

Business model configurations for successful vertical farming

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Abstract

Purpose – As a response to global population growth and increasing demand for food, farmers have been complementing traditional agriculture practices with vertical farming and indoor hydroponic systems. To facilitate the growth of the vertical farming industry, this paper aims to identify business model elements and their configurations that lead to high firm performance.

Design/methodology/approach – The research goals were met by conducting literature reviews coupled with a fuzzy-set qualitative comparative analysis (fsQCA) on five business model elements, “superior” OR “strong” performance as two possible outcomes, and the top-ranked global vertical farming growers listed in the Crunchbase Database.

Findings – From the fsQCA results, it was observed that several business model configurations lead to strong firm performance. Vertical farms growing in urban settings and having strong customer engagement platforms, coupled with a presence of business-to-business (B2B) sales channels, are more consistently associated with superior performance. These results imply that the decision configuration of location, along with customer engagement activity and sales activity are differentiating factors between good firm performance and superior firm performance in the case of vertical farms.

Originality – This paper contributes to expanding the knowledge of business model theory, business model configurations, and vertical farming management, providing specific guidelines for vertical farm owners and investors related to decision-making for higher firm performance, as well as positive environmental, social, and economic impact.

Keywords:

Business model, vertical farming, qualitative comparative analysis, firm performance, fsQCA

1. Introduction and background

During the twentieth century, while agriculture productivity experienced a progressive leap forward owing to the mechanisation of agriculture and the development of high-yielding crop varieties, agricultural practices also saw a rise in the use of water resources, fertilisers, chemicals, and pesticides alongside the increase in global food production (Gomiero *et al.*, 2011; Liu *et al.*, 2015). As traditional agriculture practices became intensive and detrimental to land and soil quality, sustainable farming approaches became a choice of necessity (Lal 2015; Lal and Stewart, 1990; Vereijken, 1992). Amidst the solutions for sustainable agriculture practices, the works of Prof. William F. Gericke on hydroponic farming found popularity during the twenty-first century (Gericke, 1940, 1945). Since then, the idea of sustainable farming practices, including vertical farming (VF) has been observed to expand steadily across the globe (Delorme and Santini, 2022; Kobayashi *et al.*, 2022). Experts in academia, practice, entrepreneurs, and investors alike have demonstrated a growing interest in the potential of VF to “revolutionise the global food system”; however, legal, technological, and economic limitations continue to create obstacles for new start-ups emerging in the VF space (Kobayashi *et al.*, 2022). The VF business is a hot topic in several disciplines or industry sectors. Two key areas that will be covered in the scope of this research are agriculture and “technopreneurship” culture. VF has attracted interest from both groups—one that is centred on agriculture and farming, while the other emerges out of the growing global technology, start-ups, and entrepreneurship culture (Butturini and Marcelis, 2020; Gustavsen *et al.*, 2022). As businesses, VF companies and well-established start-ups employ various business models and make

different strategic decisions for their businesses, these variations and different approaches impact their firm performance and value network in different ways (Shafer *et al.*, 2005).

Between the hydroponic farming concepts of Gericke and the urban VF works published by Prof. Dickson Despommier (2010), academic researchers and urban agriculture enthusiasts continue to search for technologies, farming methods, and system concepts that can facilitate the growth of sustainable, VF practices (Gafsi *et al.*, 2006). Since 2020, researchers have expanded their focus and begun to look at business-related aspects of VF. These include classifications of urban agriculture business models (Orsini *et al.*, 2020), business models of indoor cultivation systems and their sensitivity to the energy consumption of LED lighting (Balazs *et al.*, 2021), decision support systems to facilitate risk-empowered business planning for vertical farmers (Baumont de Oliveira *et al.*, 2021), digitalization and business models for VF (Thomson, 2022), financial risk analysis (Baumont de Oliveira *et al.*, 2022), economic viability of vertical farms (Appolloni *et al.*, 2022; Moghimi, and Asiabanpour, 2023), and innovation related to business models for VF (Appolloni *et al.*, 2020; Martin and Bustamante, 2021; Biancone *et al.*, 2022; Saint-Ges *et al.*, 2022; Horváth and Pongrácz, 2023). However, contributions on business models for VF are still fragmented and mostly theoretical, based on different kinds of literature review methods (e.g., Appolloni *et al.*, 2020; Orsini *et al.*, 2020; Biancone *et al.*, 2022; Saint-Ges *et al.*, 2022). Thus, additional empirical evidence is needed to further develop this research stream.

Specifically, contributions to business models for VF are:

- Still fragmented—given within a particular context such as digitization (Thomson, 2020), within limited regions (Appolloni *et al.*, 2022), limited solely to traditional farming (Moghimi and Asiabanpour, 2023), based on relatively short observation periods (one to three last decades; Appolloni *et al.*, 2022; Thomson, 2020), or not

narrowed down enough, meaning that it is considered among wider area of urban agriculture solutions together with items such as allotment gardens¹, extensive periurban farms and community gardens, or rooftop farms (Orsini *et al.*, 2020) ;

- Mostly theoretical—such results can be observed based on different kinds of literature review methods (e.g., Appolloni *et al.*, 2020; Orsini *et al.*, 2020; Biancone *et al.*, 2022; Saint-Ges *et al.*, 2022); and
- Presenting a polarized view of wealthy global north vs. impoverished south solutions (by calling it low- and high-tech solutions, e.g., Appolloni *et al.*, 2020; Orsini *et al.*, 2020) and consequently showing one-sided opinions suggesting that sophisticated technologies should be accepted and applied in developing regions and countries.

Both case-specific and review-type publications are important knowledge media; nevertheless, the points of view presented in them may not be sufficiently differentiated. Much more to the issue of business models for VF can be brought by examining the subject from a multi-case study perspective. Such an approach requires a study of several (numerous) organizations dealing with the topic, an in-depth insight into the evaluation of facts and opinions, with a particular separation of facts from opinions, to draw unambiguous, utilitarian conclusions. A multi-case study perspective enables discovery of a particular area through several aspects of the issue as well as clarify the complexity of a phenomenon (Bryman and Bell, 2015). As the multi-case study perspective is based on actual conditions of organizations' activities and operations, taking into consideration a certain number of such organizations can be thought of as empirical evidence to research streams on business models for VF.

