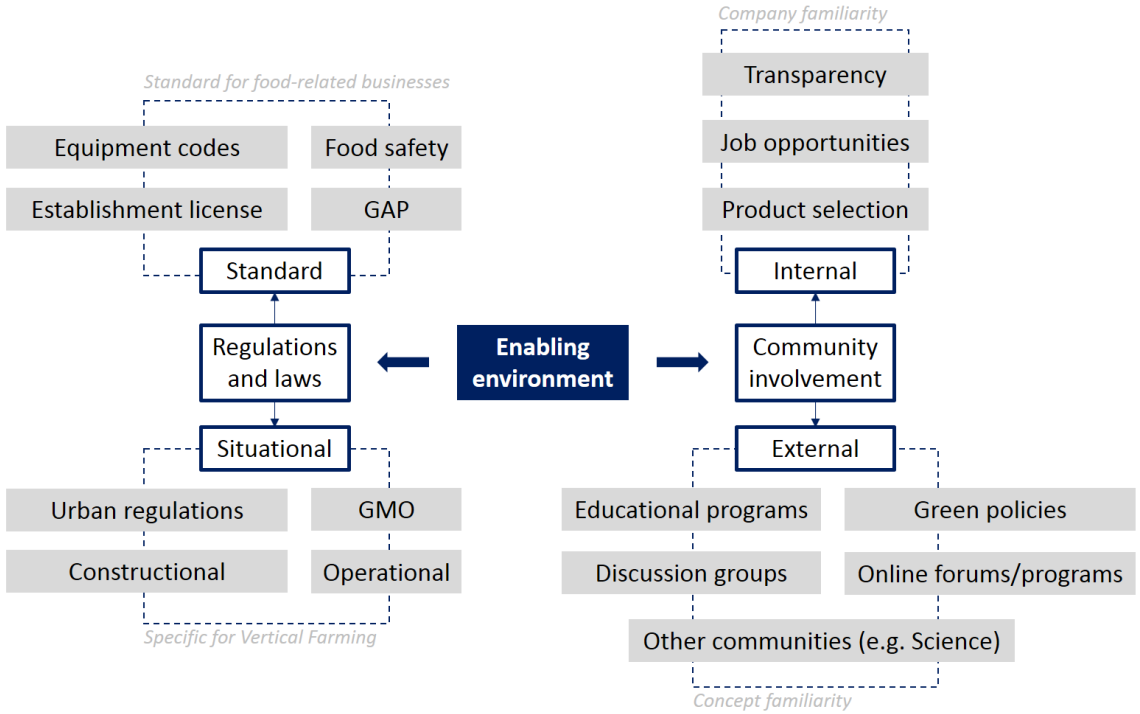

Figure 5. Overview enabling environment aspects (author)

After describing and investigating the three elements of the VFBF it is now possible to answer **SRQ1B**:

What does literature say about the organization, governance cooperation, and enabling environment elements?

The organization element mainly exists out of 3 variables namely technology, geographic location, and products attributes. These 3 variables form the core characteristics of a VF business and together with the organization element of the VF typology. The governance cooperation is characterized by the positioning in the chain and the partners who collaborate with the VF Business. The last element is the enabling environment, which consists of regulations and laws that apply for the VF and the involvement of the community. The previous mentioned elements are suggested to be key elements for managing a VF business **(SRQ1B)**.

3 Methodology

The methodology chapter will describe the methods of the empirical part in this exploratory research. The previous chapter investigated the available insights and literature of the managerial aspects of VF businesses in order to develop a VFBF. The gained information will then be used to set-up this empirical study. The study begins with a research strategy to overview the methodology. Followed by the research group section including the sample method and to describe who was sampled. The operationalization part describes how the variables will be measured. Lastly, the method for data collection and analysis will be described in order to produce valid and reliable results.

3.1 Research strategy

While technical, economical, and environmental aspects of VFing are frequently researched, VF management is still poorly investigated. Therefore, an exploratory research is selected to study the managerial side of VF businesses (variables). Exploratory research is often conducted for areas where little is known, and to investigate conceptual relationships and distinctions (Kumar, 2014). After the theoretical investigation where secondary data is obtained, the empirical investigation will exist out of interviews with VFers and VF industry participants. The research strategy was changed overtime, because experience lead to more suitable data collection methods for this report. Originally an online survey was developed and pretested. It was too long and complex according to the tester, who is employed by a VF. After shortening and strategically simplifying the design, the survey was sent out to 40 participants. However, this effort still resulted in a response rate of 18%. By creating a personal network in the VF industry over a course of 4 months, there was greater willingness for personal interviews.

3.1.1 Qualitative research

3.1.1.1 Semi-structured interviews

Interviews are commonly used in qualitative research for the collection of primary data from people (Kumar, 2019). As the VF industry is relatively new and complex the use of in-depth interviews is more appropriate for these types of situations and the need for in-depth information (Kumar, 2019).

The semi-structured interview is characterized by having pre-determined questions which are not always asked using the same wording. Each interview unfolds differently depending on the flow of the interview, the experience, and knowledge of the interviewee (Kumar, 2019; Longhurst, 2003). Questions were sometimes asked in different sequences and wording. However, all the framework variables were discussed and questioned. A semi-structured interview has the flexibility of an unstructured interview, but still has an outline to keep the interview between the lines (Kumar, 2019).

3.1.1.2 Open-ended questions

Open-ended questions are those where the answer options are not provided by the interviewer. Instead they encourage the respondent to answer in their own words (Kumar, 2014). These types of questions are recommended for exploratory research, especially when the sets of suited answers are unknown (Züll,

2016). Open-ended questions generally generate a larger range of answers. However, it requires more time and effort to answer, and the level of depth varies among the respondents (Kumar, 2014).

3.1.2 Cross-sectional study design

A cross-sectional study implies that there is only one contact moment with the study population. Cross-sectional designs are recommended for studies focused on the prevalence of certain situation that need to be identified and explored. The cross-sectional design is extremely simple and ideal to get the overall picture of a situation. However, it cannot be used to measure change over time (Kumar, 2014). An alternative for this research could be a longitudinal study design. This design enables an investigation of changes in the VF industry over time and the reliability of the developed framework. Once the aim of the research is decided, the study population group is selected and contacted (Kumar, 2014).

3.2 Research group

3.2.1 Sampling

Non-probability sampling is a commonly used method to build a research group in qualitative research (Kumar, 2019). Expert sampling is the most suitable for this research. The experts in this research are the VF growers and VF industry participants. The commercial VF industry is relatively new, but sufficiently mature enough to interview business owners and others, who are experienced in agriculture, agrotechnology, and agribusiness.

First, to start of the sampling, Google search was used to gain an overview of VFs located in Europe and North America. The used search terms were: "*Vertical farms*", "*Vertical farms USA*", "*Vertical farm Canada*", "*Vertical farm Belgium*", "*Vertical farm the Netherlands*, etc. Multiple countries were tried as well as other terms for vertical farm: "*Plant factory*", "*Indoor farm*", "*Urban far*m", "*CEA*", etc. Asian VFs were not included, despite the relatively successful VFs in Asia. The VFs on other continents, besides Europe and North America, were excluded due to the assumed lower accessibility of data. Besides the commercial VFs, a majority of the companies found were commercial growers but as well technology, research, or consultancy-based companies (internet search: ±150 companies).

The second phase of connecting with VF managers by attending two VF conferences (GreenTech, Amsterdam, and Indoor Ag-Con, Las Vegas), in addition to collaboration with the rather new Farm Tec Society. This supported the development of a contact network and increased the willingness of participation among the research group. LinkedIn was used to connect with the previously met individuals and to find additional participants. The initial aim was to have a research group of 30 participants.

3.2.2 Participants

Commercial vertical farm businesses should be approached, as the aim of the research is to develop a business framework around VF management. The commercial VFs can provide primary data on the subject of themselves. Literature and Internet sources revealed various VF types, and several more businesses that are involved in the VF industry. However, not all VFs have the same purpose, evident by the various

organizational structures. For this reason, the included literature study provided background on the various VF types and organizational structures. From the literature study, the first sub research question 1A was answered, defining what a VF business is for this study: In this study a VF is a business with an organizational level that includes commercial growers and food providers. However, due to low response of the commercial VFs, VF industry participants were also included in the research to broaden the scope of the managerial aspects. It is believed that these participants can add meaningful data.

The research group is mainly located in Europe (EU) and North America (US or CA) as can be seen in Table 4. The initial goal was to have a research group of 30 participants but a total of 25 was obtained (N = 25). A total of 13 vertical/indoor farms (VF) were interviewed and 12 industry participants (P). The selected individuals to be interviewed on VFs were mainly in top management positions. Generally people in managerial positions are knowledgeable in their provided subject to provide meaningful answers (Kumar, 2014). The industry participants are companies/persons who are involved in the vertical/indoor farming industry. Their occupation can be in consulting VFs, researching VF systems, researching the industry, investors, or operational support and service providers for vertical farms. Additionally, the approximate industry experience (in VF/indoor farming) of each participant is shown. A majority of interviewees have < 5 years of direct VF experience, showing parallels to the increased interest in this industry. The duration of each interview ranged from 15 – 60 minutes depending on the interviewee and other external factors. The interviews were conducted over a time period of 3 months.

Table 4. Research participants overview, including; ID, location, company, industry experience, function, and interview duration (N = 25)

ID	Location	Company	Industry experience	Function	Interview duration
CA-VF1	**Canada**	VF/Indoor farm	<5	Top management	20 min
EU-P1	**Europe**	Consultancy	>20	Top management	45 min
EU-P2	**Europe**	Research	<5	Business developer	15 min
EU-P3	**Europe**	Industry support	>20	Top management	60 min
EU-P4	**Europe**	Investments & research	>15 - 20	Produce industry analyst	50 min
EU-P5	**Europe**	Industry support	<5	Top management	25 min
EU-VF1	**Europe**	VF/Indoor farm	<5	Top management	50 min
EU-VF2	**Europe**	VF/Indoor farm	>20	Top management	30 min
EU-VF3	**Europe**	VF/Indoor farm	<5	Top management	50 min
EU-VF4	**Europe**	VF/Indoor farm	≥5 - 10	Top management	25 min
EU-VF5	**Europe**	VF/Indoor farm	<5	Top management	40 min
EU-VF6	**Europe**	VF/Indoor farm	<5	Researcher	15 min
US-P1	**USA**	Research	<5	Research & Management	25 min
US-P2	**USA**	Consultancy	≥5 - 10	Top management	25 min
US-P3	**USA**	Research	<5	Researcher	65 min

US-P4	**USA**	Research & training	≥5 - 10	Top management	60 min
US-P5	**USA**	Research	>20	Researcher	35 min
US-P6	**USA**	Technology & Systems	>15 - 20	Business developer	30 min
US-P7	**USA**	Technology & Systems	<5	Sales	15 min
US-P8	**USA**	Industry support	>15 - 20	Government agency	40 min
US-VF1	**USA**	VF/Indoor farm	≥5 - 10	Senior advisor	60 min
US-VF2	**USA**	VF/Indoor farm	<5	Top management	25 min
US-VF3	**USA**	VF/Indoor farm	≥5 - 10	Top management	20 min
US-VF4	**USA**	VF/Indoor farm	<5	Researcher	30 min
US-VF5	**USA**	VF/Indoor farm	≥5 - 10	Top management	30 min

The diversity of the population group provides a wider range of answers because of different experience and backgrounds. One of the participants experienced a bankruptcy with a VF 2 years ago. Failed businesses can provide useful information for the VF Business Framework. Companies who experienced organizational failure have sufficient knowledge of the precise circumstances (Jennings & Beaver, 1995).

