VERTICAL FARMING IN URBAN DEVELOPMENT

CONSIDERATIONS FOR INTEGRATION

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Preface

This master thesis is the culmination of five years study at Aalborg University Copenhagen and the final project of the 4. Semester of the master´s degree, Sustainable Cities. The thesis has been conducted in the period from 1. February - 7. June 2024.

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Danish summary

Det globale fødevaresystem er udfordret på at kunne levere fødevarer til en voksende befolkning. Et stigende pres fra klimaforandringer og urbanisering påvirker den traditionelle måde at dyrke fødevarer på og i byerne har en ny tendens de seneste årtier blomstret frem, hvor landbrug er blevet sat i relation til byerne i form af bylandbrug (Brooks et al., 2019; Soulard et al., 2017). En type bylandbrug, der har potentiale til at producere store mængder af fødevarer i tæt befolkede byområder ved brug af minimalt areal og kan supplere den traditionelle fødevareproduktion med visse afgrøder, er vertikalt landbrug (Parkinson, 2016). I dansk kontekst har vertikalt landbrug ikke haft sin gennemslagskraft med kun 5 registrerede drivende erhverv, flere med små produktioner (Erhvervsstyrelsen, 2024). For at få forståelse for, hvorfor vertikalt landbrug ikke er mere udbredt i Danmark, studeres der i dette kandidatspeciale en mulig ekstern faktor, der kan påvirke integreringen af vertikalt landbrug i byudviklingen. Kandidatspecialet har til formål at undersøges, om den måde byer planlægges på kan være en udfordrerende faktor for vertikalt landbrugs transitions potentiale og mulige integrering i byudviklingen, i dansk kontekst. Formålet er derved at besvare følgende problemformulering:

How is vertical farming's transition potential into the urban development in Denmark from an urban planning perspective?

En socioteknisk tilgang til vertikalt landbrugs transitions potentiale er anvendt, til at undersøge den systemiske ændring af samfundet for vertikalt landbrugs integrering. For at udforske emnefeltet er et litteraturstudie blevet foretaget for at undersøge eksisterende videnskabelige viden, der kan give et pejlemærke om, hvordan den generelle udvikling af vertikalt landbrug i byudviklingen ser ud. Resultatet viste et mindre antal litteratur, der beskæftiger sig med vertikalt landbrugs relation til byernes planlægning og en generel mangel på dybdegående data indenfor feltet blev bekræftet. Videre interviews og kommunikation med aktører indenfor både byudvikling og vertikalt landbrug har givet yderligere perspektiver på hvilke udfordringer vertikalt landbrug står over for i integreringen i byudviklingen, men også her er der begrænsning i data. En sammenkobling af data, der beskriver sammenhænget mellem vertikalt landbrugs udvikling og byernes planlægning, samt viden om mangel herpå, har givet indikationer på, hvordan vertikalt landbrugs transitions potentiale i byudviklingen er påvirket af byplanlægningsmæssige aspekter.

Vertikalt landbrugs nuværende position i samfundet er kortlagt og viser, at erhvervet er i sit tidlige stadie og ud fra Frank W. Geels' koncept om multi-level-perspective (MLP) kan vertikalt landbrug

klassificeres som en niche innovation, hvor de forskellige typer af vertikalt landbrug er underkategorier heraf. En transition af vertikalt landbrug ind i byudviklingen er betinget af et pres der blandt andet kommer fra behov for løsninger på klimaforandringer og urbanisering. Vertikalt landbrug er et erhverv i udvikling og nye praktiske erfaringer indtræffer, men yderligere udvikling er nødvendig for, at erhvervet kan rykke sig fra sit præudviklingsstadie til at blive et erhverv stabiliseret i samfundet.

Ud fra et byplanlægnings perspektiv er der identificeret udfordringer, der kan påvirke vertikalt landbrugs transitions proces ind i byudviklingen. Det er en kombination af den måde byen er planlagt på samt vertikalt landbrug som system, der skaber mulige udfordringer, der relaterer sig til miljømæssig påvirkning, logistiske forhold, tilgængelighed af areal samt sociale forhold. Forskellige typer af vertikalt landbrug samt den urbane kontekst har indvirkning på graden af udfordringer. Igangværende nationale og internationale redegørelser af vertikalt landbrugs potentiale kan være med til at minimere risikoen for, at byplanlægningsmæssige udfordringer påvirker vertikalt landbrugs transitions potentiale, men afhænger af resultaterne af redegørelserne.

Et andet redskab til potentielt at minimere de byplanlægningsmæssige udfordringer er analyseret til at være en eksperimentel tilgang til byplanlægning i form af by-eksperimenter. Vertikalt landbrug, i dets forskellige typer, testes i bymæssige kontekster for at udlede om der er potentiale for en vertikal farm kan integreres i den bymæssige kontekst, samt om det skaber værdi for den bymæssige kontekst. Et bredt udvalg af aktører er værdifuldt, som en privat aktør til at igangsætte et eksperiment med kommunal, statslig og andre aktører indenfor det vertikale landbrugs felt til på forskellig vis at støtte op om eksperimentet. Den viden, som indsamles kan bruges ved en potentiel integrering af vertikalt landbrug i den virkelige byudvikling. Vejen fra at udføre eksperimenter til en reel implementering i samfundet er påvirket af de konstellationer af aktører, der er sat til at undersøge og derigennem bidrage til udviklingen af vertikalt landbrug i Danmark. Der er identificeret en mangel på inklusion af aktører som arkitekter, by-, energi- og miljøplanlæggere, samt at udviklingen bygger på silobaseret tænkning, der påvirker forståelsen for udfordringer, der er udenfor eget felt. Derudover, er forskelligrettede syn på hvem, som skal drive udviklingen af vertikalt landbrug påvist og en udeblivelse af fokus på potentialer i synergier mellem vertikalt landbrug og byens strukturer, påvirker alt sammen vertikalt landbrugs transitions potentiale ind i byudviklingen.

1. Introduction

1.1 Challenges of the food system and a new vision for food production

Urban areas have become home to around 56 % of the world's population, and it is expected that more than double the number of people will call it home by 2050 (World Bank, 2023). A growing population in urban areas require innovative urban planning where essential services are included to sustain the lifestyle of the residents. The cities are on one hand attracting social and environmental challenges with its development, but also innovative solutions to help solve these challenges (Bulkeley & Broto, 2012). Apart from changing living patterns, the global population is generally growing rapid and the Earth is strongly affected by climate change, which has a significant negative impact on the vital resources used to support the world's population. This includes impact on the Earth's water, land, and soil resources, which can cause a strain on the global food supply chain and create threats to food security (Al-Chalabi, 2015). The current agricultural practices are challenged on several facets. The agriculture practices must have the ability to produce nutritious and safe food for a growing population despite climate change, while also being under pressure to reduce its environmental footprint (Brooks et al., 2019). It is projected that by 2050 the total food production will have increased by nearly 70 % to feed the growing population and with an expectation that the global agricultural land per person will drop by 66 % in 2050, compared to 1970 levels, the agricultural sector is under pressure to ensure food security. The drop in agricultural land per person is the direct consequence of the change in urbanisation and climate change (Food and Agriculture Organization, 2009). Figure 1 gives an indication on the shift seen and projected for the society.