¹ One should bear in mind that allotment gardens cannot be considered as items of trade or business in some countries, e.g., UK or Poland (OrganicLea Community Growers, 2007; Dz.U.2021.1073, 2021).

The goal of this paper is to identify how effective business models and business strategies can be created in the VF industry, particularly for food growers to overcome unsustainable agriculture practices. This research study attempts to find linkages between business model configurations (the variables OR conditions of the study) and commercial VF performance (the outcome of the study). A key part of this research is to understand and explain the variations in business model configurations and decisions, and how they affect the performance of VF enterprises.

Another important objective is to assess the equifinality and connection between the variables of the research approach and its outcomes (which, especially in the context of equifinality, implies that VF firms may establish similar competitive advantages based on varied competencies), to specify the necessary and/or sufficient variables for obtaining a certain outcome and finally to find the set of necessary and/or sufficient variables' configurations adequate that lead to the outcomes.

In line with the aim of this research, two key research questions (RQ) have been raised:

RQ1. What are the important business model elements and decisions that lead to higher (or superior) performance for commercial vertical farms?

RQ2. What are the key challenges in VF start-ups based on a case study perspective and the experience of researchers, and how can such challenges be addressed?

Thus, this paper contributes to expanding the knowledge of business model theory, business model configurations, and VF management, providing specific guidelines for vertical farm owners and investors related to decision-making for higher firm performance, and positive environmental, social, and economic impact.

These research goals were met by conducting literature reviews, coupled with a fuzzy-set qualitative comparative analysis (fsQCA) on five business model elements, “superior” or “strong” performance as two possible outcomes, and the top-ranked global VF growers listed in the Crunchbase database. From the fsQCA results, it was observed that several business model configurations lead to good firm performance. Vertical farms growing in urban settings and having strong customer engagement platforms, coupled with a presence of business-to-business (B2B) sales channels have a higher chance of leading to superior performance. These results imply that the decision configuration of location, along with customer engagement activity, and sales activity are differentiating factors between good firm performance and superior firm performance in the case of vertical farms.

The paper starts with an up-to-date literature review on VF and business models (Section 2), which helps to constitute the research gap in the combined area of VF and business model innovation. Then the research method is given in detail, including the research procedure and consequently data sources and data processing to be applied within the method and procedure (Section 3). Results are presented in Section 4 and discussed in Section 5. Additional sections are given to highlight research implications (Section 6), research limitations, and future research agenda (Section 7). Finally, the paper concludes with some remarks related to the subject.

2. Literature review: business models and vertical farming

Since this paper focuses on business model configurations for VF management, providing specific guidelines for vertical farm owners, it is expected to review some aspects of the actual knowledge related to business models and VF, both separately and as a pair. It is presented in the following subsections.

2.1 Literature review on business models and business model innovation

Business models appear to be a complex and multidimensional phenomenon that “integrates a variety of academic and functional disciplines, gaining prominence in none” (Jensen, 2013). There is little consensus regarding the clear meaning of the term “business model” (DaSilva and Trkman, 2014: 379; Massa et al., 2017). A review of more than 600 peer-reviewed articles by Wirtz *et al.* (2016) concluded that it is crucial to clarify the meaning of the business model concept. Shafer *et al.* (2005) defined the business model by prioritising the inclusion and synthesis of earlier works in the literature and simplified it to be understandable, communicable, and rememberable. They defined a business model as a representation of a firm’s underlying core logic and strategic choices for creating and capturing value within a value network. Teece (2010) described business models with similar terminology, noting that business models portray the design or architecture of the value creation, delivery, and capture mechanisms employed within a business. Osterwalder and Pigneur (2010: 14) noted that the business model describes the rationale of how an organisation creates, delivers, and captures value. The three above-mentioned, well-received definitions of business models focus on ‘value creation’ within the business and its dominion. Similarly, Casadesus-Masanell and Ricart (2010) noted that a good business model is perceived as the one that is able to specify customers, their values and way of values’ delivery to customers at an appropriate cost.

Business is fundamentally linked to the creation of value and the capture of returns from that value, and a business model is a representation of reality. As such, it needs a set of elements (components) to create its structure. Shafer *et al.* (2005) compiled a list of 42 components by reviewing 12 established publications on business model definitions, whereas Osterwalder and Pigneur (2010) discussed various key business model elements by shaping them nine overarching components (building blocks) in the Business Model Canvas. The 42 components from Shafer *et al.* (2005) and the nine building blocks from Osterwalder et al. (2005) provide a thorough insight into the study of business model elements; the former study presents a detailed

outlook into 42 possible business model components discussed in various academic publications, while the latter study proposes a lean structure of business model components, focusing on the key elements. While Shafer *et al.* (2005) study focuses on identifying as many business model elements discussed over the years in the business model literature as possible, the Osterwalder et al. (2005) study provides a guiding mechanism for managers in applied business model studies.

The Osterwalder and Pigneur (2010) business model canvas has inarguably received significant popularity in the academic and start-up sectors, as it is leaner and simpler compared to the 42 components identified by Shafer *et al.* (2005). For the sake of completeness, it is worth adding a concise reference to Maurya's (2012) lean canvas, or Ries' (2011) lean start-up methodology. The Maurya lean canvas (2012) adapts from and tweaks the Osterwalder and Pigneur (2010) business model canvas, while the lean start-up methodology from Ries (2011) is a scientific managerial methodology to test the start-up vision and learn actual customers' expectations before launching a product or service.

Managers across all industries can benefit from using a clarified concept of business model as a value-creating model in their strategic planning and decision-making (Fjeldstad and Snow, 2018: 37). These insights also facilitate managers ability to answer the important age-old questions raised by Peter Drucker (2011) such as, 'Who is the customer? And what does the customer value?' They also attempt to answer the fundamental questions asked by managers more recently with regard to climate change (therefore, related also to VF within this paper): 'How do we make money in this business that is sustainable for the environment? What is the underlying economic logic that explains how we can deliver value to the business stakeholders at an appropriate cost?'