3.3 Operationalization

Operationalization is the process of showing how the concept and its variables will be measured in empirical research (Hambrick, 1980; Lune & Berg, 2016). The variables –derived from the theoretical framework– of the VFBF need to be operationalized to gain a better understanding. This is part of the empirical research and will be used as interview guidelines. In Table 5. below all the variables are shown with their indicators. The operationalized framework act as a baseline for the questions in the interviews to create an interview guideline shown in Table 6. Depending on the interview, each topic was treated differently because of different background, experience, and knowledge of the VFer or VF industry participant (e.g. interview with investor is more financial oriented). The variables are used as a topic list for the interviews. The guideline also provides examples of generic questions for each variable. After 4 interviews, the topic of vocational training was mentioned often as a key issue for the vertical farm and indoor industry. Therefore, the researcher decided to add vocational training to the interview guideline together with a question regarding the prospective of the industry within the next 5 years.

Table 5. Overview of construct, variables and indicators

Construct		Variables	Indicators
Vertical Farm Business Framework	The organization	Technological innovation	*VF systems / Data support / Level of exposure / Sustainability*
		Geographic location	*Geo-characteristics / Climate / Urban - Rural*
		Product characteristics	*Freshness / Nutritional value / GMO / Pesticides*
	Governance Cooperation	Position in the food chain	*B2C, B2B / Distance to consumer / Food actors*
		Partnerships	*Technological / Operational / Capital*
	Enabling Environment	Social aspects	*Community involvement / Social investment*
		Government support	*Subsidies / Local recognition / Industry support*
		Legal aspects	*Legal issues / Food law / Constructional*

Table 6. Construction of interview guideline

Construct	Variable	Interview question
Organization	*Technology*	What is the importance of technological innovation for your VF?
		What are the key issues and opportunities for technological aspects in the VF industry?
	Location	Why is your vertical farm at its current location?
		Is the location important for vertical farms?
	Product	What are your product properties?
Governance Cooperation	*Loc. Food chain*	What is the importance of collaboration between various actors in the food chain for your VF?
		Is there potential for B2B?
	Partners	Who are the key partners for your vertical farms?
		How do these partners add value to your vertical farm?
Enabling Environment	*Social*	What are the social aspects of your VF?
	Government	Is there need for federal governmental support?
		Did you need local municipality support?
	Legislation	Did your VF face issues with legislation?
+	*+*	If you have other aspects that are not discussed, please elaborate below!
		How do you see the VF industry in the next 5 years
		Is vocational training the key for scalability of vertical farms?

3.4 Data collection

This section outlines how the data of the interview was collected. After the first connection with the participants, a date was arranged to conduct an interview. Most interviews were over phone and occasionally through Skype or Zoom. During the interview the researcher had the interview guideline displayed to question the interviewee. The interviews were recorded and notes were taken during the interview. The transcriptions were made after the call with the notes and records. Later, the transcriptions were sent to the participant for permission and affirmation of their given answers.

3.4.1.1 Introduction email

An introduction email is an important part of the code of conduct to prevent ethical issues in research (Kumar, 2019). The introduction email was sent after the first connection with the participant in-person or through LinkedIn, and after receiving the participant's email address. The introduction email can be found in the Appendix 7.1 and the belonging attachment (Appendix 7.2). The introductory email includes a short introduction of the interviewer and his institution, a short description of the research and its relevance, and proposes a date/time for the interview. The email also mentions that all collected data from the interviews are confidential. No company or person's name will be displayed in the report, nor linked to answers.

3.4.1.2 Interview protocol

A semi-structured interview has an interview guideline and brings the control in between the interviewer and interviewee (Harrell & Bradley, 2009). First, at the beginning of the interview, the researcher introduced himself and his institute together with the purpose and relevance of the study. The confidentiality of their provided answers was mentioned again.

Next, the interviewees were first asked to introduce themselves and their company of employment. Employment history, company history, company goal, field of expertise, etc. were always asked or intuitively shared with the researcher. As part two of the introduction, the framework and its aspect were mentioned and explained. The developed framework was then used as a guideline for the interview, but follow-up questions came depending on answers or the knowledge of the interviewee. Below in Table 7., examples of follow-up questions can be seen in different situations. Subjects that were perceived as important for the interviewee were further elaborated as well.

Table 7. Question examples depending on the interviewee's answers

Situation 1	Situation 2
Q: How important is technological innovation for your company?	Q: How important is technological innovation for your company?
A: We just wait and see what comes on the market.	***A: We are developing our own systems, so very important.***
Q2: How high is your company's need for vocational trained employees?	Q2: What are your current issues with your systems?

The sequence of the questions mostly started by discussing the organization, governance cooperation, and lastly the enabling environment. All interviews ended with the same question: how the participant assesses the development of the VF industry over the upcoming 5 years.

To finalize the interview, participants were thanked and told they will receive a transcription of the interview, and later a summarized version of the final report. They were asked to review the transcript and modify if necessary. The confidentiality of their answers was mentioned once again.

3.5 Data analysis

This section outlines how the gathered data from the interviews will be analyzed with MAXQDA, thereby translating the data into meaningful results to answer the main and sub research questions. Interviews collect qualitative data in the form of a transcript and needs a systematic approach to analyze in the best way possible (Renner & Taylor-Powell, 2003).

The primary data will come from open-ended questions, which are questions where the answer is not provided and the answer is recorded by the interviewer (Kumar, 2014). This research is exploratory and requires in-depth information to analyze the current situation. Therefore, open-ended questions where chosen. These type of questions provide the respondent the possibility to provide answers freely, resulting in a wide variety of answers by various respondents (Kumar, 2014). In this way, elements or aspects that are not included in the VFBF are revealed during the interview and can be added. Additionally, this questioning method allows interviewees to indicate agreement or disagreement towards the elements of the literature study derived VFBF.

After conducting the interviews and gathering all provided data, a content analysis was completed to identify the main answers and aspects from the respondents' answers. Content analysis was conducted with MAXQDA to computer analyze the transcribed interviews. In order to increase the validation of the data, a transcript of the interview was sent to the interviewee for conformation and verification. Validation of the information ensures the accuracy and the credibility of the data (Kumar, 2014). MAXQDA helps classify the data with coding and identifying main themes. The frequency of certain themes provide meaningful prevalence that is up to the researcher to conclude (Kumar, 2019). The main themes were developed to identify different words or phrases with the same meaning. The created codes were assigned to the various themes to enable the counting of occurrence. Kumar (2011) describes the following steps in qualitative data processing: identify main themes, assign codes, classify responses, and integrate themes and responses into the text of the report.

Qualitative data research has a first-order (open and axial coding) and second-order analyses (theoretical concepts and relations) (Gioia, Corley, & Hamilton, 2013). The first-order analysis had 2 rounds of coding; open coding and axial coding. The first round of open coding resulted in a large amount of codes (124). The code names were labelled with provided words in the transcript. Double coding occurred frequently because certain content is overarching. After the first round, all codes were displayed in an overview. The

researcher identified similar code names to subcategorize and merge codes (e.g. “direct to consumer”, “close to consumer”, “consumer distance”, “B2C” = B2C). By doing this, the amount of codes was decreased to 44 codes (Appendix 7.3). This simplified the axial coding step because the researcher gained better understanding of the transcriptions and a first perspective of code combinations. This was possible using MAXQDA and its supporting functions. In the second round – axial coding – codes were grouped in the belonging operational variables of the research. This resulted in 8 variables and 2 additional themes; *future prospective* and *other aspects. Future prospective* was used as code for answers focused on the upcoming changes and trends in the vertical farm industry. The theme *other aspects* was used as code for all the answers not directly related to the variables of the framework according to the researcher.

In the second-order analysis, all the codes and their related text segments were grouped per variable to search and suggest concepts and relations (Gioia et al., 2013). Using computerize analysis supports the systematic approach for all transcripts. The final coding structure can be found in the Appendix 7.3. Additionally, memos where used to describe codes and the thinking process of the researcher. MAXQDA can provide an overview of occurrence of codes. This was used for the reporting but cannot statistically or quantitatively be used, because it does not directly indicate the importance of a variable over another.

4 Results

This section presents the analyzed data after digitally coding the 25 interview transcripts with MAX QDA. The 5 subsections deal with respectively the 3 research constructs; *The Organization*, *Governance Cooperation*, and *Enabling Environment*, in addition to the associated variables, plus *Other Aspects* and *Future Prospective*. The latter two categories were added as result of the coding process. Each section ends with a discussion and together they will answer SRQ 2: How does the theoretically derived VFBF apply to VF businesses with regards to the three key terms?

4.1 The organization

Organization is the first key term of the framework and displays all the results given from the participants. After the results, the findings of technology & innovation, geographic location, and product will be discussed.

4.1.1 Technology & Innovation

The majority of respondents found technological innovation important. Vertical farming is a technology driven and innovative type of agriculture. The topic of technology and innovation in VFing was discussed with all but one participant. Recognizing that the terms technology and innovation can span abroad range of topics and different connotations, the subsequent answers were representative of the participant's unique background and level of understanding. The main question that started the discussion of this topic was: "How important is technological innovation for your VF?". 13 out of 25 participants answered to this question started with; "Yes, very important". Derived from provided answers, the following aspects were mentioned and discussed; cost, profitability, automation, economy of scale, high tech, track record, and proof of technology (Table 8.). The economic aspect of VF prevails as cost, profitability, and economy of scale take 100 out of 160 hits.

Table 8. Occurrence of technology & innovation codes

Code name	Occurrence (#)	%
Cost	42	26.3
Profitability	30	18.8
Economy of scale	28	17.5
Track record/Proof	23	14.4
High tech	18	11.3
Automation	14	8.8
Complications	5	3.1
TOTAL	**160**	**100**

References to cost and technology were mentioned often by all four groups (US-VF, US-P, EU-VF, EU-P). There was no clear difference between the vertical farmers (US/EU-VF) and VF industry participants

(US/EU-P). Participants from VFs said they are currently experiencing high costs due to labor and energy. The answers from US/EU-Ps also referred to technology and labor as being a major cost. Cost and profitability were frequently mentioned in combination with the terms; economy of scale, high tech, and automation. Investing in high tech solutions was thought to help increase the automation process, by introducing robotics thereby also reducing labor costs. Despite recognizing the importance of technological improvements, 4 VFs admitted that their current systems are yet not highly advanced. Instead, they keep their systems simple, efficient, and affordable. Only when there are more proven systems available, would they invest in more automated systems. They use automation in some steps of the process, but only when necessary.

> "*We came in contact with turn-key delivery system providers, but our conclusion was that these people didn't know the market. You produce crops in an expensive system. They didn't know the real issues, how to solve them, and how to reduce the cost."*

These interview excerpts and 14 out of 25 participants also illuminate the involvement of new parties in the VF industry and emphasis the need for valid proven technologies and systems. One of the EU-P is an investor in agriculture and mentioned the lack of track record. Not only is there a lack of proven technology, but also a deficit in overall proven business models. This gap discouraged the investor to invest in European and American VFs in general. The need for validated VF systems and business models are followed by the need for standardization and sustainable metrics for the industry. Standardization was mentioned by 3 industry participants and 2 VFs but where coded under the term Track record/Proof.

> *"There is not enough proof to justify everything. I think this industry needs sustainability metrics that have more proof of what they are doing and bring some standardization in the industry."*

> *"The technology part can be confusing for the VFs. We are having global sustainability development goals now for the first time. We know about the advantages of vertical farming, so there is room for a global standardization for Urban and VF food production."*

> *"So now, any light company can do whatever they want, and claim whatever they want. Which also makes it harder for vertical farms where to look for. We don't know how good company A is compared to company B. Therefore, the light equation is really important."*

> *"A problem with vertical farms is over-promising and underdelivering the technology. So under-promising and overdelivering is a valuable key aspect."*

Two industry participants who are also active in conventional agriculture and horticulture, and one VFer with a farm outside the city, were more critical about VFs in city centers. They believe that economy of scale can hardly be reached within a city. There are too many factors inhibiting the possibility to have such a large farm in a city. The US-P with 20 years of experience in agriculture doesn't believe that vertical farms can disrupt the food systems with the models they currently have. The VFs don't have the right scale and greens to feed populations.

"Vertical farming is a new trend in agriculture, and I believe it is currently overrated. There is a lot of non-sense and storytelling sold to the public and investors. Companies are talking about feeding the world but in the meantime, they are producing high end products for a really niche market. They are definitely not disrupting the food chain and solving food security."