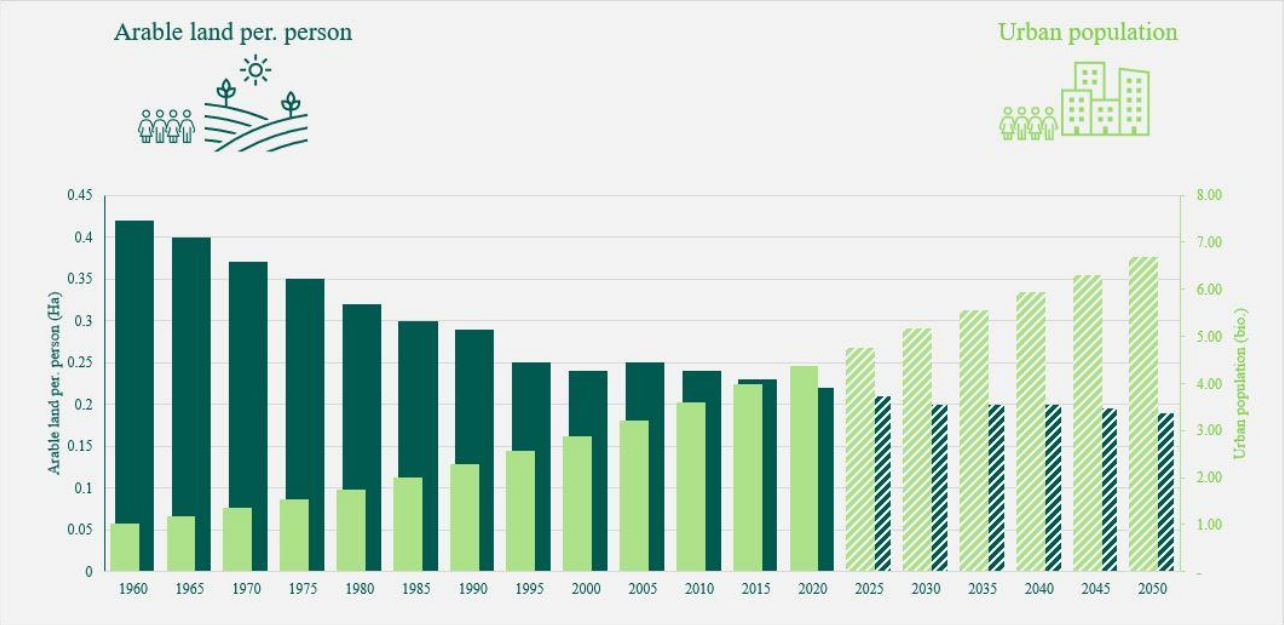

Figure 1: Arable land per. person vs. urban population from 1960-2050 on global scale (Own production, 2024, data from Bruinsma, 2009; United Nations, 2018)

The projections can be changed or adapted depending on the development or transition that takes place in the agricultural- and other sectors. This can affect whether there is a need for a new approach and new systems to grow food or whether there is simply a need for changes in practices in the current system. For example, a shift in land area from feed to direct food production does not necessarily result in the need for new food systems, but simply a shift in practices in the current food system (Bruinsma, 2009). However, introducing new systems can be a supplement that can be part of transforming the sector, given the challenges it faces.

A new vision on the food production system that can meet urban demand, with consideration for the Earth´s resources is worth investigating as a supplement to today´s agricultural practices (Al-Chalabi, 2015). Countries in the global north are also experiencing issues with food security for the urban areas, which is mainly a consequence of ecological and political sensitivities (Morgan, 2010). An idea in this regard is to explore how to produce food that can be integrated into the development of the urban areas where the majority of food is consumed. A long-term historical division between policies and planning for food production and urban development has made the food system less visible in urban areas compared to a system such as housing or transportation. In the design of urban planning the inclusion of food and agriculture is therefore lacking and a demand for better inclusion is needed to connect consumers with food production (Soulard et al., 2017). Although this division has formed urban development, an increase in urban-dwellers or local engagement in alternative food networks,

as urban gardening, has raised in recent decades in urban areas. The form of urban agriculture can vary from social or entrepreneurial food production that are either individual or community based. Depending on the form of urban food agriculture it can be designed to positively contribute to the development of a vibrant urban environment. For instance, social food production can lead to community among users, greening of the urban area or learnings about food production (Soulard et al., 2017). A more entrepreneurial food production primally foster an urban food system that is locally rooted with a short food chain that also open to produce for the global market (Morgan & Sonnino, 2010). Urban agriculture has the potential to link agriculture, food and the urban development and, "*by taking a city region perspective, connecting flows, creating synergies, and planning for sustainable urban food systems*." (Soulard et al., 2017, p. 4, data from Wiskerke, 2015). Investigating the entrepreneurial form of urban agriculture, a type of food production that can be in high-density urban areas, thereby creating proximity to the market with low transport costs, while offering a production without pesticides and chemicals and minimal food waste, is best known as vertical farming (Parkinson, 2016).

1.2 Definition of vertical farming

The concept of vertical farming is not new to the scientific world and the hype around the technology was especially triggered by Dickson D. Despommier's publishment, "The Vertical Farm: Feeding the World in the 21st Century" in 2010 and Toyoki Kozai's publishment, "Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production" in 2016 (van Delden et al., 2021; Despommier, 2010; Kozai et al., 2016). In Despommier's work he addressed how vertical farming, using little space, can secure the entire food supply on a global scale, by growing safe indoor crops with minimal use of resources and with an innovative vision of every city producing its own local food (Despommier, 2010). Kozai's technological focus has particularly examined the benefits of using light-emitting diodes (LEDs) to optimise the efficiency of lamps for production (Kozai et al., 2016). Since the two publications, researchers and industry professionals have continued researching and testing several vertical farming scenarios that offer perspectives on the original statements.

The definition of vertical farming ambiguous, as different researchers and industry professionals have various opinions on what factors should and should not be included in the definition. Vertical farming can be considered a production method under the concept Controlled Environment Agriculture (CEA) systems. CEA systems are defined by systems where the environment can be controlled such as

cultivation in greenhouses, mushroom- or insects farms or vertical farms (Cowan et al., 2022). All these systems can also be a part of urban agriculture, as it refers to food cultivation and production that are happening in the urban area (Chatterjee et al., 2020). The definition of CEA and urban agriculture is too broad an interface to use as a definition of the vertical farming system but can be used to search relevant literature.

By examining the concept of vertical farming in more detail, it can be deduced that the crops in the system can either be grown in multilayers, as vertical walls or just in one layer in a controlled environment. The technology can be defined in many ways, for example as a sunless cultivation system, plant factory with artificial light (PFAL), skyfarm, Zero-acreage farming, indoor farm or for others a vertical farm (Butturini & Marcelis, 2019). A highly agreeable definition in the scientific world is that what is perceived as a vertical farm, is characterised by crops grown in fully controlled production processes, without exposure of sunlight. In this thesis the technology will be referred to as vertical farming and with the definition of a fully controlled environment without sunlight.