Fjeldstad and Snow (2018) offer key insights to help managers understand how a value is created in a firm. They link a firm's value configuration with its business model elements to see the symbiosis for complementary value configurations. To allocate this topic within urban farming, it is worth mentioning various global seed production companies such as Syngenta, Bayer, or KWS operate complementary, free of cost web-based farm management platform for farmers as a value-adding tool to increase the functionality of the seeds that they provide to their customers. Fjeldstad and Snow (2018) also highlight the importance of having a plan for changing and realigning the firm's business model based upon the environmental conditions in which the firm operates. This process requires firms to be constantly vigilant to monitor emerging trends and to be agile and flexible to alter business models. Another key insight from Fjeldstad and Snow (2018) brings attention towards foresight in anticipating the future of a firm's business model with regards to emerging trends that present new value-creation opportunities for the firm. The global economy is increasingly digital and moving toward an exponential growth in the technology development space, which requires firms to repeatedly reconsider their chosen business models to be agile in operational management as well as in the dynamic interaction between the business model configurations.

Furthermore, Ries' (2011) lean start-up methodology stresses the importance of scientific management (Ries, 2018; Taylor, 2003) and systematic approaches for experimenting with and validating new products and services. Ries has put emphasis on training the mindsets of managers and knowledge workers in any size company to do things methodically with scientific foundations.

To build or maintain a continued innovative approach to their business, the firms (here: VF companies, agencies, and cooperatives) should focus their attention on changing and realigning their business models, certainly including technological, economical, and especially environmental conditions in which the firm operates. Moreover, they should focus on a plan for

changing and/or realigning business models based on observed emerging trends and be agile and flexible to alter business models, especially if new value-creation opportunities for the firm appear. This is combined with an issue that cannot be omitted by such firms, namely that they should implement systematic approaches for experimenting with and validating new products and services.

2.2 Literature review on vertical farming

As Chesbrough (2010) points out, technology by itself has no single objective value. The economic value of a technology remains latent until it is commercialised in some way via a business model. The same technology commercialised through two different business models and business strategies may yield two different returns (Chesbrough, 2010: 354). Teece (2010) asserts that new product development efforts should be coupled with a business model defining their ‘go to market’ and ‘capturing value’ strategies to progress towards growth. This might explain why VF has been yielding different returns in different parts of the world, facing challenges in identifying the right business model.

VF can increase the crop yield by ten times per square meter of land used, and it can also be cultivated year-round due to the controlled environment of cultivation (Benke and Tomkins, 2017). As the name suggests, VF is an attempt to grow various crops and plants in vertical structures to create a ‘vertical farm’. It aims to optimize the farming process by using air or nutrient-rich water to replace the use of soil for plant growth and cultivation. It is perceived as an innovative way to grow more food in less space and with fewer production input resources. In VF techniques, the climate is tightly controlled and monitored in such a way that the temperature, humidity, gas exchange, and light are all regulated to ensure the best possible crop growth conditions.

Various types of vertical farms can be found all over the globe, depending on a facility's size and the purpose of its use. Butturini and Marcelis (2020) found (a) vertical farms in a form of artificially lit plant factories in industrial-scale buildings; (b) modular vertical farms allocated in shipping containers; (c) in-store farms i.e., vertical farms allocated in public spaces related to consumption or retailing; (d) appliance farms, i.e., a vertical farm appliance integrated into a home or office.

Examples of VF applications are found at both the start-up level, and corporate enterprise level. VF has also been developed in many parts of the world. Despite the cross-continental prevalence, vertical farms are operated identically across regions. Accordingly, there have been considerable variations in the performance of vertical farms.

In terms of the business management literature on VF, the discussed topics are varied. Emerging literature continues to discuss the economic viability and investment prospects, digitalized value creation systems, and new market expansion strategies, and modular growing-service systems of VF (Appolloni *et al.* 2022; Thomson 2022; Martin, and Bustamante 2021; Allegaert *et al.*, 2020; to name only a few). These studies provide comprehensive overview of the current state of VF including the economic viability of the various VF business models and technologies (Appolloni *et al.* 2022; Kalantari *et al.* 2017) including exploration of the VF state-of-the-art in the fields of plant growth, product quality, automation, robotics, system control and environmental sustainability (van Delden *et al.* 2021), business model innovation (Thomson 2022), and novel value-creation systems for VF (Martin and Bustamante 2021) also by comparison in relation to traditional/mainstream farming solely (Moghimini and Asiabanpour, 2023). Despite the significant insights from Appolloni *et al.* (2022), van Delden *et al.* (2021), Kalantari *et al.* (2017) and other literature review materials, the research are most often based on a review of existing literature rather than on actual empirical data (coming directly from companies), which can be treated as limitation of the studies strength. Similarly, the strength of

the findings in Moghimi and Asiabanpour (2023), Thomson (2022), Martin and Bustamante (2021), is limited e.g., by the small sample size. Therefore, further research is needed to generalize the findings on VF's business models to a larger population.

VF is a costly facility, and the investment costs to build a 37-storey vertical farm can add up to €200 million (Banerjee and Adenaeuer, 2014), and currently there are more than \$100 million in construction expenditures (Ehmke and Zuckerberg, 2022). The expenditures are driven up by several factors, which include the cost of real estate/land, a decision to purchase/rent the land, the initial cost of setting up the VF unit/system to operational capacity, the choice of the growing system, used technologies, and applied level of automation, etc. (Brin *et al.*, 2016; Banerjee and Adenaeuer, 2014). A successful VF must be competitive with the traditional farms, and provide crops at lower operational costs and also provide better quality and freshness of produce. VF is not completely achieving the above-mentioned conditions. In a study by Professor Louis Albright, an average of bread-dedicated wheat grown through vertical farms would cost \$27, whereas the traditional farm provides it at \$1.296 (Shackford, 2014). Such costs of wheat associated with traditional farming are significantly lower; however, available arable land and water are decreasing (agricultural land shrinking: Tuan, 2021; it is worth mentioning that according to Moghimi, 2021; Beacham *et al.*, 2019 VF consumes only 1/10th of the water compared to traditional farming). In the future, the reduced availability of arable land can lead to a decline in wheat production, which may further lead to a surge in the price of bread (Shackford, 2014). As this reference was published few years ago, it is important to check the current situation. Moghimi (2021) mentioned that the total production cost in the case of VF is 1.50 USD/kg on average vs. 0.60 USD/kg in the case of traditional farming. Based on the study of Allegaert *et al.* (2020), these overall costs can be lowered by improving technologies in terms of lighting, heating, ventilation, air conditioning, automation, and the evolution of green energy.