Despite the critic of the current VF industry, this participant (US-P) believed in the future potential of VFing, especially in certain situations. The participant sees more feasibility and profitability in greenhouses to encounter food security in critical areas.

A number of industry participants (14 out of 25) mentioned the subject of the energy consumption of VFs. Vertical farms often market themselves as sustainable farms. Some participants (4 out of 25) find the high energy use somehow contradicting. Even the VFs participants refer to high energy bills during the interviews. However, there is a belief that the energy industry landscape will also evolve in a couple of years. Public policies and raising prices will affect the use of energy coming from fossil fuels, while the renewable green energy sector will grow, becoming significantly cheaper according to some participants. Together with the belief in the innovation of these technologies and an increase in efficiency, more affordable VF systems may be created.

"The KWh price will change over time… Some companies in the US don't focus on the energy cost, because they believe it's going to change anyway…"

"We need to figure out the Energy equation and integrated new types of innovation in the VF industry."

Another view of the energy aspect, among 3 out of 25 participants is the location of your farm. If you're located in areas of the world where land is cheap, the placement of solar energy becomes cheaper.

"In the areas we work, the solar energy is very cheap, because of the low price of land. This is key for having cheap energy. This makes more sense to build a vertical farm…"

Within energy the need for better Heat, Ventilation, and Air Conditioning (HVAC) was mentioned by 6 out of 25 participants. Plenty of vertical farms struggle with HVAC and ask for improvements. It creates also substantial capital costs and sometimes causes problems for plant growth.

Besides innovation in technology and energy components VF participants mentioned the continued need to improve other operational aspects such as mixing units, water filtration, nutrition delivery systems, seeding, etc. One VFer and industry participant mentioned the need for innovation in seeding and plant genetics. There is a great need for modified seeds and plants specifically for indoor farming.

"I see a lot of potential innovation in the seeds and we need to optimize that for indoor farming, however there is more innovation needed to accelerate this industry."

4.1.2 Geographic location

In the ideology of vertical farming the VF farm is expected to be located within an urban area (Despommier, 2010), but in practice VFs can be found in rural, peri-urban, and urban areas. Competition comes with geographic location but that is further elaborated in section 4.4 *Other Aspects*.

Table 9. Occurrence of geographic location codes

Code name	Occurrence (#)	%
Urban core	9	34.6
Climate	7	26.9
Food supply	4	15.4
Specific demographic	3	11.5
Suburban	3	11.5
TOTAL	**26**	**100**

The key aspect for the decision making of VF's location is in the VF's goal, vision, and model. Among the interviewed VFs, there where VFs in the city center (5), around the city (5), and in rural areas (2) (The division of location was based on how the interviewee mentioned the location of the VF). Depending on the location, they have different business models. With each location comes a certain market or demographic to feed.

> *"… they build local farms for restaurants and other organizations, which is a good model for vertical farms who are directly in the city. In this way you have a certain market… you can reduce your distribution risk and you can grow for a specific demographic. This gives you a certain stability and can bring you the focus on growing with a consistent product quality for your market, even if you have a small-scale farm."*

Some of the industry participants and VFs have a visionary perspective of VFs in the city. They see it as a tool to add value to the cities of tomorrow. There is the belief of greater added value (e.g. food self-sufficiency) for the community when the food production is within the city.

Others saw vertical farms around the city—in more suburban or rural areas—as more feasible. According to them this higher feasibility is caused by lower land prices. It is believed that the disadvantages of extra distance to the customers is not going to change a lot if the VF is on the outskirts of the city, instead of within it. In this way VFs can more easily reach an economy of scale and realize lower initial costs. Furthermore, depending on the location, the farm can experience lower regulations pressure if it is further away from densely populated areas.

> *"The cost of the ground wasn't that much. We are currently renting."*

> *"Within three miles we do have high end restaurants. It is a poor area but further down it is totally different."*

"We are in the side boarder of this city, 9000 square meter, 14 000 bags per day, and everything goes to the city. The ground wasn't that expensive. We are still on agricultural land. I don't believe in reconverting spaces into vertical farms. We built a fully new building outside the city, so everything is on point and there are no facility issues"

Next to distance also physical climate plays a dual role in the decision making for the location. An agricultural beneficial climate suits conventional agriculture. Therefore, poor and harsh climates can be more suitable for greenhouses and vertical farms due to the ability of controlled environment farming. However, certain climates can help with energy and heat production by using alternative green sources of energy.

"I think it all depends where you are. If you look at West-Europe and for example Canada. There you can perfectly grow in greenhouses. Due to the climate and location."

"The regions we are working have poor climate for [traditional] agriculture."

"The area is geothermal beneficial – and so low expense in thermal energy, and electricity."

4.1.3 Product

Product attributes were not always discussed during the interviews resulting in a low number of occurrences. These low scores were probably because vertical farms produce products from the same product range (herbs, greens), and market the same product attributes; local, ultra-fresh, tastier, no chemicals, and produced in a sustainable way. Therefore, the researcher didn't emphasize on this topic during the interviews, and it seemed self-evident for the interviewees.

Table 10. Occurrence of product codes

Code name	Occurrence (#)	%
Premium	9	56.25
Consistent quality	5	31.25
Branding	2	12.5
TOTAL	**16**	**100**

Most of the interviewed VFs grow a product in the range of aromatic herbs, leafy greens, microgreens, or salads. Only one EU-VF claimed to be able to produce tomatoes, cucumbers, and bell peppers, but will launch these products in an indoor farm in Africa. The same VFs that kept their systems simple and efficient, focused more on the quality of the end-product. It is critical to have consistent high-quality produce because it is sold as a premium product, which has to fulfill higher consumer expectations. The process to reach the required quality takes time and experience in growing indoors. 10 out of 25 participants mentioned the consistent high quality as one of the most important aspect of the business.

"We market it just as a good quality local product. Not really as indoor farming products. Freshness is just in our quality aspect. People buy it because of the quality and it's the quality that makes the people happy."

"We are different in terms of consistency and the quality we provide. We have done 4 years of research just with the focus on the end quality of the product."

These so-called high-end products have a high price that can be contradictory with the vision of "feeding the world". This contradiction results in criticism towards vertical farming. This criticism was mentioned by 3 US-Ps but countered by other VFers. Vertical farming is in a development phase and needs these fast-growing greens to develop the skills and expertise to grow. It is believed that later on, more varieties will be possible to grow and extend the market. The American VF market experienced issues with foodborne diseases and caused a lack of trust among consumer, which is why salads and leafy greens are seen as more suitable for growing indoors. These vegetables are a part of our diet and it makes sense to grow them. One of the European industry participant's organization did a consumer research in Europe with the results that people don't want to pay more for VF products.

"Most VFs are producing high-end products, that is a trend that everybody sees. So how do we help those people in poor areas is a good question. But selling these high-end products is the beginning of a phase to get there and that is how it goes. At some point we will have lower prices."

"Company X did a research among consumers, if they are open to pay more for the VF produce, but people don't want to pay too much more for it. If you can produce it at the same price and better quality then it might be working, otherwise it is very unlikely. But you shouldn't think you can ask double the price. That might only work in more extreme circumstances."

Besides quality, VF products can play an important role in health and enjoyment. The unique growing circumstances can create more nutritious and tastier vegetables. Taste and nutritional value are higher because of the energy levels the plants get. This enables them to grow more secondary metabolites that are the nutrients and aromas. Higher nutritional values can be interesting for health and nutrition aspects. New varieties and rich in aromas can be interesting for restaurants and chefs in the development of new dishes. However, one industry participant said that people in Europe wouldn't be that impressed because Europeans are already used to high quality products.

"There are a few reasons. We can bring much more flavor and nutrients in the product compared to outdoor produce. The plant gets so much more energy it can produce more. There are 3 levels of photosynthesis. The first one is for surviving, the second one for growing, and the third one is the production of secondary metabolites if it gets enough energy. These secondary metabolites are also the nutrients and flavors in the produce."

"You wouldn't be impressed by the premiumness of the salad they sell here."

4.1.4 Discussion

Technology and innovation are a major aspect for vertical farming. It is an important point of focus for the VFer. Technology and innovation both can increase the cost and it decrease cost, when the right decisions are made. Cost is a major issue for vertical farms in relation to labor, energy, land, building, and systems (Angotti, 2015; Banerjee & Adenaeuer, 2014; Zeidler, Schubert, & Vrakking, 2017). Going for highly advanced technological systems requires a lot of capital and operating costs. Having advanced machinery requires suitable building infrastructure and appropriate expertise to operate that machinery. However, automation and the implementation of robotics in the farm can reduce the total labor cost. Some larger VF companies shouldn't be seen as only exclusively regarded as farms, but rather as technology companies who are developing systems and formats. VFs should be careful in the decision making for their selection of VF model and in deciding on the degree of technological advancement. Various available systems on the market still have operational flaws that can affect the efficiency of the systems and the quality of the end-product. VF technology does not offer a simple positive or negative picture, but various operational aspects are involved in what makes it a complex matter. The major aspects of geographic location are climate and the distance to the city core in relation with the company's business model. Harsh climates or altitudes are believed to be more suitable for vertical farms. However, talking all other items into the decision-making, vertical farms can be found anywhere, contrary to initial expectations on VFs. Keynote of the product section is the need for an optimized production process with a drive for consistent high-quality produce. Even if the VF has a market for its product, low-quality can be harmful for the business. There is a wide variety of opportunities in terms of nutrition, health, and applications for VF products.

4.2 Governance cooperation

Governance cooperation is the second key term of the framework and displays all the results given from the participants. After the results, the findings of position in the food chain and key partnerships will be discussed.

4.2.1 Position in the food chain

Position in the food chain is not the same as the location of a vertical farm. The variable includes the subject of the VF in relation to other actors in the food chain and the consumer.

Table 11. Occurrence of position in the food chain codes

Code name	Occurrence (#)	%
Distribution center	12	40
Grocery chain	5	16.67
Food manufacturers	5	16.67
Vending model	4	13.33
Restaurants and public spaces	4	13.33
TOTAL	**30**	**100**

An often-discussed model, with the participants, is the location of a vertical farm next to or close by a distribution center (DC). This is overarching with the geographic location aspect. It is believed that this is logistically more feasible and economically interesting. This was mentioned by 8 participants both American and European, 4 of the VFs were also currently doing so, or working towards it. The distribution center can be both a vegetable and fruit DC or a grocery chain DC. The DC model is suitable for large scale production transport, while still benefiting from being local depending on the location of the VF. This also reduces the operational focus on dealing with the transportation of products. Being in the city center can cause problems for transportation due to traffic and other factors. However, small-scale farms do not necessarily have to do this and can be located in the city center to be hyperlocal.

> *"We are on the campus of a very large distribution center. We use one of their buildings, so our produce just goes across the street where it later goes to retail warehouses or service warehouses. It is all pretty close. You don't need to be close to the consumer, but close to the distributor."*
>
> *"Yes, that look very interesting and looks like a good idea to build closer to existing DCs."*
>
> *"The idea is to be close to the city so you can decrease the food miles, but think about what the major food retailers are doing, e.g. Walmart, they have 47 DCs, and they want to work with VFs near their DCs, and there are a lot of opportunities. The point is to build large farms near retail centers, so you have some serious cut in the supply chain. Also building your produce near the distributor is good and can make big contracts."*

There is also the belief--mainly mentioned by industry participants--for a business models where VFs primarily produce for food manufactures, B2B. They see a lot of potential in this area but need more proof of working models. The focus should be on more critical produce to produce plant-based ingredients, greens for fresh-food service, or other models.

> *"For sure, nice things can be developed, especially in the food ingredients sector. For example, stevia. It is an easily growing plant but currently it is difficult to get a good product."*
>
> *"I believe there is a lot of value in the B2B, the cooperation of a VF with the larger food manufacturers. I know a few examples, but the names are confidential. But yes, that's where the real opportunity is."*

The code grocery chain was used, but the answers were often closely related to the DC model. Several VFs (6) have contracts with grocery chains but not necessarily linked with the DC of the chain. However, they emphasized the importance of having a contract with a buyer, so you create more certainty.