At current state, the most suitable crops for vertical farming are crops that are consumed fresh, has a short growing period, and does not require a large space. These criteria fit for leafy vegetables and herbs, which are mainly grown in vertical farms (Salim Mir et al., 2022). Commodity crops, as rice and grains, or root crops, as potato or sugar beets, are not suitable for vertical farming as it is inefficient to start growing them for the purpose of sale. There is no added value in growing the crops compared to on field area, so the capital investment is not worth it (Asseng et al., 2020; appendix C). The possible crop selection limits vertical farming's ability to feed the entire world's population, as Despommier originally argued in his work (Despommier, 2010). Despite the selection, the food produced in vertical farming systems will have a year-round guaranteed quality and quantity that customers demand, as it is produced in a controlled environment. The crops are not exposed to climate challenges as traditional agricultural practices are facing and not depended on the outside climate and soil composition. Vertical farming can thereby be seen as a farming practice that can be fitted to local conditions and help benefit the food production in that area. It can for example be a supplement food production in extreme climates, where it is difficult to grow all the necessary crops in the open field that are essential to feed the population, but also in more neutral climates, where the struggle instead is land use in a high-density area (van Delden et al., 2021).

Vertical farming, as a fully controlled environment, can be in a variety of structures depending on the area of placement and the desired crop volume (table 1 and figure 2).

Table 1. Varity of structures of vertical farming

Category	Explanation
Underground farms	Converting a basement or unused tunnel into a vertical farming system. Often used for medium to large-scale production.
Container farm	Containers placed on ground in the urban area used to implement a vertical farming system. Often for research purpose and for small-scale production.
Building-based farm	<u>Two types of integration:</u> Buildings converted into a vertical farming, where it replaces parts of or all the existing components of the building. For example, an old industrial building in the urban area. Holistic integration of a vertical farming system, where the system is integrated in the building design. For example, a warehouse build for the purpose of vertical farming. Both types are often used for medium to large-scale production.
Rooftop farms	Vertical farming system placed on rooftops in closed buildings. Often used for small scale production.

(Own production, 2024, inspiration from (Butturini & Marcelis, 2019; Kozai, 2018;Association for Vertical Farming, 2023)

Figure 2: Visualisation of the various structures of vertical farming in urban area (Own production based on table 1, inspiration from Benis & Ferrão, 2018, pictures from: Gyuró, 2021; Nabo Farm, 2023; Salling Group, 2021; Square Roots Indoor Farms, 2024; Zhu, 2019))

The choice of structure and location for the farm can challenge urban development in various ways. Depending on the development pathway each structure ends up following based on research, economics, regulation and so on, will affect what challenges need to be overcome from an urban planning perspective and what potential can be realised. As an urban farming practice, vertical farming relates to an entrepreneurial food production and has an industrial perspective of producing food, that can supplement traditional food production with the value of shorter food miles and no pesticides in production. Compared to other urban farming practices, as small community gardens, value is more focused on social aspects, where vertical farming fits less with these social dimensions (section 1.1). It is different ways of connecting the urban area with agricultural practices. The different structures of vertical farming support the development of a green city to a greater or lesser extent, as production is indoors in controlled conditions. A container farm or rooftop farm is more visible production for citizens, but depending on how a vertical farm is integrated into a building and promoted to the citizens, it can also be visible, perhaps only to some citizens (figure 2, appendix B.3). In terms of contributing to the UN's 17 Sustainable Development Goals (SDGs), vertical farming can either directly or indirectly have an effect. What SDG to highlight depends on the structure of the vertical farm that is considered as well as the location and how it is implemented in connection with the urban development (Jaeger, 2024). SDG´s to emphasise the general scope of vertical farming are, SDG 9, Industry, innovation, and infrastructure, SDG 11, Sustainable Cities and Communities, and SDG 12, Responsible consumption, and production. The SDG´s are about fostering innovations that can support the development of urban areas though a change in production and consumption patterns (United Nations, n.d.). For vertical farming to advance to a position where it can in a large degree contribute to the SDG´s, further research needs to be made in terms of identifying and overcoming key challenges for the technology (Jaeger, 2024).

In a Danish context, vertical farming is not a large industry, with five companies registered in the Central Business Register (CVR) as producing food in vertical farms. All small scale that mainly grow microgreens, in underground, container-, or small scale-building based farms (table 1; Erhvervsstyrelsen, 2024). One vertical farm, Nordic Harvest, stands out from the rest and is the first larger vertical farm in Denmark producing in a holistic integrated building-based farm (Nordic Harvest, 2020; Erhvervsstyrelsen, 2024). The small industry in Denmark can be due to either one or a combination of internal and external factors. One factor to investigate, to try and understand the conditions for vertical farming in Denmark, is whether it is the way that urban areas are planned that challenge the development and integration of vertical farming in a Danish context.

2. State-of-the-art: vertical farming in urban development

To understand the amount of knowledge that has already been gathered and researched in regards of vertical farming and the way urban areas are planned, a literature review of existing scientific knowledge within the field is conducted. The result of the review will help determine if additional research is needed within this field to support a knowledge gap and potentially help understand why vertical farming is in its current form, a small industry, in the Danish context. This section describes the outcome of the literature review, where the extracted knowledge is later used in the analysis part of the thesis. The review is based on 41 scientific literatures describing factors related to vertical farming in urban development. The outcome of the literature review highlights the state-of-the-art within this field.

Outcome of literature review

The literature review shows a large range of literature when searching for the words vertical farming and urban development (figure 6, section 5.1). When reviewing the literature, it becomes clear that the majority only deals with vertical farming and not the combination with urban development. These literatures are mainly covering various technical aspects of vertical farming and emphasise on the investment costs of operating high energy-consuming farms, due to the fully controlled indoor production and automation of processes (Kabir et al., 2023; Kalantari et al., 2017a). The end result of the literature review shows a limited selection of 41 publications, concerning aspects related to vertical farming in the context of urban development. These 41 publications are generally broad publications that address multiple conceptions of vertical farming. As shown in Chaudhry and Mishra, 2019, the literature focusses on comparing different vertical farming production systems' ability to be incorporated into urban requirements, whereas Parkes et al., 2022 has more focus on reviewing the building types suitable for vertical farming (Chaudry & Mishra, 2019; Parkes et al., 2022). It shows that not all publications focus on a variety of perspectives on the topic, but a synthesis of multiple literatures is necessary to draw a comprehensive overview of the challenges for vertical farming in urban development.

In many of the publications vertical farming and urban development are generally categorised in the broader context of urban agriculture and issues related to food security in urban areas, as shown in Trienekens & Omta, 2022, Sarkar et al., 2019 and Sayigh & Trombadore, 2022. It affects the number of conclusions that can be drawn from the literature, as a distinction must be made between challenges related to the spread of the broader concept, that also include greenhouses, rooftop gardens and living walls, and the concept of indoor controlled farming as vertical farming. There are shared challenges,

but also differences. The section that focusses on vertical farming in the context of urban development is often a small section in the publication. A frequent perspective drawn from the section is that there is a need for investigating the challenges for integrating vertical farming in the urban areas, but the literature does not state how. This is the example of Sashika et al., 2024, who state that there are multiple challenges to overcome, but it requires more specialised knowledge to do so, or as Lu and Grundy, 2017 conclude that, "*Key topics for further investigation include: ecosystem approaches and integrated urban management; the need for new policy and regulatory models; social and economic approaches to urban agriculture…"* (Lu & Grundy, 2017, p. 401). The literature presents more of a vision for vertical farming and how the technology can develop, but less reflective of how vertical farming is developing in practice. That current literature on the topic demands research in the field may indicate a knowledge gap and a reason for studying the topic in this thesis.