2.3 Business models for vertical farming – consideration thus far

There are various factors worth taking into consideration while assessing the performance of business models associated with vertical farms. These are derived from business model elements developed by, among others, Upward and Jones (2016), Krumeich *et al.* (2013), Osterwalder and Pigneur (2010), and Shafer *et al.* (2005), and the results of empirical research conducted by researchers looking into specific industries. Thus, among those factors, there are some general ones like stakeholder's involvement, including customers engagement (Appolloni *et al.*, 2021; Dossow and Kern, 2022; Johnson *et al.*, 2008; Zott and Amit, 2010), profit formula with revenue streams, including B2B sales (Johnson *et al.*, 2008; Dossow and Kern, 2022; Zott and Amit, 2007), and location (Appolloni *et al.*, 2021; Dossow, and Kern, 2022; Benke and Tomkins 2017). On the other hand, firm-specific and industry-specific factors also matter (Hawawini *et al.*, 2003; Zott and Amit, 2007; McGahan and Porter, 2002), which in the case of VF are agronomical parameters like growing system, type of crop or product, and crop yield (Benke and Tomkins, 2017; Appolloni *et al.*, 2021). And additionally, factors for evaluating VF performance, water and energy consumption can also be listed (Benke and Tomkins, 2017). It can be concluded that while a cohort of these studies provides a holistic understanding of VF, their business models, and value-creation networks, a gap in connecting business model decisions and variations to VF performance still exists.

Key performance and impact indicators can be applied to support the evaluation of VF. These metrics may be quantitative or qualitative based upon modelling, analysis, and literature review findings on VF companies through open-source information platforms. These key performance indicators are business model characteristics that help to describe a vertical farm's performance.

3. Research methods and data

To study the relationship between VF business model configurations and firm performance, high-performing commercial vertical farms were studied using a fuzzy-set qualitative comparative analysis (fsQCA; Ragin and Davey, 2022). Data on the top-performing vertical farms were collected through the online Crunchbase database.

3.1 Qualitative Comparative Analysis (QCA)

Developed in the late 1980s by Charles Ragin and colleagues, the QCA was originally designed to facilitate research in history, sociology, and political science. The types of analyses for which the QCA was developed classically involved the comparison of countries with one another; this is a typical ‘small N-many variables’ scenario, where the number of examples of a phenomenon is small (for example, rising economic powers in global affairs) and the number of variables that might explain a given outcome might be large (for example, the factors/conditions, which give rise to food insecurity in rising economic powers). Although QCA studies began with studying macro-level cases such as states, in a recent study by Oana *et al.* (2021: 19), QCA was observed to be most widely used for “business or management” literature research studies listed in the top 10 journals publishing comparative analyses-related research between 1987 and 2019. The QCA methodology has been further found to be applied in studies of cases on all different levels, micro (individuals or small groups) and meso-level (organisations, firms etc.) (Delmas and Pekovic, 2018; Hervas-Oliver *et al.* 2015; Khan., Rezaei and Valaei, 2022). A characteristic that distinguishes QCA from other statistical methods is that it takes a ‘case’ rather than ‘variable’ perspective in its analysis. In so doing, it aims to transcend the qualitative/quantitative division, changing the focus of investigation from the individual study to the different configurations of intervention, participant, and contextual characteristics that together are responsible for the interference (not) resulting in the outcome of interest (Ragin, 2009). As evidenced by the large number of published articles in indexed and high impact-factor journals conducted using QCA, the methodology seems to have been widely

accepted in the scientific field, as noted by Roig-Tierno *et al.* (2017). They observed that the basis of QCA's configurational approach is the analysis of 'sufficient' and 'necessary' causes to produce the outcomes. Taking into consideration the abovementioned drivers, this methodology can assist in understanding if there are any sufficient or necessary variables in business model configurations or decisions that result in high performance of VF companies.

3.2 Research sample

To identify cases for research using an exploratory approach, we extracted a list of currently operational vertical farms around the world through the Crunchbase Pro online database by searching for the keywords "vertical farms", OR "vertical farming", OR "hydroponics", OR "aquaponics", OR "aeroponics". A total of 636 search results were identified through this keyword search. Crunchbase is rapidly being discovered by scholars from different fields as a new database on innovative start-ups and companies with potential for economic and managerial research (Dalle *et al.*, 2017). Out of the 636 search results, a sample size of the top performing 50 commercial, vertical farms were selected to study the relationship between VF business model configurations and firm performance, using a fuzzy-set qualitative comparative analysis (fsQCA). Originally, according to Greckhamer *et al.* (2013), most prior studies using QCA were based on small-N items from 10 to 50 cases (references are not quoted here directly as they are not research-related). QCA is useful also in large-N situations, over a 50-item sample. 50 cases applied for current research can be treated as a medium-N sample (in statistics, by convention, a sample of up to 30 items is considered a small-N, while a large sample is considered larger than 30 items; Skarbek 2013). These performance rankings were generated by Crunchbase based upon factors such as level of public engagement, funding events, acquisitions, and revenue size, etc. 19 firms of the 50-item sample were excluded as they were irrelevant and invalid for this study since they represented companies offer VF tools and equipment as a value-service, product instead of plant cultivation. Consequently, the selection

of 31 vertical farms, based on Crunchbase's algorithm was applied within the research, allowed to avoid cherry-picked performance measures to select a specific sample for this analysis. Out of the identified 636 search results, 605 were classified as invalid sample cases for this study due to incomplete, insufficient, and/or inadequate information making the comparison impossible, or they were not VF growers themselves, thus being rejected as samples. Herewith, 31 case studies were selected representing the top 31 VF companies by performance. The QCA study has been used to integrate the strengths of the case-oriented approach and the variable-oriented approach, which allow a systematic cross-case comparison of the selected case studies. Medium-sized sample groups are best for QCA (like the one given in this paper). as noted by earlier methodology guidelines and best practices in QCA and fsQCA.