There have been substantial investments in the vending model type of a VF to place in a grocery store. This investment occurred during the period of interviewing. Resulting in various talks discussing this newer model. Two VFers and 3 industry participants don't believe in this model. They think it is not practical nor feasible, due to low profit margins of small retail margins and the small-scale model. Alternatively, it helps the vertical farm industry by introducing the concepts and building consumer acceptance of the technology. It also adds a sense of trendiness to the retailer. One US-P mentioned that the vending

machine VF model has greater potential outside of Europe. However, two industry participants said you can't compare it with larger VFs because it is a totally different business model.

> *"It is a different model, and you cannot compare directly. They changed their model from providing the vending model and maintaining it to a model that just can be used as a shell. This can be good for the vertical farm industry because it shows the consumer the technology, the freshness, and the possibilities for different varieties."*

> *"Retailers don't make money with it, I think. It is just an extra service for consumers a mimic, hype, image, like having your own orange squeezers to make fresh orange juice. But the operational management looks pretty difficult to do…"*

Selling VF products to restaurants continues to be an approved positioning due to the premium characteristics of VF products. By selling the produce to restaurants, higher prices can be asked. As of today, this position is still often observed. Some participants see opportunities for public places such as school, large companies, and hospitals.

> *"they build local farms for restaurants and other organizations, which is a good model for vertical farms who are directly located in the city"*

> *"Facebook, Google, schools are also good opportunities for vertical farms to produce food for a large group of people locally."*

4.2.2 Partnerships

Partnerships are important in any business. This sub section presents the key partnerships for vertical farms according to the respondents.

Table 12. Occurrence of partnership codes

Code name	Occurrence (#)	%
Expert knowledge	15	40.54
Operational support and service	12	32.43
Local knowledge	7	18.92
Trader/Seller	2	5.41
Venture capitalist	1	2.7
TOTAL	**37**	**100**

The answers about partnerships were sometimes overlapping with the variable being the position in the food chain. Some VFs and industry participants referred to the importance of partnerships with retailers or food manufacturers, but one US-P referred to his collaboration more as customer relationship then as a partnership. One of the US-VF had a long quote on partnerships showing the different understanding of partnerships.

"University for research, nonprofit organizations for CSR work, policymakers. Collaboration with retailers is more customer relationship than partnerships."

"Technology providers, lightning companies, dosing companies, system providers, environmental controls, pluming, ACs, electricity, … Critical one, but also looking for partnership with universities and academics for helping you with research, also very important… Unavoidable key partners are also the certification organizations, testing, ..."

"The larger cooperation bought our company and we are vertically integrated."

There is a variety of possible partnerships, but key partners are often the ones that fill in the expertise or knowledge gap of a focal firm. Depending on the VF's own resources, the suited partner can vary. If there is a gap regarding farming skills, a collaboration or partnership with farm specialists is often mentioned (14 out of 25) as solution. However, if the gap is more a technological issue, respondents refer to the technology supporting companies for a collaboration. Various VFs and industry participants mentioned the role of universities and non-profit organization in case of a gap regarding research and development. The vertical farm industry is still in its development phase which increase the need for collaboration.

"We are still looking for research partners to collaborate and start projects. We are focused on an open knowledge chain and focused on optimization of the cultivation techniques and circular methods. I believe that a close collaboration with the industry can add value through practical experience."

"It depends on the company and their skill set. In this phase collaboration is important because it is a new industry, and a lot still has to be developed."

Local knowledge encompasses answers where the respondents emphasized on specific need for local knowledge or relations with local partners. VFing is often about local food production, but there is a need to adapt the business model to the local habits or consumer preferences. Meaning that you can't build the same farm in different cities or producing the same products.

"You cannot just show up and deploy a system and sell produce. There is need for that local feeling and it is also still people oriented."

"You need suppliers who know the local market, you need a local investor, and work with local universities."

4.2.3 Discussion

The position in the food chain plays a major role in the business model of a vertical farm. Each position has different key deliverables but having contracts and the certainty of a buyer can support the business more than selling to consumers directly. Buyers can be food manufactures, restaurants, food deliveries, wholesalers, retail consumer, etc. Various VF typologies will result in different decision making in the selection of a position in the food chain (Thomaier et al., 2015). There is need for more validation of certain business models, in the coming years, a more diverse business landscape will be seen.

Like in any innovative industry VFing is in need for collaboration and partnerships in order to succeed (Nieto & Santamaría, 2010). VFs are improving and optimizing their production systems. There is a high need for collaborations due to gaps in knowledge and expertise. An interdependency is created as tech and research companies also want to gain new insights and collect data from commercial VFs. Partnerships in the form of vertical integration can enhance the ability to innovate and improve the market position (Ziggers & Trienekens, 1999). One of the US-VFs is applying vertical integration and expressed the benefits that may come from this. The importance of local contractors, suppliers, and organizations should not be underrated.

4.3 Enabling environment

Enabling environment is the third key term of the framework and displays all the results given from the participants. After the results, the findings of social aspects, governmental support, and legal aspects will be discussed.

4.3.1 Social aspects

Social aspects are often linked to urban agriculture and vertical farming, especially with regards the community-oriented VFs (Thomaier et al., 2015). The topic of social aspects was often started with the question: "How important are the social values of your VF" or "How important is community involvement for a VF?" The following results occurred (Table 13.):

Table 13. Occurrence of social aspect codes

Code name	Occurrence (#)	%
Social value	13	43.33
Consumer acceptance	9	30
Community involvement	8	26.67
TOTAL	**30**	**100**

Social value was found to be a broad term, give the diverse responses of the interviewed participants. A few US-VFs (11 of 25) see social value and community involvement as an important aspect of vertical farming in cities. However, it plays a larger role in smaller-scale VFs and is used more as a marketing tool by the larger commercial VFs for consumer acceptance and acknowledgements according to 4 participants.

> *"Really important, it is one of the critical points of a vertical farm business.*

> *"I think for the larger ones, it is more a marketing aspect, but for the smaller once it is more mission related."*

Two US-VFs are focusing more on the importance of adding social value to the community than creating a new VF solution. Their mission statement is people-oriented; they do social investment. It is believed by

several VFs and industry participants, that in these cases true value is created. However, profitability stays a key aspect for any VF business.

> *"They need more investments in these areas to support. We will exclusively hire people who come out of prison, returning citizens, and help them preventing going back by giving them jobs and support them to function in society."*

> "We were looking to add value to the community and find a way to help people with a disability by providing work. It was about creating a workspace that was easily accessible for the community."

These quotes provide evidence truly adding value for a community, but beyond that—there is a low belief in social values, because measuring social value for a community is difficult. Community involvement was often mentioned in the interviews, but they didn't necessarily relate to social value. Community involvement is also the interaction with local organizations. This may concern local chefs, organizations, and municipality. Engaging the community is a advertise tool to share the existence of the VF within its local area, doing so was recommended and mentioned by various participants during this study.

> *"You need to know the local community, you need to know what they want, what they need. They also need to know what you are doing. You have to collaborate to have that social aspect."*

> *"We have people coming over to taste our products, like chefs, and they really appreciate our products and are surprised how good it is."*

Community involvement was also mentioned in relation with consumer acceptance and recognition. Vertical farming is still an unknown area for many consumers both in the US and Europe. Therefore, VFs and other organizations should work on the recognition of vertical farming as it is believed to support the business.

> *"Yes, there are educational opportunities, and showing all the good aspects and benefits of vertical farming and getting them familiar with the phenomena of vertical farming, changing their perception. Getting to customers and market can still be hard to enter. So, it can help you to establish in the market."*

> *"Yes, absolutely, but you need to tell your story well. In the beginning people are often skeptical of a fully indoor growing product, but once the try it and understand it, they really appreciate it. We did a lot of panels, working with retailers, chefs, and they were all positive."*

However, a few participants said community involvement is not always necessary. People already eat from hydroponics systems (e.g. salad), but they don't know it. It is not only about how local your product is but also about how good it is, besides being farmed indoors. A lot depends on the local population and how sophisticated they are. Two participants mentioned that it is very unlikely that you can sell high-end products in an area with low income (e.g. the new farm in the Hague).

> *"I don't think it is the role of the grower to teach people about vertical farming that is something for others. In the future it is not about the distance of the farm to the consumer but about the farmer himself and its product."*

4.3.2 Governmental aspects

The governmental aspect is the variable that includes all topics about the involvement of municipalities, regional authorities, and federal government. The starting question for vertical farmers was: "Did your vertical farm receive government support?", and for industry participants: "Do vertical farms need government support?"

Table 14. Occurrence of governmental aspect codes

Code name	Occurrence (#)	%
Governmental support	19	73.08
Acknowledgements	4	15.38
Policies	2	7.69
Relationships	1	3.85
TOTAL	**26**	**100**

Governmental aspects are strongly location-related and will be different for every vertical farm, even for farms in the same country. All vertical farms mentioned government involvement during the interview, but they may have experienced it differently. All agreed on the lack of recognition and support from their government. This does not necessarily relate to one-on-one business support (subsidies) but more on the support of the VF industry as one (defining vertical farming, recognition of industry, clear regulations, etc.)

> *"We didn't have any support in that sense at all, no subsidies."*
>
> *"Now… nothing because there is no market, so that's normal."*
>
> *"Not only for the Dutch but for most of the governments, vertical farming is not yet in the regulations and is not really defined. There is no clear pathway for when you want to start a vertical farm."*

Only one CA-VF pointed out positive support from their government, on various levels.

> *"Yes, we do, the government is really open and receptive to urban farming, so we have several levels of government support, from the municipality and federal government."*

There is an increase in recognition but only on low levels. The industry is still too small and the proof of feasible business models is not there yet. On this account it is normal that a federal government does not include VFing in their program. Both in Europe and in the USA, a lot of money goes to conventional agriculture. This has historical and political reasons. Open field agricultural is one of the oldest economic sectors and has a large market share. Open field farming is still the major food provider of cities. The governance of agriculture is more controversial and has a lot of political power. There is a form of protection for the conventional agriculture, but it is also a way of life. Only West and North Europe have a more progressive political model behind agriculture, that support different ways of agriculture and innovation according to US and EU-Ps.

"The Dutch government defined the top sectors, and agricultural is one of them. They find technology important in horticulture, but they are still waiting to see how vertical farming will turn out and develop. It is different on the more regional level, they are more enthusiastic."

"The USDA has a special history and "unique conservative character". Their focus is primarily on the large cooperative farms and it is very political oriented. There are now more sub-organizations involved that are working on climate aspects in agriculture and on vertical farming. There are a lot of interesting people there. They also have a grant for vertical farming research, which is helpful for the CEA industry."

4.3.3 Legal aspects

Compared to the two previous variables, legal aspects were not frequently mentioned. Legal aspects are closely related to the government aspects and was often overlapped during coding. This subject concerned regulations and legislation applied on VFs, and if it inhibits certain aspects of VFing or not. For example in literature, zoning was often reported as an specific issue for VFs. Areas in cities have building restrictions and local policies that might can restrict farming (Al-Kodmany, 2018; Angotti, 2015; Mukherji & Morales, 2010).

Table 15. Occurrence of legal aspect codes

Code name	Occurrence (#)	%
Regulations	9	69.23
Building and land	4	30.77
TOTAL	**13**	**100**

Most US/EU-VFs struggled with the same regulations that every food business must deal with. There is a whole series of food regulations (e.g. food safety) and other aspects that food companies need to apply and check. Only 3 US-VFs mentioned specifically zoning and real estate issues. The downside of zoning and other regulations is that it can be time consuming. Thus, legal aspects can delay a VF, but it didn't inhibit the start of the business. Together with the building regulations, various VFs dealt with controls and inspections. Sometimes controls and inspections require adaptations (e.g. enclosing ventilation unit on roof). Legal aspects go together with the governmental support for smoother regulations for urban farming. One US-P mentioned under the legal aspect more as a real estate problem with the understanding of the extreme high prices of land in cities.