The literatures in the review are published from 2002-2024 with a predominance of articles published from 2018 to 2024 (figure 3). It highlights a small but growing research within the topic. Research is still in its initial stages, and it can help explain the limited amount of published literature and that further research is valuable.

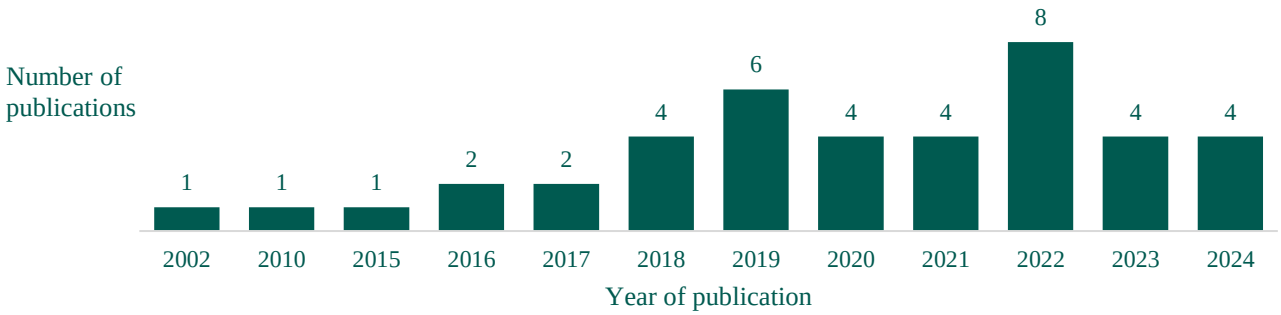

Figure 3: Distribution of the 41 publications by year of publication (Own production, 2024)

The literature is also characterised by referencing to same well-known authors within the field, for example to Despommier, Kozai, van Delden and Marcelis (Jaeger, 2024; Kalantari et al., 2017b; Parkes et al., 2022; Shahda & Megahed, 2023). Especially Despommiers publications from 2010 "The Vertical Farm. Feeding the World in the XXI Century" is frequently referred to (Kalantari et al., 2017b; Salim Mir et al., 2022; Benis & Ferrão, 2018). His publication is considered one of the starting points for research into vertical farming (section 1.2), but with a critical view, it is also an "old" reference within the field, since vertical farming and the possibilities for it, has developed significantly and is no longer just a futuristic vision. Statements from his work has therefore already been proven and disproven.

The four authors that are well-referenced in the literatures are from US, Japan, and the Netherlands, and when a case is described in the literature these counties are mentioned regularly (Shahda & Megahed, 2023; Salim Mir et al., 2022;Wiskerke, 2020). It indicates that these countries have the latest and most advanced research in the field. In Asia's mega cities vertical farming have been commercialised since the begin of the hype in 2010 and is integrated into the urban planning as a practical solution for the scare horizontal space. Vertical farming is here seen as a safer way to produce crops than in open fields, as the crops are not exposed to the air pollution that many of the densely populated areas are exposed to (Specht et al., 2016). The global market's interest in the technology has increased over the past decade with a global investment of $1.2 billion in 2021, but in Europe vertical farming is still a small sector compared to the marked in Asia or the US (Stevenson, 2022). Even though the Netherlands are at the forefront of vertical farming research, the general view in Europe is that vertical farming is a type of farming made by tech entrepreneurs and therefore not considered to be on par with the culture of agricultural productivity by local farmers that has always existed in the EU (Specht et al., 2016). The sector is capital-intensive, and it is still uncertain what is the most profitable way to use the technology in the urban area (Butturini & Marcelis, 2019). It indicates that it is valuable to investigate more into the challenges of integrating vertical farming in the urban development in European context.

3. Research question

In the previous chapter, the outcome of the literature review showed that scientific research into the connection between vertical farming and the way urban areas are planned, is limited. Vertical farming has only made a small imprint as an industry in the Danish context. This information combined with the showed need for further research on whether urban planning affects vertical farming's development, this master's thesis aims to investigate, whether a factor for vertical farming's limited development in Denmark is due to the way urban areas are planned.

The research question is as following with supporting questions:

How is vertical farming's transition potential into the urban development in Denmark from an urban planning perspective?

1. What is vertical farming's current position in society and its potential pathways for transition into urban development?
2. How does urban planning practices affect vertical farming's transition potential into urban development?
3. How can urban experimentation as a transition approach support the transition process of vertical farming into the urban development?

4. Research design

A research design is made to outline how the data collection methods and the theoretical framework are used to analyse data to address the research question. Figure 4 illustrates the research design.