3.3 Research data and procedure

A key central feature of the QCA approach is its focus on configurations. QCA can be applied as a predominantly case-oriented approach—where the focus is on the complexities of in-depth contextual case knowledge with the identified cross-case patterns—or otherwise as a variable-oriented approach (also in use: condition-oriented approach)—where the focus can be moved to the cross-case patterns in terms of set conditions (Thomann and Magetti, 2020). QCA as a variable-oriented approach is feasible, especially for the analysis of medium-sized samples, which suits well for our sample size of 31 cases. QCA techniques are formalised in the sense that they are based on mathematical languages and tools, such as Boolean algebra and set theory (Caramani, 2008; Duşa, 2020; Rihoux and De Meur, 2009).

The cases applied within the research are derived from global VF companies, as discussed earlier. Application of the method requires the selection of variables, which can have a significant impact on the outcome of interest (high performance). For this study, the following five variables have been identified for testing the complex equifinality and connection between the variables and the outcome:

1. Location (LOCAT): cases in which members of the set represent the presence of a VF facility in an urban setting (more than 50,000 population)
2. Customer Engagement (CUSTN): cases in which the members of the set focus on the ongoing cultivation of a relationship with their customers, with the view to creating deep connections with customers that drive purchase decisions, interaction, and participation
3. Revenue Stream (MREV): cases in which the members of the set represent the presence of multiple revenue streams in the business model
4. Crop Types (CROP): cases in which the members of the set represent the presence of more than one type of crop variety in the VF strategic choice
5. Business-to-business Sales (B2B): cases in which the members of the set represent the presence of a B2B channel in the business model
6. Outcomes: “High (superior) performance” OR “good performance”

These variables constitute the fsQCA model of high-performance, which is given as a function of variables, namely: *High-Performance* = $f(LOCAT, CUSTN, MREV, CROP, B2B)$

The data set is measured with binary scores (i.e., 0 or 1) satisfying the crisp-set QCA (csQCA) measurement. These set membership scores are subsequently transformed into truth tables, which are explained in Section 4. These business model elements as variables have been selected because of their relevance in determining the success and performance of vertical farms based upon the discussions in Sections 1 and 2. For example, the application of VF practices seems more practical in urban settings, where population is high and land availability is low; therefore, ‘location’ (LOCAT) has been chosen as one variable. As noted by Baden-Fuller and Morgan (2010), there is “no single way by which a business can make money, but many

possible variations within each”. Therefore, equifinal business model configurations for high firm performance likely exist. Albeit being different in their composition, these business model configurations symbolise alternative pathways through which businesses can deliver, capture, and retain value.

Table I presents the summary of data on vertical farms used in this study.

Insert Table I about here.

Membership in the variables of this data set is exclusively binary: cases are either members {1} or non-members {0} of a variable. As established earlier in the methodology, these are also referred to as ‘crisp’ sets in csQCA (crisp-set qualitative comparative analysis) studies. Furthermore, the outcome in this data set is an indicator of the best performing companies (high performance in the cases). Performance is difficult to measure with binary scores; therefore, ‘fuzzysset’ scores were calculated based upon the Crunchbase rankings (CB Rank).

4. Results

With five variables in the QCA study and two possible outcomes {0} OR {1}, the possible number of truth table combinations or configurations is equal to 2^k where k is represented by the number of variables ($k = 5$). Table II shows five possible conditions that can be consolidated as 32 varied combinations in the QCA study (2^5). However, several configurations have not received any matching combinations from the sample case studies. These are known as the logical remainders in the csQCA and fsQCA studies, as described in the research literature (Crongvist and Berg-Schlosser, 2009; Ragin, 2009; Rihoux and Ragin, 2009; Schneider and

Wagemann, 2013). Three kinds of possible results for each of the 32 configurations can be observed; therefore, four result types can be given under consideration in total:

1. Positive cases: All cases within a set are instances of the outcome
2. Negative cases: No cases within a set are instances of the outcome
3. Logical remainders: No cases in the dataset with the particular configuration of outcome and conditions
4. Contradictions: Some of the cases are not instances of the outcome and some do

In Table II, an asterisk (*) is used to combine variables (equivalent to ‘AND’), and a tilde (~) is used to indicate non-membership in a variable condition (equivalent to a mathematical subtraction sign). Therefore, for example, a case with the conditions “located inside an urban area, with strong customer engagement platforms, multiple revenue models, multiple crop types, but without the presence of a B2B sales channel” would be labelled as “Location * CustomerEngagement * RevenueStreams * CropType * ~ B2B-Sales”. The “configuration set label” column of Table II shows the labels of sets for the various configurations of these five conditions.

Insert Table II about here.

Ragin (2009) also stresses the importance of appropriate cut-off levels for consistency, arguing that consistency readings should be as close to 1 as possible for strong membership in the outcome set. It is widely noted in QCA research methodology studies that it is difficult to draw causality, linkages, and conclusions when consistency scores are under 0.750. For this

study, a consistency cut-off level of 0.800 has been adopted as the fuzzy-set readings are high for the outcome set. Configurations yielding consistency of a value exceeding 0.900 have been termed as ‘has having full membership in the outcome set (high performance companies)’, whereas configurations yielding consistency greater than 0.800 are associated with having ‘strong, partial’ membership in the outcome set. Cases in configurations with consistency readings of with a value not exceeding 0.800 are associated with non-membership in the ‘high performing companies’ set; however, no configurations of non-membership in the outcome set were reported.

Insert Tables III-IV about here.