"Zoning, water issues, whether you use your own water or municipality water both have strict regulations. We also had some issues with items that were attached on the building, which were for environmental control."

"No, just the regular regulatory stuff and issues, but there were some restrictions and questioning in some respects. But food safety was the biggest one."

"No not at all."

"Food standards, local strict zoning rules, just the regular pathway is pretty strict."

The industry participants (10 of 25) pointed out the same aspects as the VFers but discussed more the policy making around this subject and the relation to governmental actions. The subject of a unique label for vertical farm products was mentioned as well, but in a way that it is not necessarily for the industry. This topic popped up because VFing is claimed to be better as organic produce. There was once a discussing in the industry for a specific VF product label to show the consumer CEA products and its assumed benefits.

> *"Yes, no doubt, but it is not that big of an issue anymore. However, it requires a lot of talking and it is very time consuming and it is about finding the right partners in the municipality."*

> *"I think there is just a lot dealing with policy and zoning issues. It really depends on where you are, for example each state has different rules."*

> *"There is a lot of things going on and there are many policymakers, but they don't know what is going on. It is currently hard to represent the industry because it is new and innovative. The regulations are also an important part because, we are growing food where there was not food growing before. So, food safety questions arise as well. Also, the definition of vertical farming is very vague and unclear."*

4.3.4 Discussion

Vertical farming is often related to social aspects, in reality there isn't that much substance in it. A vertical farm can be both commercial and social-oriented, but it is rare. Depending on the VF business model there is a tradeoff between optimized production process and social engagement. The provided social value to a community of a VF should be more investigated before marketing certain claims. Other urban models (e.g. community gardens) seems to be more socially valuable (Thomaier et al., 2015).

VFing as it is today, has too small of a market share to be fully incorporated by the government. The political culture and history of agriculture is different depending on the geographic location. Vertical farms can count more and more on local municipalities' support, especially the people-oriented VFs (Barber, 2013; Deelstra, Boyd, & Biggelaar, 2001). Although, VFing still needs to prove itself by developing larger farms with an economically interesting track record. Only then more involvement of governments will show up. The climate agreements also force governments to look at more environmentally friendly and sustainable agriculture (Jordaan, Davidson, Nazari, & Herremans, 2019).

Major legal aspects for vertical farms are issues among zoning, building a farm (food production) in a city and food regulations. However safe work space wasn't mentioned by the participants but is relevant (Al-Kodmany, 2018; Angotti, 2015). Zoning was not discussed with VFers who has their business outside the city. Currently, there can't be changed that much about the food regulations. It only emphasizes the need for food quality management and expertise to meet the obligatory requirements. Legal aspects are part of the enabling environment but are also found to be more a result of the governmental actions towards vertical farming.

4.4 Other aspects

Besides the three key constructs (organization, governance cooperation, and enabling environment) many other aspects where raised by the participants. Some aspects where more frequently mentioned than others. Below an overview of all other aspects. One third of all used codes during the content analysis was under this section. The researcher decided to make 4 subsections: training and education, market and industry, cross-continental, and others. The topic training and education was mentioned so often that the following question was added to the standard questions: "How important is vocational training for vertical farms?".

Table 16. Occurrence of other aspects codes

Code name	Occurrence (#)	%
Training and education	38	30.16
Market and industry	35	27.78
Cross-continental	24	19.05
Data and knowledge sharing	12	9.52
The Netherlands	8	6.35
Hybrid model	7	5.56
Agricultural issues	2	1.59
TOTAL	**126**	**100**

4.4.1 Findings of other aspects

Training and education

The need for more educated and specific trained employers was a critical aspect mentioned by all participants. No matter the model of VFs (social and commercial-oriented), there was always a high need for properly trained and skilled employees. Problems with technology was not necessarily the gap, but finding people educated in plant science, growing and maintenance of plants, and farming, etc.

> *Finding the right people is currently a big issue for the industry, there are a lot of tech people, but a lack of agricultural expertise and workers, who know how to grow. Getting these people trained is also hard to do, because you need actually farms to learn how to work with these technologies. There is also now competition with other industries for these types of people like the cannabis industry.*

According to four participants the industry is cherry picking the head growers from all areas. Especially the larger farms with a lot of capital investment. This situation became also more difficult because of the rise of the cannabis industry who are looking for the same people. There are agricultural schools, but they don't always have the right curriculum. The VFs are not necessarily looking for highly educated farmers but also looking for the practical experienced indoor farmers. This lack of agricultural experience was assumed to be a reason why some vertical farms went bankrupt. They often referred to the high costs,

but farming was a major issue as well. As was repeatedly mentioned, a VF needs a consistent premium quality and that requires expertise.

> *"More importantly, fundamentally, is the plant science that goes with the management of your facility. How the plants grow, how they don't grow, and how to deal with diseases and problems."*

> *"Absolutely, our workers didn't have real training nor field experience. One grower had the competence and just came from school but missed the experience, the other grower had experience but missed some knowledge."*

> *"Yes, that is sort of a problem. It is hard to find the right biologists and agronomist for these kinds of jobs. But we were lucky to found a few."*

However, six VFs solved this problem by collaborating with experts and operational support services. Ten of the EU/US-Ps are working on this issue in some degree to support the vertical farm industry. The support goes from talking with universities to developing new curriculum and starting programs to create training centers. Farmers of the future, who will work in the VFs will need more knowledge than only growing plants. There is a need for that unique combination of plant science, farming skills, and a feel for technology. The issues for the universities and training centers is the need for funding the programs and trainings facilities.

> *"We will need more training centrums for the farming, but also technicians for the robots."*

> *"Massively, not only vertical farms but for all hydroponic systems and indoor farms. It is also normal due to the low count of commercial facilities. I think universities can play a huge role in this and they should learn to work with various systems, because in this industry the tendency is to keep a lot secret. We need to collaborate more and come up with better solutions."*

> *"It is already hard to work in a greenhouse, so it makes it even more complicated for a vertical farm and especially when you go to areas where food was never grown before. There is a lack of training and there are no schools and programs. It not about the low wage labor but people who understand the systems, it is not like field farming."*

Market and industry

Market and Industry is a broad spectrum that includes various coding; industry life cycle, investments, market share, competitive environment, and VF industry, etc. It is important to realize that the vertical farm industry is still in the development phase of the industry life cycle. Meaning, VFs make up a small market size, but have high differentiation, and are innovation oriented (Johnson & Whittington, 2009). There is a wide variety of VF typologies with different goals. Therefore, it is important not to compare all vertical farms with each other. A VF with 250 million (EU or USD) investment has different long-term goals than a VF focusing on economical independency for people with a disability. However, they produce similar products for a certain market. The agricultural market is a commodity with many competitors and low prices. This is key in the decision making for the VFs in what to produce and for who. European

participants (4 EU-P) mentioned that VFs shouldn't come with premium salads in West Europe, because that is not going to work for now. This does not mean VFing is not possible, but that it requires a provision of more unique produce.

> *"I think they have a chance, but you have to look good at what you are doing. Don't start with salad or other mass produce. If you have a product with added value and you can grow it in a VF, you may have some chances. For example, in Poeldijk. There is a facility of Future Crops, producing herbs for Dutch supermarkets, that works, and they are really excited about it, so yes there are opportunities."*

Various participants are still wondering how the larger VFs with high investment capitals are going to gain back their investment with a reasonable ROI. Two industry participants with major experience in agriculture where also more critical towards these phenomena.

> *"However, there is a lot of money available and the investors have huge funds that they can use to invest. The story is easy to sell, I don't understand why so many people are fooled, and everybody who is already in the business for many years don't truly believe in it, they don't believe it can feed the world. Only the IT and high tech believe in it, if Amazon invest in it, it must be good…"*

> *"But I think a lot of the current businesses will go bankrupt. But if they fail, they can still sell their business and get some return but who is going to buy those systems?"*

> *"I'm also wondering how current investors are expecting to win back their investments. Because the cash flow is very low and is basically nothing. I'm really wondering how they are going to win back their money."*

> *"Yes, they are mainly spending money, a lot of money, and storytelling. They are working on creating something really big to sell afterwards. It is something purely financial. You are making a balloon and make it as big as possible and sell it before it pops. I'm doubting their agricultural skills and environmental skills, but that is what I think."*

Other US participants and one EU industry participant believed more in these models and emphasized on their long-term goals. Those types of VFs should be viewed instead as technology companies. Their goal is more focused on developing an IPO, figuring out automation and robotics, and meanwhile finding new produce. These high tech and funding environments are more typical for the North American industry.

> *"They get their ROI back through scaling."*

> *"They need to start thinking differently. Knowledge is now the value behind it and not the business case. Of course, the ultimate goal is to make money at some point. But look at Facebook, it took them a very long time to make money. You have to look at it as the tech industry, IPOs, etc. and apply it on traditional industries. Forget the old traditional way of business we do in Europe and the agriculture still has those conservative decision makers. But of course, you can't say this without evidence."*

"Their long-term goals are to diversify by offering other produce, but for now there are a lot of reasons why they are only growing salad. Salad is growing because of the occurred food safety issues, it is a fast-growing product, and the requirements are a little bit lower than other crops."

Cross-continental

Subsequently on the previous findings, is the characterization of the cross-continental code. This code compared the Asian, European, and North American VF market. Participant where asked for their vision of the three markets.

Europe is seen as the most difficult situation for commercial vertical farms because of the efficiency and quality of its current food system. Especially in West Europe, if you go to a low-end grocer or a high-end grocer, you'd likely find the same produce, at relatively low prices. However, in terms of plant expertise and knowledge, Europe is seen as the strongest by 5 participants, which is beneficial for the development of vertical and indoor farming. VFs in Europe have a chance but as mentioned before, they need more added value and unique produce to be able to compete with the current market or find a new way of business models.

"It is hard to fit in an efficient and good food system in Europe for the vertical farms. Look at Urban Farmers in the Hague. They had to compete with all the professionals around them, which made it very difficult. I think it should be more for educational purpose and doing tours."

"Not sure about the specific models in each continent but overall, I think Europa has an overall better history with value for produce, which is why VF industry is overall better there. However, your current systems are better and there is already a strong availability of fresh produce compared to the US."

"In Europe it is hard to create your own brand because a lot of it is traded and rebranded."

The United States market is mainly supplied by Californian or Mexican produce. Consumers started to realize shipping produce year around across the country was not sustainable, especially when California experienced 8 years of drought. Also, recalls for various salad varieties affected the trust of the current food system. The damage to the environment of the conventional agriculture is more recognized. These aspects affect the consumer acceptance for more local and high-quality food. Generally speaking, the US produce market provides two levels of quality: cheap mass-produced produce from California and Mexico, or more expensive local produce.

"The highest price you can get is in the American market compared to the other produces. That makes it more feasible over here, I think."

"The US has the model that everything comes from California. More and more people dislike this model. But compared to here, where everywhere you go, you have good produce. But in the US, you have more different levels of quality produce, so also differences in prices. That gives more opportunities for VFs to have higher prices."

Asia has a greater history with vertical farming especially Japan, Singapore, and China. Participants indicated that vertical farming may have better adaptation in Asia. This is likely due to a lack of trust in their food systems after repeated scandals, environmental issues, and disasters (e.g. Fukushima). Parallelly, their wealth is rising, allowing consumers to spend more for VF produce. Asia has many technology hubs that enables the VF industry as well. Situations like in Singapore, where they import most of their food supply, supports the drive for vertical farming. Governments recognize the problems and protention of the situations and start supporting the industry more.

> *"In Japan a lot changed since Fukushima."*

> *"People in China don't trust the regular vegetable, even the government can't ensure the food safety. So obviously people have more willingness to pay 5x time more for vegetables that are safe to eat. Also, china is getting more and more rich people who can afford it."*

Others

Lesser discussed subjects included the lack of data and knowledge sharing amongst VFs, the possibilities of hybrid models between vertical farms and greenhouses, the role of the Netherlands, and agricultural issues. Most of the industry participants complained about the lack of information sharing to support each other. Technology companies need data to improve their systems in order to help the vertical farms. According to some VF industry participants, secretive behavior is normal in emerging innovative industries. There is also still a lack of working models, so people are careful in the way they share data and information.