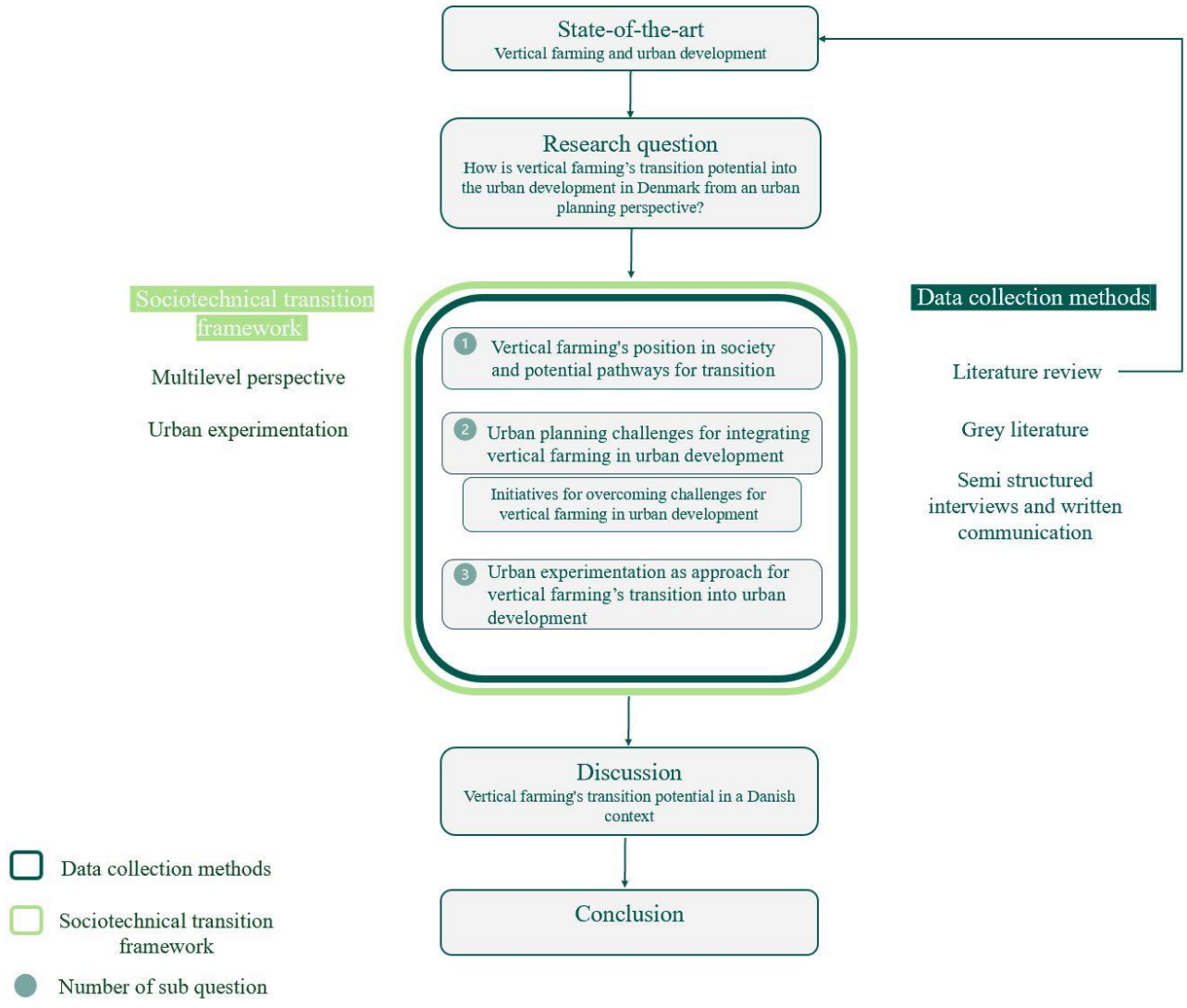

Figure 4: Research design presenting data collection methods and theoretical framework used to analyse the research question (Own production, 2024)

In the state-of-the-art section preexisting knowledge in regards of vertical farming's impact by the way urban areas are planned is defined and the outcome help shape what data to collect, the theoretical frame to use and what to investigate in the analysis. The outcome of the literature review that is presented in the state-of-the-art section, highlight that the field is a relatively new research field, with potential for this thesis to provide new insights into the field (section 2). This thesis has therefore aspects of an exploratory way of conducting a study as a purpose with the thesis is to disseminate

knowledge and achieve new perspectives in the field of vertical farming development, by focusing on how one aspect is being covered. The aspect that is focused on, is whether the way urban areas are planned, impact the development and integration of vertical farming. The outcome of the thesis can prioritise further research, by giving an idea if this aspect is fully covered or if there is a need to further investigate this aspect, where the thesis can one of the first steps for further research (Peniel, 2016).

To examine the research question, the study is guided by a qualitative research approach, which is mainly characterised by the choice of data collection methods. The methods are based on descriptions of experience and practical and theoretical observations, but however also supported by quantification of certain elements to describe the qualitative research (Peniel, 2016).

The theoretical framework and the chosen data collection methods define how the analysis is conducted and the outcome from it. By applying a sociotechnical transition framework to the question regarding vertical farming's impact by the way urban areas are planned, the topic will be analysed from the perspective of whether vertical farming has transition potential to adjust the urban development in a Danish context. The transition potential will by studies through the multi-level perspective, based on Frank W. Geels, the S-curve and by applying a transition approach that fits within the framework, which is urban experimentation. The findings from the literature review, which is outlined in the state-of-the-art section, is unfolded and analysed in combination with data collected from semi structured interviews, written communication and grey literature, to investigate the research question within the sociotechnological transition framework. Each sub question is presented in an analysis part, highlighted by numbers in figure 4, where the combination of the answers will lead to an understanding of the research question. The result from the analysis is used to discuss if vertical farming has a transition potential in a Danish context or what should be further considered for greater potential of a transition and stabilisation of vertical farming in an urban development.

5. Methods for data collection

To examine if the development of vertical farming is impacted by the way the urban areas are planned multiple methods are used for data collection. The methods are a literature review, use of grey literature along with semi structured interviews and written communication conducted with selected stakeholders within the field of vertical farming and urban planning.

5.1 Literature review

The methodological literature review has been used to investigate the state-of-the-art of vertical farming in the context of urban development (section 2). The literature review has been conducted as a semi-systematic collection of published research in the field. With this approach the idea is not to cover all published material through the review but selecting literature that give the necessary perspectives on the chosen topics (Snyder, 2019). As with the topics of vertical farming and urban development it is different groups of researchers that study the concepts (Wong et al., 2013). Horticulturists, plant physicists, engineers and architects are examples of different stakeholders, who study the two topics for different reasons. In a semi-systematic review, the aim is to combine the different perspectives presented in the literature to get an overview of the research field and identify knowledge gaps (Snyder, 2019). In this paper the literature review helps to assess, which parts of the field of topic are less analysed, which is used to narrow down the problem field and creating the research question. The literature review has been divided into three phases: design, conducting, and analysis of the review. A general overview of the literature review is visualised in figure 5.

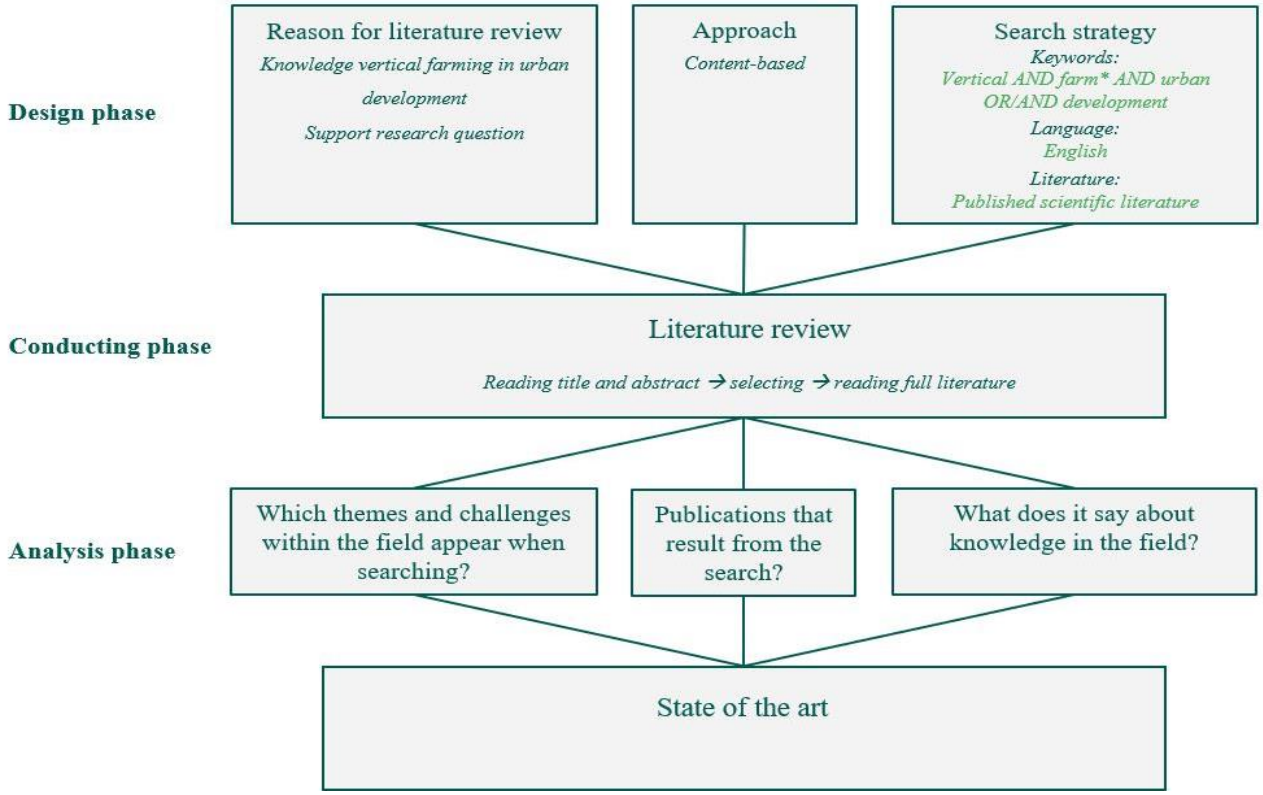

Figure 5: An overview of the conducted literature review based on a design-, conducting- and analysis phase (Own production, 2024)