As the selected outcome of focus was ‘high performing companies’, and the selected case studies were the top 31 performing companies, all cases have at least partial membership in the outcome set, and certainly zero cases of non-membership in the outcome set have been observed.

Table III shows the results for the fsQCA run for high firm performance linked to business model elements. Business model elements driven by high performance in VF companies are linked to only one configuration – a strong presence of customer engagement and the presence of B2B sales channels. Table IV shows the results for the fsQCA run for ‘good firm performance’ linked to business model elements. A presence of multiple revenue models is linked with strong (or good) firm performance. While the presence of multiple revenue streams in the business model is a sufficient condition for good firm performance in VF growers, strong

customer engagement, and presence of B2B sales platforms are sufficient conditions for top (highest) firm performance in VF growers.

As the findings induced from the fsQCA on business model elements as conditions seem insufficient for interpretation without considering the decisions as conditions of the outcome set, two more fsQCA analyses were performed where business model elements and decisions were set as the conditions, and high performance (Table V) and good performance (Table VI) were established as the outcomes. Solutions from these two fsQCA analyses reveal that the presence of VF growers (companies) in cities of urban setting, with strong presence of customer engagement tools, and the presence of B2B sales channels are sufficient configurational conditions for the highest (superior) firm performance in VF companies, while the presence of multiple revenue streams or the use of various crop types are sufficient conditions for good firm performance.

Owing to the causal complexity of the results (configurational causality rather than conditional/variable-oriented causality), there is more than one path toward the desired outcome (equifinality); different results for explaining absence of cases in the set of high-performance companies. Although necessary and sufficient conditions have been identified through the fsQCA analyses for high firm performance, it is not being concluded that the presence of these conditions causes higher performance in VF companies. It is only being suggested that certain conditions from the configurations displayed in the dataset have been linked as pathways that lead to the outcome (high performance in VF companies). Similarly, for the alternative outcome being tested under the same conditions (outcome: good firm performance), the presence of certain conditions is linked as being a pathway towards the outcome. In these analyses, causality is not being claimed between the conditions and the outcome. But the presence of certain conditions within the condition-configuration lead to the outcome of interest.

Solutions Formulas:

CUSTN * B2B → High Performance (Superior) [1]

MREV → High Performance (Good) [2]

LOCAT * CUSTN * B2B → High Performance (Superior) [3]

MREV + CROP → High Performance (Good) [4]

MREV ← High Performance (Good) [5]

CROP ← High Performance (Good) [6]

(*) represents AND; (→) represents sufficiency for the outcome; (+) represents OR; (←) represents necessity for the outcome.

5. Discussion

It has been noted in previous publications on VF that the idea of VF seems more approachable in urban settings (Al-Kodmany, 2020; Teo and Go, 2021). Existing research also highlights that, owing to rising urban populations, arable land shortages, reductions in drinking water, food deserts, and associated carbon emissions (cf. Al-Kodmany, 2020; Tuan, 2021; Moghimi, 2021; Beacham *et al.*, 2019), VF in urban settings can help offset the challenges. As urban areas tend to have higher populations, hence higher consumer demands for agriculture, it can be more speculated that VF can be conducive in urban settings to achieving more value rather than rural areas with lower populations. Secondly, the presence of customer engagement in the business model i.e., urban citizens into VF, also ensures that the achieved value is retained. Thirdly, multiple revenue streams in the business model further create new sources of generating financial earnings to reward the firm for their value-creation.

Furthermore, having multiple varieties of crops growing in a vertical farm improves the utility of the VF system as it is enabled to cultivate various types of vegetables, fruits, and crops. Hence, those multiple crops become a source of extra value creation in the business model.

Lastly, companies selling their goods or services through a B2B model, experience an increase in the volume and value of their sales, thereby being able to capture and retain a larger amount of financial value from the sale. These five conditions are hypothesised to result in higher (superior) firm performance (the outcome). Alternatively, these conditions are also assumed to lead towards high (good) firm performance – this performance level is lower than the superior most performance but still good quality in terms of success.

The complex causality on which fsQCA focuses has several characteristics. First, it investigates how conditions work together as a causal recipe for causing an outcome, known as conjunctural causation. Approaching causation like this is different from the net effects approach, which focuses on the effects of individual variables. Another aspect of complex causality is equifinality, which means that more than one condition or combination of conditions might lead to the same outcome. Further, QCA identifies if and how a condition works differently in different cases. In one case, the presence of a condition might lead to an outcome, and in another case, the absence of that condition might lead to that outcome. QCA thus allows for a context-specific analysis of causation, or practically equifinality. Lastly, QCA assesses asymmetric causation, meaning that the recipe for the occurrence of the outcome is not simply the opposite of the recipe for the non-occurrence of the outcome. Therefore, the explanation of the non-occurrence of the outcome cannot be derived from the explanation of the occurrence of the outcome. The non-occurrence of the outcome must be assessed separately.

QCA also enables the analysis of complex causality because of its set theoretic approach (Schneider and Rohlfing, 2013; Fiss, 2007). For example, on set theoretic approaches, let us take the set of VF companies that are growing in an urban area with a population of more than 50,000. Suppose that all companies with that condition are also members of the outcome set (companies with high level of firm performance). Not all VF companies with high firm performance are growing in urban areas, but the reverse is true. All VF countries growing in

urban areas have high firm performance. In that case, the condition set of VF companies growing in an urban area would form a part (or a subset) of the outcome set of VF companies with high firm performance. This could be interpreted as an indication that urban areas are conducive to VF growers because whenever VF companies grow in urban settings, they also have high firm performance. In set theoretic terms, urban-setting as a location would be considered a sufficient condition for the outcome (high performance), sufficient in the sense that the presence of VF companies in urban-settings by itself results in higher firm performance.

The same line of reasoning applies to more complex models with multiple variables. For instance, from the results presented in Table V, all VF companies growing in urban areas (variable LOCAT {1}), having a strong customer engagement platform (variable CUSTN {1}), and having B2B sales channels (variable B2B {1}) have the highest (superior) firm performance (outcome Y). Therefore, the configurational variables LOCAT and CUSTN and B2B together, are sufficient conditions for the highest (superior) firm performance in VF companies (see equation [3]). Equation [4] implies that multiple revenue streams or multiple crop varieties are sufficient as individual conditions, as well as configurational conditions to result in the outcome, high (good) performance.