> *"It is normal in the early stages of any industry. Sharing service, data, infrastructure will become greater. Same happened in the software industry. Over time they developed standards and open sourcing. I think in the long term it will be beneficial for the VFs to work together."*

> *"The overall knowledge is basically a secret and that makes it also self-destructive, but that's of course an innovation"*

The role of greenhouses in the VF industry is larger among most of the EU-VFs and EU/US industry participants. City-VFers have less belief in greenhouses and see it as something totally different than VFing. Two of the US-Ps were strong believers in greenhouses and its potential to solve food security in critical areas. The belief in economy of scale is greater for greenhouses. At least four interviewed participants said before deciding to build a vertical farm, the possibility of building a greenhouse should be checked. One US-P mentioned that the VFBF developed for this thesis would also be applicable for the greenhouse industry in the US. Greenhouses are less appealing than VFs but is also a growing industry in the US. The media is more focused on vertical farming because it has an innovation factor that draws higher funding than the traditionally perceived lower-tech greenhouses. One participant who is in the US training people to work in greenhouses and VFs said that like the VF industry, the US greenhouse industry

also lacks government support. A lot of the interviewees believed in a hybrid model between a greenhouse and a vertical farm. It is about using the benefits of both models.

> *"We see more greenhouses getting built but there is not that much hype about it. We also consult a lot of greenhouses. The two industries are very close, and we will see some crossover technologies. Some of the vertical farms are starting collaboration with them for food safety aspects."*

> *"First, the upfront cost is high for both of them, there are no subsidies, and no insurance for growing anything indoor. Horticulture is like a stepchild in the US. It is really tough to be a new grower on economic scale with a greenhouse."*

> *"I think they are not going to build high end hydroponic vertical farms, but more the Dutch style greenhouses. I think we will see more hybrids between vertical farms and greenhouses."*

The US is struggling with various agricultural issues such as an aging farming population. This is also seen in Japan, but less in Europe. The average farmer age is between 55 - 60 years old and has a lack of successors. A second issue is that the manual labor often is done by immigrants (legal and illegal) from Central and South America. The current political situation in the US makes it more difficult to find cheap labor, especially when US citizens demand higher wages and better working conditions than those found in conventional agriculture. This is a strong argument to build more greenhouses or vertical farms that will eventually be more automated and can create an enjoyable work environment. Additionally, the involvement of high-tech systems and the need for educated people entice more young people towards agriculture. There are more opportunities to develop a career path in the VF industry since the rise of technology.

> *"It is part of creating value in this merging industry. It is a form of agricultural seduction. It is a fact that technology is a big driver in this world and it is something new and more fulfilling. The agriculture industry also needs this, because the age belt of current farms is going to the age of 60. Also, the working forces on these farms are from Central and South America. These people are working in poor condition for a low wage."*

> *"I think it is less of a problem. I know it is in Japan and USA, but here there are enough people getting educated in this industry and in the production of food. So, it is not the biggest problem. The addition of technology makes this industry more appealing again and people like this."*

4.4.2 Discussion

An important aspect to consider for vertical farms is the recruitment of properly trained employees and an overview of the competitive market where the vertical farm is located (Al-Kodmany, 2018). Depending on the company's model, appropriate employees need to be acquired. If you have only one grower, then it is beneficial that the person has knowledge and skills in the technological aspects as well. In a larger VF multiple people can be hired for specialized job positions. The need for appropriate employees is a major variable and is therefore, included in the framework as part of the enabling environment. This additional

aspect will be named Education & Training and is key in the success of vertical farms. As is with any new business, a market analysis is necessary to decide what should be produced and how the product or service should be presented (Johnson & Whittington, 2009). Some participants were less enthusiastic about the the continual need for improving VF systems with more technology when product quality is affected, however technology is a great way to attract young people back to agriculture and involve them in primary food production. Technology is the key driver in attracting young people (Iyengar & Jackman, 2004).

4.5 Future perspective

The last question during each interview was about how the participant sees the development of the VF industry in the coming 5 years. According to the participants' answers, the following subjects in Table 17. were mentioned.

Table 17. Occurrence of future perspective codes

Code name	Occurrence (#)	%
Technology	16	44.44
Specification and Differentiation	13	36.11
Future market composition	6	16.67
Mixed living space	1	2.78
TOTAL	**36**	**100**

4.5.1 Findings of future perspective

It was mentioned by 12 participants that in the next 5 years technology will keep improving like it is currently going. The main improvements will be in efficiency, new technologies, more robotics, and automations. Automation was mentioned by 16 / 25 participants, especially in terms of finding more applications (e.g. in various production steps) for automation to be use and recognizing the possibility of its impact on the future of the VF industry. A more standardized production process may have major effects on the fluctuating labor cost and overall efficiency.

> *"But in the next 5 years we will see commercially viable picking automation guaranteeing the same quality."*

> *"The systems for environmental control will be enhanced and better manageable, I hope there will be some form of standardization in the industry. There will be different varieties of systems like you have with cars, major universities implementing hydroponics degrees and indoor specializations."*

> *"Automation and reducing the fluctuating labor cost is going to be the biggest development."*

There is still a lot of uncertainty among the participants, especially the US/EU industry participants. Like mentioned in section 4.1.1 there is need for the proof of working technology, feasible business models, and proof of the VF product claimed attributes.

"A big obstacle now is the proof of the system, so the beginning and showing that you can do it. Also, on large scale."

"There will be more and more valid and proven data. The big breakthrough will come when it is profitable and energy efficient, lower production costs in general."

Besides growing salad, participants believe in the increasing feasibility of different crops besides leafy greens and herbs. Some participants predict indoor production of bell peppers, cucumbers, etc. while others predict some fruits coming from the VF industry large-scale. There will be an increase of product diversity. This will support the recognition of vertical farming worldwide.

"Freshness and variety of crops and bringing new crops are key."

"They have the potential for diversified food production on a local level with a small footprint."

"… and we will see more different produce, like tomatoes and strawberries, products with more value."

Positive prospects aside, some industry participants said that the industry will see numerous business failures and newcomers. The industry will have larger farms to reach sufficient economy of scale to enable more impact on the market. However, the opinions of the research group are diverse. Four industry participants believe more in greenhouses and the hybrid models to solve food security issues, as they find greenhouses more economically feasible. Six industry participants have less belief in VFs if they continue to be more expensive, consume high amount of energy, and lack product variety. Other VFers and industry participant have a different view on this and truly believe in its potential of growing food in metropolitan areas. Some (6/25) participants asserted the growing potential of local community-oriented vertical farms. Five industry participants mentioned the rise of the cannabis industry and its high potential. The marijuana industry uses similar technologies. Along the same line of reasoning, the potential of vertical farming for pharmaceuticals was also mentioned.

"It is a booming business and there will be a lot of larger companies and participants, but a lot of them will disappear and some will succeed."

"I think we will see more local farms, adapted to their community, in certain areas, selling directly to consumers because having a retailer or other parties in between that can affect your profitability and price point."

"We will see more vertical farms in the world where conventional agriculture and greenhouse won't work, like in the middle east, or other critical areas."

The answers in section 4.5 are of course assumptions and beliefs of those in and around the industry, but all have a similar vision for the future of vertical farming. The industry will see more participants, more educational support, and more funding. The growth of the VF-industry will go parallel with the change of consumer's behavior towards food. Interest in the origin of food is on the rise, people are more

environmentally conscious, and more skeptical towards the conventional food industry, which will lead to more acceptance towards vertical farming and its products.

> *"I think there will be overall market acceptance."*
>
> *"There will be an increase of consumers and recognition towards vertical farming. But there must be more proof of how good the produce is of vertical farming."*

4.5.2 Discussion

The participant's perspective toward the current VF industry, influences their view of the future VF industry. The main agreement was on the need for further development in all areas of vertical farming, but mainly in technology and products. Consumers and agriculture are changing, there will be more appreciation and understanding for vertical farming in the future (Imhoff & Badaracoo, 2019; Rahnama & Rajabpour, 2017). Vertical farming can play a great role in this story (Kalantari et al., 2018). To achieve growth in the VF industry—besides the technological and operational improvements—more education is needed to support farms with 'farmers of the future', whether they are greenhouses or vertical farms. The cannabis industry may have greater potential in VFing than VFing for produce. The cultivation of marijuana is legal in much of the US, bringing major interest and funding. This makes sense in terms of product value per kilogram of product compared to leafy greens. However, the participants believe more varieties of greens and fruits are coming to vertical farming, in addition to more critical produce (e.g. food ingredients) with higher values.

4.6 Conclusion

After discussing the results of section 4, SRQ 2 can be answered.

SRQ 2: How does the theoretically derived VFBF apply to VF businesses with regards to the three key terms?

The VFBF includes all aspects derived from literature and unveiled new critical points of the VF industry. Before using the framework, it is important to know the specific VF's vision. Is the vertical farm industry-oriented, people-oriented, or a solution for food security?

The key term **organization** is the firm centric element that includes technology & innovation, geographic location, and product attributes. In terms of technology & innovation, the economic aspect (cost, feasibility, economy of scale, and profitability) is still negative for vertical farms, but having an optimized production process is equally important. It is not necessary to have high tech systems with robotics to be able to produce a consistently high-quality product. The selection of a geographic location for the VF has a large impact on the VF's strategy and plays an overall role in the success of the farm. Harsh climates or places with a lack of conventional agriculture can be suitable for VFs, in addition to locations with abundant renewable energy. Being in the urban core of a city can be limiting compared to being in peri-urban or more rural areas. Urban areas have great potential in terms of social value and niche business

models. Meanwhile, peri-urban or rural areas have greater chances of reaching an economy of scale and partnering with larger corporations. The product attributes (e.g. local, pesticide free, etc.) of VFs are all similar. But offering mass produced products like salad is unlikely to be profitable, only in the rarest occasion.

The second key term **governance cooperation** is the element of working with various partners and actors in the food value chain. The position in the food chain is largely influenced by the geographic location but determines the business strategy of the VF. In the first years of commercial vertical farms B2C was primarily dominant in the industry. However, a lot of opportunities are there with different buyers. Working on a larger scale can support the potential relationships with large food manufacturers and retail distribution centres. The existing infrastructure can support the VF and still have major supply chain cuts as the VF can be built in the area of its potential buyers. The variable key partnerships has an important role of filling in the specific knowledge or expertise gap the VFs might have. A second type of possible partnerships is with local organizations to better understand the local character of certain areas and its customers, such as—do we need farming expertise, do we need technological support, what are the local organizations?

The third key term **enabling environment** is the supporting element of the VF business and industry. The social aspect was found to be important to some, and not so much to others. The social/people-oriented strategy is more likely for (peri-) urban areas as the farm is located in a living space. There is a trade-off between being truly socially valuable for a community and having an optimized VF system on a reasonable economy of scale. However, community involvement can be beneficial as it can lead to consumer acceptance and connecting with local organizations. Having government support shouldn't be a main concern for a VF as it is something that can grow over time as the industry market share increases. There are more opportunities to have local municipality support, especially when the farm is social-oriented. The two major concerns for the legal aspects are food safety, zoning, and building regulations. The fourth aspect is education & training that provides the industry with vocationally trained people. Both in farming skills and academic knowledge-based plant science and agronomy. This need is required due to the lack of head growers in the industry. Technology driven vertical farming is a great way to attract younger farmers and students to agriculture.

In Figure 6. the finalized Vertical Farm Business Framework can be seen with the three key terms and their belonging variables. Vertical farming was approached as a wicked problem due to the many variables that play in the industry, especially in this stage of industry life cycle. The key variables identified from the interviews and referred to by the participants with higher importance are marked in **bold.** Additionally, a blue star is added for variables more important for people-oriented farms and a red start for the more industrial-oriented vertical farms.

The variables revealed from the question on the future of VFing are not included as they are assumption of the upcoming possible landscape of the VF industry. An important take away is that the vertical farm

industry is still in the development phase, evident by high use of the variables *proof of technology* and *need for standardization,* which is normal for new industries.