Design phase

The design phase of the literature review determines the reason for the review, the approach of the review and what search strategy to use, which all impact the output of the review (Snyder, 2019). The reason for conducting the literature review has been to support answering the research question by investigate the concept of vertical farming in the urban development. The literature was reviewed with the purpose of finding content where this combination of vertical farming in urban development was described. The type of qualitative analysis approach used for the literature review was therefore with the focus on the content (Braun & Clarke, 2006).

The search strategy has been determined by the choice of databases and the selection of criteria to include or exclude. Three search databases were used to look for literature, to reach a broader amount of usable literature (Snyder, 2019). The databases used were Wageningen University & Research's library search, Scopus and Google Scholar. The choice of databases has been based on previous experience that they can deliver valuable results, also within the field of vertical farming. Wageningen University are frontrunners on research on vertical farming, as per section 5.3, and searching through their library can be an opportunity to retrieve some of the latest published literature in the field as well as literature they use in vertical farming research. To supplement the findings from Wageningen

University & Research the databases Scopus and Google Scholar were used. Through the two databases, it was possible to get a broader search for literature as there in general are published more literature in these databases. Wageningen University & Research has a strong focus on technological development in agriculture, which is reflected in the literature when using the database. The other two databases, due to their broader selection of literature, provide literatures that also have other perspectives, including more focus on urban development. The searches in the databases therefore complement each other for a more comprehensive selection of literature in the field.

Before committing to a specific search strategy, unsystematic searches were conducted in the databases to test whether the intended search strategy would support the purpose of the review or give a skewed sample of literature. This was done to minimise the risk of drawing conclusions from incorrect gaps from the literature in the field (Snyder, 2019). The chosen search strategy was to search in the databases for English written literature with the keywords; vertical AND farm* AND urban AND/OR development. Different types of literature were distinguished. The search focused on collecting published scientific literature and not grey literature that has not yet been published, to understand the amount of literature that is widely available in the field at current state. A restriction in the search for literature in the databases was therefore made. For Wageningen University & Research´s library search and Scopus a restriction was made to only show published articles, chapters and books and in Google Scholar it was selected to only show review articles.

Conducting phase

The conducting phase is where the design choices are executed in practice. The literature review was conducted in March as a part of the initial research for the thesis. Through the databases a range of literature was found. The literatures are primarily rooted in engineering and technology studies, agricultural studies, business and economy studies, sociology or geographic studies. To select the relevant literature for the chosen purpose, all retrieved literature was read based on a strategy. The strategy was to first read the title and abstract and from there selecting the relevant literature to read in its entirety (Snyder, 2019). Figure 6 visualises the selection process of literature from initial search to final reading in the three databases used.

As figure 6 shows, a large range of literatures were found when basing the search only on the chosen search strategy based on keywords, language, and article type.

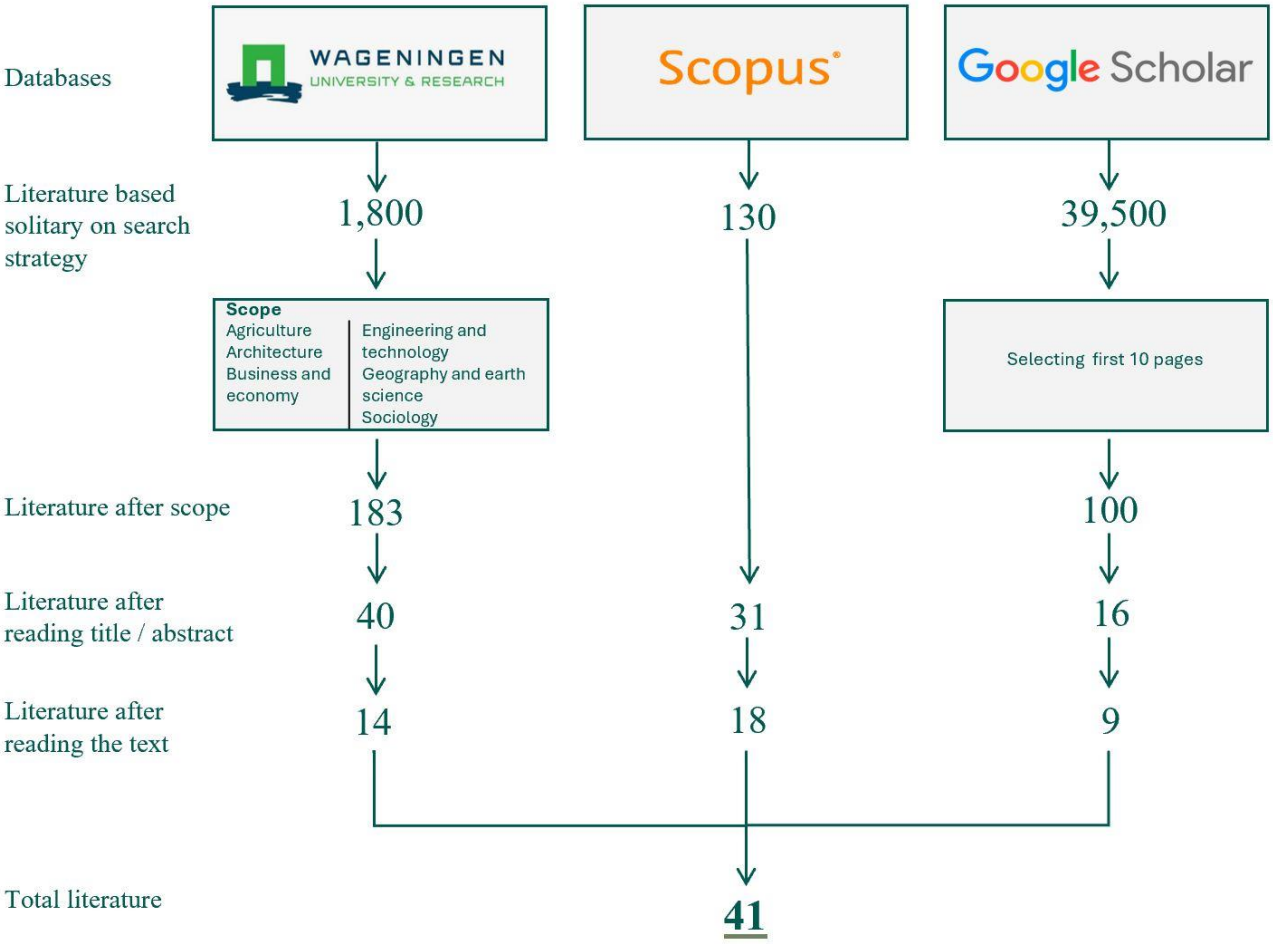

Figure 6: Conduction phase, showing the narrowing process of the literature (Own production, 2024)

To narrow the search, two of the databases had additional restrictions added to the search strategy. For Wageningen University & Research library a delimitation was chosen to focus the search on topics, where relevant knowledge about vertical farming in urban development could be identified. The amount of literature changed from 1800 to 183 publications based on the scope. For Google Scholar a decision was made to only research the first 10 pages of presented results, equivalent to 100 publications. The further in the search list, the articles became less relevant, and more overlaps were identified with the two other databases, resulting in the decision to stop after 10 pages of research. The decision changed the amount of literature from 39.500 to 100 publications.