Similarly, equation [1], and [2] show results from the fsQCA analyses where solely business model elements such as (CUSTN, MREV, B2B) were tested, separately for both outcomes. The strategic choices (LOCAT, and CROP) were not included during these fsQCA analyses. Equation [2] suggests that having multiple revenue streams in a business model is a sufficient condition for high (good) firm performance, while equation [1] implies that having strong customer engagement and B2B sales channels is a sufficient configuration for higher (superior) firm performance.

To summarise the fsQCA analyses, the Truth Table models 1 and 2 (Tables III and IV) present positive results but are insufficient for detailed interpretation of the business model

conditions. Therefore, further analyses were conducted by adding two more conditions to the data set and creating Truth Table model 3 and Truth Table model 4. Results from Truth Table model 3 (Table V) and Truth Table model 4 (Table IV) add more colour to paint the picture of interpretation of the variables and outcomes, and therefore are important and sufficient to explain the linkage between the conditions and outcomes. Since having multiple revenue streams or crop types is sufficient for good firm performance, it can be inferred that the presence of multiple revenue streams or multiple crop types in a VF business model is positively associated with good firm performance. Similarly, a presence in urban settings, along with a strong customer engagement platform and a B2B sales channels are sufficient conditions for the outcome and therefore positively associated with highest (superior) firm performance. The fsQCA performed two separate analyses: a necessity analysis for identifying necessary conditions, and a truth table analysis for identifying sufficient configurations (Thiem and Dusa, 2013). For the necessity conditions, analyses indicates that multiple revenue streams and multiple crop types are necessary isolated conditions for good firm performance, as well as configurational conditions for good performance. These fsQCA analyses were conducted through the QCA Add-in function on the Microsoft Excel program, provided by Lasse Cronqvist (2019).

For this study, the top 31 VF companies in the world were identified through the Crunchbase online ranking platform. The Crunchbase rank algorithm takes several variables, such as the level of community engagement, funding events, news articles, and acquisitions, into consideration to generate a ranking. Such rankings of the companies listed on Crunchbase are fluid and subject to change over time. Time-sensitive events for example, product launches, leadership changes, funding rounds affect the Crunchbase ranking of a company (Vizcocho, 2021). However, several Crunchbase users have reported that the data provided on Crunchbase can be outdated and invalid (TrustRadius, 2022). To tackle this issue, data from Crunchbase

has been tallied and validated through the information available on LinkedIn, social media, and company websites. The key strengths of the Crunchbase database for this research are, the internal ranking system which homogenously measures company performance across several factors, and the availability of data on VF companies in a single database. A complete database covering the information on all vertical farms around the world does not exist currently, but Crunchbase enabled to identify 636 VF growers and businesses offering technology and equipment for VF around the world. As the Crunchbase database also included VF technology and service providers, while the scope of the study is aimed only at VF growers, company LinkedIn pages and webpages were used to ensure that technology and service providers are excluded from the sample size (each company was checked one by another). In this experimentation, initially 50 case studies were identified out of which 19 were excluded owing to their association with technology and service providing companies and lack of association with VF growers.

6. Research implications

6.1 Theoretical contributions

This paper contributes to expanding the knowledge of business model theory, business model configurations, and VF management, providing specific guidelines for vertical farm owners and investors related to decision-making for higher firm performance, and positive environmental, social, and economic impact. More broadly, the results of this research provide new insights into how vertical farms operate and what are the specific characteristics of their business models, thus in this sense contributing to the organizational theory. The findings from this study align with the results from existing research. For instance, firm performance is known from Zott and Amir (2008) as a fit between business models and strategy and a function of specific business model characteristics. Findings from the fsQCA analyses also confirm that firm performance, as a function of business models and strategy, can vary with specific business

model elements or with various configuration sets of those elements and decisions, further supporting the claims of George and Bock (2011).

Three business model elements that are found to be associated with higher firm performance are revenue streams, customer engagement, and sales activities. Findings from the study indicate that having multiple revenue streams can be a necessary condition to lead toward high firm performance. Furthermore, the presence of strong customer and community engagement platforms combined with B2B sales activities can yield superior firm performance. As suggested by Saarijärvi *et al.* (2013), firms could introduce customer value co-creation mechanisms that support customer value-creation as well as firm value-capture aspects thereby creating a sort of ‘multiplier affect’ in the firm’s value network.

To the best of the authors’ knowledge, the presented approach has not previously been applied to evaluate the performance of vertical farms in the context of their business models by QCA. Therefore, the research presented here is a relevant contribution to the theoretical perspective on the developed subject. This study adds a multi-case study perspective by application of fsQCA to the literature from a theoretical and methodological viewpoint. Furthermore, the QCA raw data matrix along with the truth tables and outputs have been reported, allowing replicability of this QCA study in the future; consequently, it can be treated as another example of contribution to the theoretical perspective on the subject. QCA studies utilise strong technical, scientific, and mathematical concepts that are difficult to discuss within the scope of this study.

6.2 Practical implications

The research on business model configurations and their association with superior vertical farming firm performance presents several managerial implications. Specifically, the study underscores that vertical farms situated in urban environments, incorporating robust customer

engagement platforms, and leveraging B2B sales channels exhibit a consistent pattern of configurations leading to high firm performance. Notably, the presence of multiple revenue streams and the cultivation of diverse crops within the vertical farming system are identified as sufficient conditions for favourable performance outcomes. However, it is crucial to emphasize that the actualization of superior performance for commercial vertical farms requires intentional decisions, including the incorporation of elements such as multiple revenue streams, customer engagement platforms, and the establishment of B2B sales channels. To optimize performance results, the integration of business model development activities with strategic planning is recommended. Managers should prioritize the incorporation of various revenue streams and crop types, viewing them not only as configurational conditions but also as necessary isolated conditions for achieving optimal performance. The co-occurrence of multiple revenue streams and crop types is highlighted as a key factor for success, emphasizing that these elements should ideally complement each other within an undertaken project.