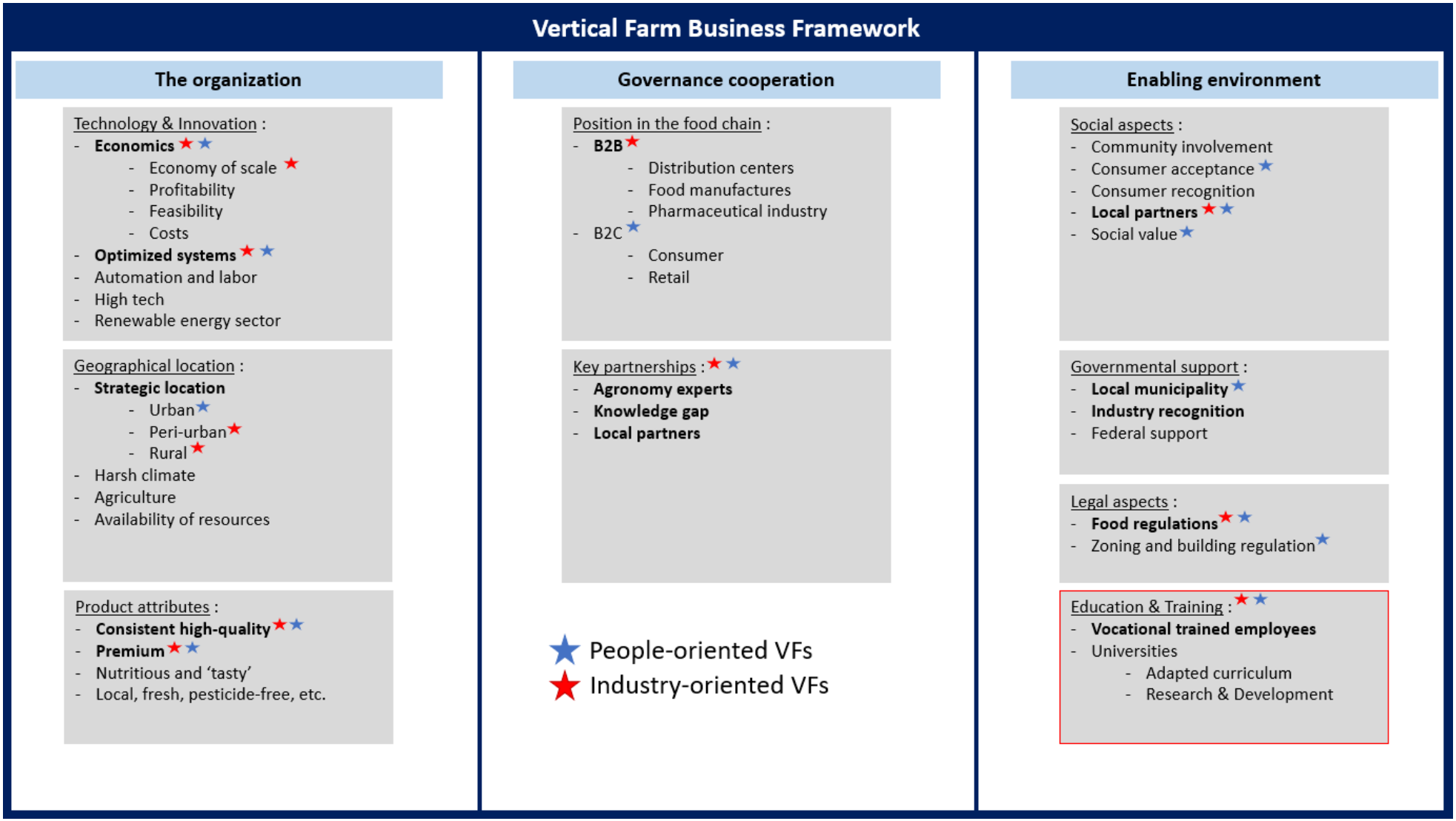

Figure 6. Vertical Farm Business Framework (Author)

5 Conclusion

This section outlines the overall conclusions of this research, by answering the sub research question: "**What conclusions can be made about the VFBF based on the information elicited from interviews using the key terms?" (SRQ3)**. The three key terms of the Vertical Farm Business Framework are the organization (Technology and innovation, geographic location, and product attributes), governance cooperation (position in the food chain and partnerships), and enabling environment (Social aspects, government support, legal aspects, and enabling environment). To end, the limitations of this study will also be briefly discussed, in addition to the possibilities for future research.

5.1 Research conclusion

The need for a resilient agricultural system is on the rise due to the negative consequences of urbanization and global problems with conventional agriculture. Over the past 10 years, the drive for new agriculture methods that can alleviate climate change brought us vertical farming, a promising and innovative way of farming. As such, vertical farming developed different typologies and meanings, which resulted in various new business models, as well as searching for the ideal system and product. Vertical farming became a trendy business with multiple actors and influences that created a wicked situation for making a singular overview. During the development stage, the success rate has been low, evident by several failed VFs. Despite the failures, the perceived future opportunity of this innovation continues to raise substantial funding. Wicked situations are described as complex, intractable, open-ended, and unpredictable situations. This research approached vertical farming in a similar way to properly frame the current situation. Therefore, the aim of this research was to create a Vertical Farm Business Framework in order to gain meaningful insight and to create a multidimensional overview.

The research started with a literature review to better understand what vertical farming is, what the opportunities and challenges are, and defining vertical farms for this research. This answered the first research question (section 2.1).

SRQ1A: What is the relevant definition of a VF business?

In this study a commercial VF is a business with an organizational level that includes commercial growers and food providers, growing their produce soilless and indoors, vertically stacked or on a roof.

The second part of the literature review described and identified the 3 key terms of the VFBF (section 2.2).

SRQ1B: What does literature say about the organization, governance cooperation, and enabling environment elements?

The organization element mainly exists out of 3 variables namely technology, geographic location, and products attributes. These 3 variables form the core characteristics of a VF business and together with the organization element of the VF typology. The governance cooperation is characterized by the positioning

*in the food chain and the key partners who collaborate with the VF Business. The last element is the enabling environment, which consists of regulations and laws that apply for the VF, governmental support, and the social aspects (**SRQ1B**).*

Interviewing 25 industry participants provided insight to the dynamics of the vertical farm industry. All participants are active in a vertical farm or are contributors to the North American and European VF markets. Establishing a vertical farm business is a complex matter that involves several aspects and decision making. Vertical farming can be considered in two ways—as a solution for feeding growing populations in a more sustainable way, or as an innovative business opportunity. Analyzing and reviewing vertical farms in the sense of solving global food security is off scope. If the energy equation is not solved, an economy of scale won't be reached, calorie dense products will not be grown, resulting in too little a contribution to the food system. In the perspective of innovation and business opportunities there is more to come. However, this research is not intended to decipher if VFing is a viable business, instead it's focused on unveiling the wicked situation that is the vertical farming industry.

The first variable of the key term *the organization* is Technology & Innovation (section 4.1.1), which are major aspects in this industry, especially during the first phase of the industry life cycle. Investing in high tech VF systems to grow crops can be risky while there is still a lack of proven technology. Cost remains a major issue for VFs due to the necessary labor, energy, land, building, and systems to grow and operate a VF. An ideal VF business would have optimized systems, reduced labor costs, and a consistently high-quality product. The interviewed participants believe it is only a matter of time that improved technologies in terms of lighting, HVAC, and automation are developed, in addition to a change in the energy equation that depends on the evolution of green energy. These changes can drastically decrease the overall costs of vertical farms. The current cultivar of choice includes a variety of leafy greens, this selection is reasonable because they grow rapidly, are part of our diet, have nutritional value, and can command a premium sales price (section 4.1.3). Vertical farming is location dependent and has a large impact on the business model of the VF. The location influence of a VF comes from its placement in an urban, per-urban, or rural area, and the climate and altitude conditions. However, no single location offers a simple net positive or negative result (section 4.1.2).

The second key term is the governance cooperation. An important decision for a VF farm is its positioning in the food chain (section 4.2.1). Of the participants interviewed, the current most common position in the food chain was selling direct to the consumer or to grocery stores. Impending new partnerships, vertical farms will collaborate with distribution centers and specific food sectors to further integrate into the food chain in new ways. There is still a strong belief in the potential and feasibility of VF integration, but new higher value products must arise (e.g. stevia, marijuana). As the industry is still developing many solution and improvements are still needed. This supports the need for good partnerships. While the major partnerships are technology or agronomic based, local partnerships also contribute to the success of VFs due to specific knowledge on local needs of an area (section 4.2.2). The need for partnerships and

data sharing is also in the interest of tech and research companies. Data sharing supports finding solutions and new developments for the VFs.

The third key term is the enabling environment. In the discussion of social aspects, urban farming and vertical farming are overarching terms that can cause confusion and misuse of terminology. More evidence is needed to prove the social value of vertical farms in cities (section 4.3.1). However, community involvement can be a great way to connect with the local market and population. Despite the mentioned time consumption, legal issues were not found to be a major concern for vertical farms outside of zoning. As is for all food businesses, food regulations are strict, reaffirming the need for food quality management and expertise. Government support is important for the overall VF industry but not necessarily for a specific local farm (section 4.3.2). It is predicted that as the market share and public acknowledgement of VF produce increases, the government support of the vertical farm industry will also increase. Additionally, local municipalities can bring support in different forms (e.g. funding).

Besides the three key terms of the framework and its variables, additional subjects were discussed during the interview process (section 4.4). The need for properly trained employees, especially in the area of plant science and agronomy was revealed as a major issue. It is important to have a knowledgeable team that can mitigate growing issues to assure product quality and system efficiency. In this way governments and universities can play an important role by aiding and establishing new curriculums specific to indoor farming. Despite the negative criticism of VFing's current issues, this technology driven industry attracts a newer and younger generation of future farmers. A market review of competitors was found to be another important aspect of a VF business. It is thus useful to know what the current market offers in terms of fresh local produce. Greenhouses also play a part in this story, as they share similar technologies with more proven success. Hybrid models can act as a leeway while the energy equation is not solved, providing validated processes delivering more affordable farming on a larger scale. Future greenhouses will take over technological developments of vertical farms and vice versa.

In the future perspective (section 4.5), vertical farming must prove itself more. Automation, energy efficiency, increase of educational interest, and economic feasible business models will be drivers to support this industry. The developed framework encounters the aspects of vertical farming, providing an overview of the industry from different angles.

Main Research Question: Can the creation of a vertical farm business framework help present an overview for commercial vertical farms?

*Yes, this framework is holistic and includes all aspects of vertical farming and created a better overview of all the important aspect under each key term of the VFBF (*Figure 6.*). The framework also displays the more important aspects derived from the answers of the 25 participants who are active in the vertical farm industry. Additionally, it displays critical points for people or industry-oriented vertical farms.*

5.2 Recommendations

This VFBF can support commercial vertical farms, vertical farm industry participants, and researchers. The VFBF may introduce new points of attentions for vertical farms and the understanding of how to approach this innovative emerging industry. It is important to identify the goal of your vertical farm and your strategy to achieve these goals. Looking at the current available products and conventional agriculture is important to understand what you need to deliver. The potential of greenhouses shouldn't be underestimated or overlooked. Current greenhouses can be efficient and more economically feasible. Even if vertical farms can add social value to a city, building your farm around the city can be much easier and avoid certain issues. Keep in mind the possibility of growing cities, the suburban areas of today can become urban in 30 years.

5.3 Limitations

This research was exploratory and qualitative, making it difficult to draw generalizations and hard to determine if the results are statistically significant. In this new growing industry, it is hard to contact many commercial vertical farms. Many businesses are still in the research and development phase, and the variety is large. The broadness of this research is great for identifying various aspects of a VF and understandings them, alternatively the broadness makes specifying and narrowing down certain topics hard. The dynamics between the North American and European market are different and has influence on the participant's answers and vision towards vertical farming, in addition to the different levels of experience in this industry. Besides the different experience level, vertical farmers and industry participants have different opinions and visions towards the industry. Some are working in terms of food security, others have people-oriented farms, and some focus on industry-oriented vertical farms by developing new systems, new products, or try to research economy of scales.