The review of the literature in the three databases also revealed several overlaps of literature, which are not included in figure 6. The overlaps may indicate that the most relevant articles within the field of vertical farming in the urban development are found by searching through the three databases.

The literatures selected to read in full, were mainly a selection of large publications with an average of around 200 pages. They had relevance to various aspects of vertical farming and urban development, including describing urban agriculture more generally. Not all of which had direct relevance to investigating the link between vertical farming in urban development. To optimise the search and read with a focus, the table of contents was screened to find relevant sections in the literature and the keywords, used in the initial phase of the literature study, were searched for. Vertical farming is referred to by a variety of definitions in the literature and in some literature more indirectly described in connection with urban agriculture (section 2). Therefore, a broader search in the literature was also conducted to find which sections contained perspectives on vertical farming in urban development. The relevant sections were then read in depth. The result was that a total of 41,430 publications were narrowed to a sample of 41 articles related to the words vertical farming in urban development.

Analysis phase

In the analysis phase, it was assessed to what extent the total collection of 41 publications could contribute knowledge to explain the state-of-the-art when examining vertical farming in the context of urban development. When reading through the 41 publications, a focus was for example, to investigate if there were challenges or themes with relevance for describing the current state-of-the-art in the field. Herby which stakeholders, approach and year of publication were mentioned. These perspectives helped understand if there were scientific knowledge within the chosen topic field of vertical farming and where to find it. At the same time, it gave perspective on what knowledge is still not available, which showcase a knowledge gap (Snyder, 2019; section 2).

5.2 Grey literature

As an addition to the data collection using scientific articles, data has also been collected using grey literature. The term grey literature refers to research that is not commercially or academically published, which can refer to unpublished academic work, research- or government reports (Paez, 2017).

With the chosen thesis topic, it has been proven, through the data collection from scientific articles, that there is a gap in research into this field (section 2). Using grey literature can provide perspectives from pilot projects, dissemination of research with for example negative results or developing projects

within for example the industry itself (Paez, 2017). Results from these studies can bring valuable knowledge into an investigation of a topic as vertical farming and its relation to urban development as scientific research in the field has proven to be in its initial stage (section 2). The data can indicate whether the chosen thesis topic is a topic that needs further investigation, or if the field contains fewer challenges than first thought when researching the field (Paez, 2017).

5.3 Semi structured interviews and written communication

Semi structured interviews and written communication have been used as a data collection method to support the findings from the theoretical literature review and the use of grey literature, but also to explore more into the practices that shape the way urban areas are planned and the conditions for vertical farming's integration into urban development. Stakeholders have been selected that work more practical with the topic. Inputs and perspectives from 13 stakeholders have contributed to the findings and help shape the structure and direction of the thesis. The process for the interviews and communication with the selected stakeholders can be divided into three phases, comparable to the phases for the literature review: preparation for the interview/communication, conducting of the interviews and analysing and evaluating the findings.

Preparation phase

In the preparation for the interview/communication the focus was to identify, who to contact, consider the approach for the contact and what questions to include in the communication. The literature review indicated a knowledge gap regarding need for further research into the urban contexts impact on vertical farming's integration (section 2). The selection of stakeholders was based on the assumption that the stakeholders could provide perspectives for this knowledge gap. It was of great interest to gain insight into both the urban planning field and the vertical farming industry and preferably get in contact with stakeholders, with perspectives on a combination of the two fields. A professional network was used to find interviewees, which is believed to have led to an easier contact process and willingness to be interviewed. The interview/communication process has been ongoing during the thesis period, so it has been a dynamic process of when stakeholders have been contacted and who to contact has followed the knowledge expansion throughout the thesis period. Contact was made via email, presenting the thesis topic, and providing information about what the potential interviewee could contribute to the thesis, for them to decide if they were the right person to answer

the questions. All stakeholders received an e-mail based on this structure, personalised to each stakeholder. An overview of the interviewees and the eventual references they made to other stakeholders, who also got contacted, are visualised in figure 7.