The study highlights that various business model configurations can yield high firm performance, with variations influenced by factors such as company size, industry type, and company structure. Vertical farm managers should consider those while designing their business models. Furthermore, the research emphasizes the crucial role of B2B sales channels, identifying them as sufficient conditions for achieving superior firm performance. In light of these findings, managers in the VF industry should strategically leverage and invest in B2B sales channels to enhance overall business outcomes and ensure sustained success.

In addition, established companies should regularly update their business model, or they might fail to anticipate disruptive trends and challenges ahead. It is one of the options to ensure up-to-date and innovative approaches to the business, as mentioned in the literature review. This can be achieved, for example, by mastering employee (managers') knowledge on customer

needs and problems, by increasing flexibility in managers to pivot and alter business models, by creating field specialist managers and improving their ability to collaborate, and by training managers in foresight and strategy to enable them to monitor the emerging trends and technologies in the competitor space. Business models also facilitate the firm by aligning operations and key activities with the business strategy, improving communication within the company's network of 'value stakeholders', and providing a competitive advantage to firm through the development of the firm's 'unique selling point' or value proposition(s). Business models can help managers visualise and verbalise what their business is undertaking (creating, capturing, and retaining value), how they are doing it (key activities and resources), whom they are creating value for (customers, target segments), and what their support mechanisms within their operational ecosystem (key partnerships within the value network) are. For these reasons, unpacking business model configurations and VF management presented in this study can serve as guidelines for vertical farm owners and investors on decision-making for higher firm performance, and positive environmental, social, and economic impact.

7. Research limitations and future research directions

One of the key challenges during this research was the lack of data available on VF companies and / or their failures, especially in the case of unsuccessful vertical farms. A cross-comparison between the failed VF business models (of unsuccessful vertical farms) and the successful VF business models could have yielded more accurate consistency and coverage results, leading to a better understanding of the evaluated business model configurations. For instance, all evaluated cases during the empirical study were examples of successful vertical farms; the findings may be considered biased as a result (to overcome that challenge, citations, recommended readings, and online reference sources for public access have been cited for more information on the key terms, and concepts). Therefore, the outcome of all configurations was either superior firm performance or good firm performance. A third configurational outcome

classified as non-membership in the superior or good performance sets would have represented failed business model configurations. Reported cases with this outcome would be identified as failed VF companies.

Moreover, the sample size of 31 top-performing VF companies may not seem representative enough to draw broad conclusions, and other factors may reveal beyond the identified business model elements that contribute to firm performance. These limitations are addressed by using the QCA method in this study and a broad literature review that allowed to identify important business model elements considered in this study. The QCA has been noted to be popular as a growing niche research methodology since its introduction in 1987. The QCA research method offers the potential to identify necessary or sufficient conditions for an outcome, while also facilitating a systematic comparative analysis of case study material. This will be essential for this research, to identify the presence of any necessary or sufficient business model elements.

Further research in this area can use open-source information through webpages, and Facebook interest groups to identify and analyse cases of failed VF business models. Future research to contribute towards the growth of the VF industry should take a deep look into the commercial energy costs, water and other media supply costs, commercial rental costs, and populations across major urban areas to identify suitable locations where VF can thrive. These model cities could be hypothesized to have high food demand (i.e., higher populations), low commercial rental costs, and low commercial energy and other media costs (i.e., reduced fixed costs, and maximized profit margins). Additionally, while the study identifies several necessary and/or sufficient conditions for high firm performance and good firm performance, it does not explore the underlying mechanisms or processes by which these conditions lead to improved performance. Future research could investigate these mechanisms in more detail to provide a deeper understanding of the relationship between business model configurations and firm performance in VF.

8. Conclusions

The study on business model configurations linked with superior VF firm performance suggests that vertical farms located in urban settings and having strong customer engagement platforms along with a presence of B2B sales channels have the highest consistency of business model configurations that lead to high superior firm performance. Moreover, the results conclude that “having multiple revenue streams in the business model”, or “having a variety of crops/plants/vegetables grown in the vertical farming system” are also sufficient conditions that lead to good firm performance. Yet, to answer RQ1, it should be mentioned that higher or superior performance for commercial vertical farms can be ensured only by implication of such elements and decisions as “having multiple revenue streams in the business model”, “having customer engagement platforms”, and “the presence of a B2B sales channel”. This and more results from the QCA are given with the following solution formulas:

⇒ Customer Engagement * Business-to-business → High Performance (Superior) [1]

⇒ Multiple Revenue Streams → High Performance (Good) [2]

⇒ Location * Cust. Engag. * Business-to-business → High Performance (Superior) [3]

⇒ Multiple Revenue Streams + Multiple Crop Types → High Performance (Good) [4]

⇒ Multiple Revenue Streams ← High Performance (Good) [5]

⇒ Multiple Crop Types ← High Performance (Good) [6]

(*) represents logical AND; (→) represents sufficiency for the outcome; (+) represents logical OR; (←) represents necessity for the outcome.

The answer found for RQ1 can be valuable as well for the case of RQ2. It suggests building the business model for VF based on varied revenue streams, keeping contact with customers through engagement platforms not to mention B2B sales channels, which should be developed

as well. Others are given valuable hints within Section 6 under additional insights that firms, or actually their managers or policymakers, can glean from the research and apply to their regular operations.

Findings from the study suggest that business model development activities for VF should be coupled with business strategy planning for the best performance results. Various business model configurations can lead to high firm performance, where these configurations can vary according to several factors (for example: company size, industry/sector/branch type, company type, etc.). Findings from the study also suggest that using fuzzy-set qualitative comparative analysis and necessity condition analysis for VF can be useful methodologies to identify sufficient and necessary business models and strategy configurations linked with high (superior) firm performance. Nevertheless, this type of analysis has several limitations presented in this paper. These limitations can be overcome by including case studies with poor, low firm performance or the ones in which business models failed as an outcome.

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