5.4 Future research

Vertical farming has many research opportunities in the technological, social, economical, and governmental areas. To further validate this research, it is possible to redo this research after 5 years or when more success stories occurred. Useful research could be on the social value of vertical farms in cities or applying the framework to the cannabis industry or to greenhouses. If there is a higher quantity of vertical farms, this research can be more quantitative focused or used to look more similar VF format to further specify the VFBF. However, it is important to consider again the perspective towards the VF industry—whether for business opportunity or as a more sustainable global food source—into account when researching vertical farming.

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7 Appendix

7.1 Introduction email (example)

Hello XXX,

It was great to be at Indoor Ag-Con and meeting you!

I would like to continue our talk about my vertical farm research framework that I'm developing for my Master study at Wageningen University and Research.

In the attachments you can find more information about my research. If you want to do an interview with me, please send me a **date and hour for next week (10 – 14 May)**. I'm currently in Berkeley, CA (UTC -7).

If you have any questions, please ask.

Kind regards,

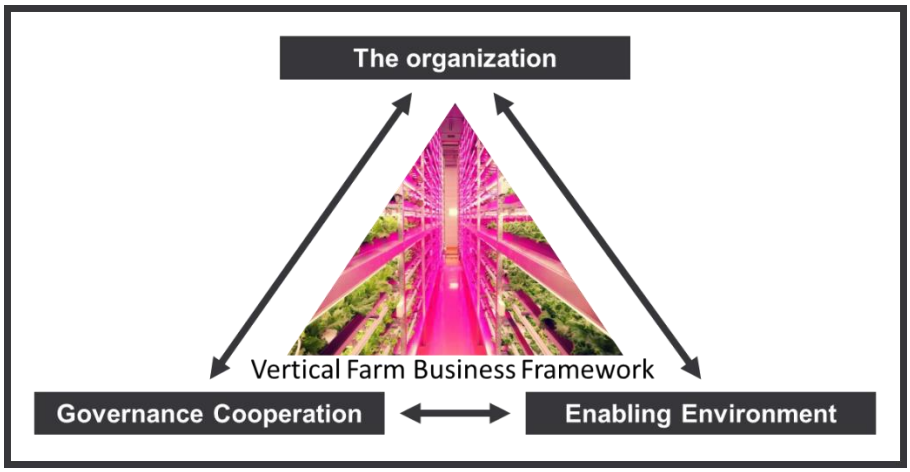
Simon Allegaert

7.2 Attachment of introduction email

Dear participant,

I'm currently studying at Wageningen University and Research in the Netherlands, completing my Master of Science in Food Technology, with a specialization in Food Innovation and Management. Presently, I'm conducting my MSc Thesis on vertical farm (VF) management.

With the onset and growth of the VF concept and its subsequent businesses, there are many opportunities for academic study. One gap in the current research is on business and managerial aspect of VFing, therefore, I developed a VF Business Framework. As participant in the VF industry, you contain knowledge and experience that can contribute to the progression of the VF sector by conducting a short interview with me. Your answers can aid in validating the new VF Business Framework so that further research may be pursued, whilst increasing the recognition of the VF Industry.



The research is exploratory in that it aims to gain insights in the following three elements of the VF Business Framework: the organization, the governance cooperation, and the enabling environment of a vertical farm (VF). Below the three elements are further elaborated.

We can assure you that your answers will be treated strictly as confidential. The gained data is for exploratory purposes and is not case specific. After participation, the data will be processed in the thesis. Following its completion, the executive summary of the report can be sent to you, if desired.

Lastly, I'd like to commend you for being part of an industry working towards a better future. I too hope this research will facilitate success in creating a better future for VF's presently, and beyond.

Kind regards, Simon Allegaert, +32 495 16 20 84 simon.allegaert@wur.nl
dr Emiel F.M. Wubben, Wageningen University and Research emiel.wubben@wur.nl

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The Organization

The first element of the framework is 'the organization', this element consists of the core competencies and the operational aspects of the company. The first aspect includes the discussion and the decision

making in terms of how the company will create its product, with the consideration of how advanced and innovative the technology systems used will be. The second aspect is the various positioning and location possibilities of a VF. This aspect is important to consider and is one of the core elements of the VF ideology. Additionally, VF vegetables and herbs have higher prices per kilogram due to the still high production costs. Therefore, the product attributes are also a key element for commercial VF businesses. Product characteristics are important to consider in terms of product acceptance, product placement, and product marketing, to have proper willingness to buy.

Governance Cooperation

The second element of the framework is governance cooperation. This element involves the strategic task and collaboration between the actors and partners of the VF chain. Vertical farming requires several actors and partners to sustain a successful business. Because farming crops indoors is an innovative, technological, and agricultural business, partnerships are needed to support investment in its research and development. Problems associated with VFs – such as high production costs – are continually improved through new developments and research breakthroughs. These improvements thereby increase the sustainability and profitability of the VFing business. Through these collaborations, an appropriate marketing strategy and marketing plan can be designed, triggering the sale of the VF's uniquely produced products. Therefore, it is crucial that the VF manager select the most beneficial actors and partners to create a strong value chain. In doing so, the business can deliver its high-valued VF products to the market and to its consumers with ease.

Enabling Environment

The third and last element of the framework is the enabling environment. This element involves the interrelated conditions surrounding the VF, including but not limited to regulations, laws, bureaucratic, politics, and culture. A positive enabling environment is needed for vertical farming to empower the business and stimulate the movement of its product. Within this element, the regulations and community aspects are the key conditions for vertical farms, as to enable the creation of the specific environment vertical farms need. In this case, enabling environment is sometimes also referred to as a business-enabling environment, based on its ability to empower an industry rather than a social community.

7.3 Code structure

Construct	Variables (axial coding)	Indicators (open coding)	Text example from interviews
The organization	Technology and innovation	Automation	*We will need to figure out how to decrease the labor and this will be possible because of robotics and more automation.*
		Economy of scale	*However, the industry needs more commercial successes, but I'm not sure if it's going to be on large or medium business scale.*
		Track record/Proof	*But there must be more proof of how good the produce is of vertical farming. I still wonder how they are going to get there investments back.*
		Profitability	*If your analysis is bad and you have no marks or no profit, then it is not going to work, and you are doing something that is wrong.*
		High tech	*I think they are working to complicated, too high tech and are missing the point. They are being too difficult and may be using too many algorithms.*
		Cost	*it is not going to work anywhere soon unless electricity gets cheaper or free*
		Complications	*Combining the wrong components in building typology and using the wrong potentials in energy consumption result in a negative situation.*
	Geographic location	Food supply	*Basically, in most of the western countries the food supply is working perfectly, low prices and good produce.*
		Sub urban	*We are in the side boarder of this city, 9000 square meter, 14 000 bags per day, and everything goes to the city. The ground wasn't that expensive.*
		Climate	*Especially locations with harsh climates, which makes it difficult for conventional agriculture to grow food.*
		Demographic	*In this way you have a certain market. I also saw that in Japan, and so you can reduce your distribution risk and you can grow for a specific demographic.*
		Urban core	*But like you see in New York and Chicago, having a greenhouse on a roof can also be a perfect solution for urban farming.*
	Product	Branding	*It is private label. It has to be. It is hard to bring your own brand, there was no room for. However, we would love to.*
		Consistent quality	*This give you a certain stability and can bring you the focus on growing with a consistent product quality for your market, even if you have a small-scale farm. A problem with vertical farms is over-promising and underdelivering the technology. So under-promising and overdelivering is a valuable key aspect.*
		Premium	*People are not going to eat indoor produce because it comes out of an indoor farm, but just because it will taste better, and it will be cleaner and safer.*
Governance cooperation	Position in the food chain	Food manufactures	*I believe there is a lot of value in the B2B, the cooperation of a VF with the larger food manufacturers. I know a few examples but the names are confidential. But yes that's were the real opportunity is.*
		Retail	*We have standing orders with a large grocery chain here.*
		Restaurants and public spaces	*Facebook, Google, schools are also good opportunities for vertical farms to produce food for a large group of people locally.*
		Vending model	*And the idea of small VFs on supermarkets doesn't look economically feasible.*

		Distribution model	*You have basically two models. Being next to the distribution center of a large retailer or building a farm for a certain area with the aim of feeding that specific area with a super local food chain.*
	Partnerships	Trader/seller	*The trader, the client, is a crucial point, the others depends on the modal or what you actually need?*
		Venture capitalist	*In this stage, money is really important, so my key partner is the other venture capitalist. He is really good in finance, which is import in this stage.*
		Operational support and service	*You need to find the right partners for the installations and environment control aspects, good seed suppliers, and if you don't have the knowledge to run farm then you need a good partner for that as well.*
		Expert knowledge	*VFs need educational capacity and research capacity, so academics can help to validate and figuring out. But of course, some tech providers are also important.*
		Local knowledge	*We are also connecting with all the resources in our regional, local area to make them aware that we are transforming ourselves*
Enabling environment	**Social aspects**	Community involvement	*Really important, it is one of the critical points of a vertical farm business. You need to know the local community, you need to know what they want, what they need. They also need to know what you are doing. You have to collaborate to have that social aspect.*
		Consumer acceptance	*I'm not sure, because a lot of people already eat hydroponics, but they don't know. Educating people about all the possibilities and opportunities of vertical farming can be really helpful and cool to do. And I'm already talking with organization doing that now*
		Social value	*We were looking to add value to the community and find a way to help people with a disability by providing work. So it was about creating a workspace that was easy accessible for the community.*
	Governmental aspects	Governmental support	*Yes, we do, the government is really open and receptive to urban farming, so we have several levels of government support, from the government, municipality and federal government.*
		Policies	*There is a lack of policy*
		Relationships	*Yes, we need more support, I'm also talking with some politician*
		Acknowledgements	*There is more need for recognition of the systems, as in recommendation of vertical farms in cities.*
	Legal aspects	Regulations	*Food standers, local strict zoning rules, just the regular pathway is pretty strict.*
		Building and land	*I don't really know, but I think city farms struggle with real estate.*
Undefined	**Other aspects**	Hybrid model	*The border between vertical farms and greenhouses will fade away. Large farmers have come to us and asked for help with the lights. I see more an intermediate form of an indoor farm and a greenhouse who is more efficient and proven. When that happen, we will see much more of them.*
		Agricultural issues	*VFs profile themselves as food providers of the world, but they are making high end expensive products, which is a contradiction.*
		Market and industry	*The founders of the bigger vertical farmers are really big believers in this industry, and they managed to set up something and get investments. However, they still can fail or never be able to really compete.*

		Data/knowledge sharing	*It is normal in the early stages of any industry. Sharing service, data, infrastructure will be come greater than keeping every secret. Same happened in the software industry. Over time they developed standards and open sourcing. I think in the long term it will be beneficial for the VFs to work together but they need a center.*
		Asia/EU/USA	*People in China don't trust the regular vegetable, even the government can't ensure the food safety. So obviously people have more willingness to pay 5x time more for vegetables that are safe to eat. Also China is getting more and more rich people who can afford it.*
		The Netherlands	*You can visit in the Netherlands the commercial indoor farms. They all grow their crops or flowers and market them, but they laugh with those vertical farms. Because they have so much experience in this agrobusiness.*
		Training and education	*Canada just recently legalized marijuana and the Canadian marijuana industry is picking up all the growers. Therefore, we go straight to the universities to get people. But at the end we don't have problems with finding people who are really excited to work for us, so it is not a problem.*
	Future perspectives	Future market composition	*It is a booming business and there will be a lot of larger companies and participants, but a lot of them will disappear and some will succeed. The ones that will succeed will be really big. It's only going to work if you are able to grow all crops and on very large scales.*
		Technology	*Cutting the price of LEDs, involvement of new areas joining the VF/CEA industry, micro energy devices, better energy systems, all aspects that are really important. Biomass is a good solution for energy but that is really hard to do in a city or urban area.*
		Specification and differentiation	*They have the potential for diversified food production on a local level with a small footprint.*