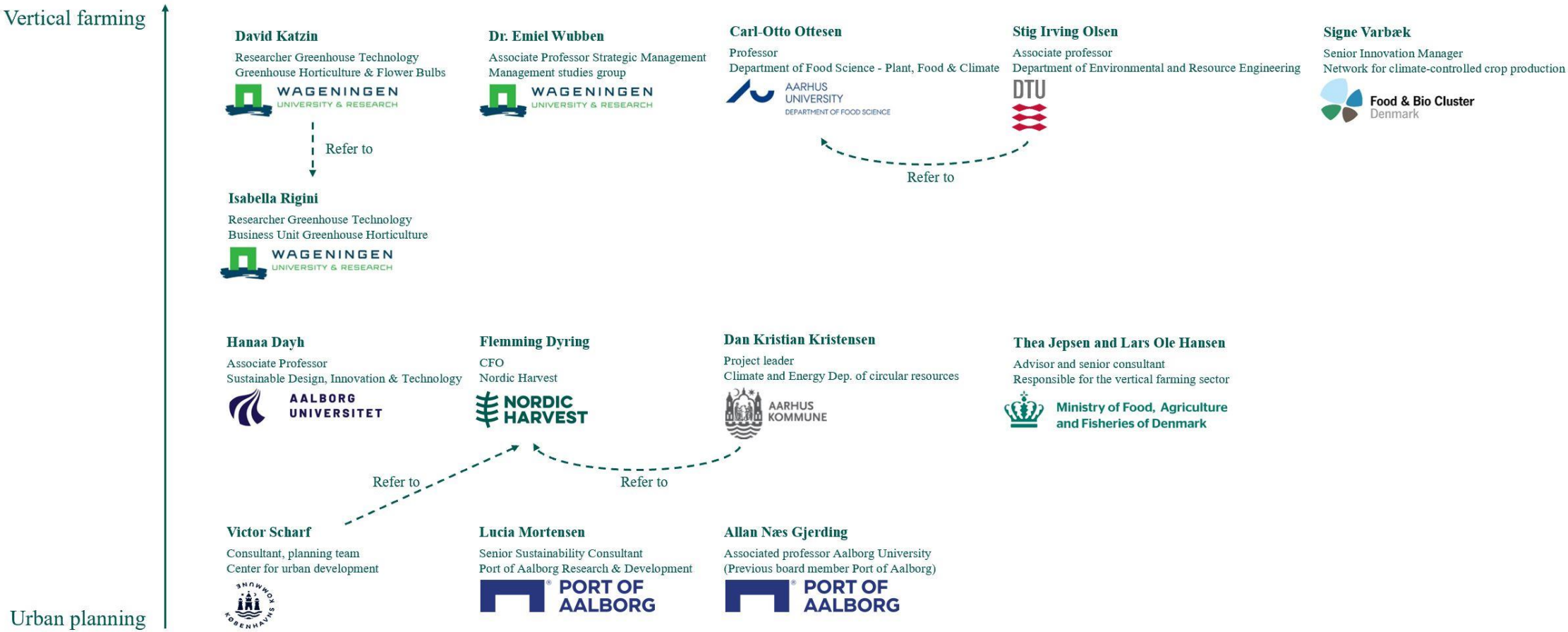

Figure 7: Overview of stakeholders interviewed or written communication. A subjective categorisation of the stakeholders based on their background, on a scale from occupation with urban planning to vertical farming, is made to show the diverse contact that has been attempted, to gain the most suitable perspectives on the chosen topic for the thesis. (Own production, 2024)

An interview guide was created and adapted to each interviewee and used as a guideline for the interview. An example of the interview guide is shown in appendix A. The questions in the interview guide were designed to combine the fields of urban planning and vertical farming to encourage the interviewee to provide perspectives on the integration and impact of vertical farming in urban development. Scientific researchers or professors at Wageningen University & Research was interviewed or communicated with, because Wageningen University & Research is a global recognised university for agricultural research, and established and emerging industry professionals from all over the world come to the university to learn and exchange the latest research in vertical farming from the interviewees and other experts (Wageningen University & Research, 2024a;Wageningen University & Research, 2024b). To gain insight into the Danish conditions surrounding the topic, contact has been made with professors both within more scientific knowledge of vertical farming or with an urban planning angle. The business community, municipalities and the subject-specific ministry have provided insight into the practical conditions for vertical farming in urban development.

Conducting phase

The interviews were mainly conducted as online meetings in Microsoft Teams, with a few in-person interviews. The length of the interviews was between 30 min. to an hour. Before the interview started, each interviewee was introduced to the topic of the thesis and was asked for consent to record and use of perspectives in the thesis. The semi-structured approach allowed for deviating from the interview guide and to ask follow-up questions on perspectives from the interviewee, which resulted in a more active conversation (Brinkmann, 2014). Although the questions were asked with a focus on getting perspectives on a combination of the fields of vertical farming and urban development, the interviewees' background were often more in one of the fields, which influenced the answers.

In the communication process with the stakeholders that gave their perspectives on the topic in writing there was a large focus on expressing the questions in a detailed and an understandable way to receive sufficient answers. Receiving answers in writing is "self-transcribing" and ready to be analysed and potential misunderstanding in translation of what the interview said, is minimised through this way of communicating (Brinkmann, 2014).

Analysing and evaluating phase

Each interview was transcribed with the use of the AI-transcription tool, CLAAUDIA and its feature Whisper Transcription, which are used and can be accessed by Aalborg University students and employees. After the transcription, each interview was read through and repeating words were removed and the structure was made easier to read. Through the reading of the transcription content that could complement or contradict perspectives from literature or other interviews was highlighted in the transcript. It was a form of unstructured coding of the interviews. Through the process of writing the thesis, relevant sections of the interviews could be found more quickly based on the highlights.

Reading through each transcription of the interviews and the written communication, it was explored whether the stakeholders had referred to other stakeholders that should eventually also be contacted, if not already done so. For each stakeholder it was also decided whether to send follow up questions over e-mail, if some questions should be changes for the next interviews, or additional questions occurred through the communication that was relevant to ask other stakeholders.

5.4 Reflection on methods for data collection

To decrease publication bias and strengthen the validation of the results when investigating the topic, multiple data collection methods are used.

In the search for literature, it was primarily theoretically perspectives on the thesis topic that was highlighted and to support these findings stakeholders within the field of topic was contacted and their perspectives could provide more practical knowledge to use for investigating the field.

To receive valuable perspectives for conducting the thesis it was important to create questions that were possible for the stakeholders to reflect on, to minimise that the answers could not provide the desired perspectives or only few examples could be given. In the preparation for the interviews research into the stakeholder’s background and published work, was valuable for understanding whether or not they were stakeholders that could provide some perspectives on this thesis topic. Even though research has been made into the stakeholders beforehand, it was only during the conduction of an interview that it was proven if the interviewee was able to provide the perspectives needed. Setting time aside to prepare for interviews, can lead to more useful interviews and less time wasted on interviewing stakeholders that cannot give the perspectives needed.

Collecting data through written communication, it was especially important to have well-structured questions, so the format of the questions would not get in the way of the perspectives that could be given from the stakeholder. The process from asking the questions to receive answers from stakeholders could be long, but it also enables that multiple stakeholders could be reached at the same time. Communicating in written form can limit the communication and often shorter answers are provided and then maybe need for follow-up questions to capture the perspectives. There is a risk of misunderstandings due to the form of communication, whereas with in person interviews it is easier to sense misunderstandings in the communication. However, the interpretation of written answers can be less than with answers from interviews, as written answers do not undergo processing such as transcription or translation that can lead to misinterpretation of the stakeholders' answers given in interviews.

Starting point for searching literature was based on searches through the three databases, Wageningen University & Research, Scopus, and Google Scholar, primarily used to find sources for the literature review (section 5.1). The sources were validated by investigating the timeline, the methods used and if the source was referring to other literatures. Combining these information's could prove whether the specific literature was fitting for extracting knowledge, to use for investigating this thesis topic. When looking for additional literature to support or counter arguing the results from the literature review or from communication with stakeholders, the literature was often found through the references in the literature that had already been used and proven valuable for investigating the topic. What to analyse and the conclusions to draw from this thesis is affected by the literature used, what stakeholders has been contacted, their perspectives on the thesis topic and who or what both literature and stakeholders have referred to. The scope can either be perceived as too broad or too narrow depending on what is being emphasised. For example, if the chosen stakeholders are either too similar or too far away from each other in their knowledge-background, it can challenge, what can be derived from their perspectives and used to analyse the thesis topic. The data that is collected through the data collection methods can always be used and give some perspectives to the thesis topic but including other literature or other stakeholders could give different perspectives that is not highlighted in this thesis. It can change the conclusions that can be drawn from the thesis. For example, including some of the elements presented in the section for further study, section 10, can change the outcome of the thesis.

6. Theoretical framework

The data that are collected through the multiple methods, to examine if the development of vertical farming is impacted by the way that urban areas are planned, is also combined with a theoretical framework. The framework is used to analyse how a societal transition can be made to integration vertical farming in the urban development. In this thesis the sociotechnical transition framework is used to describe the transition of urban development for integration of vertical farming.

6.1 Sociotechnical transition framework

The sociotechnical framework covers the approaches multi-level perspective (MLP), strategic niche management and transition management. Sociotechnical transition in society is often viewed as an incremental continuous process of change to society that can result in structural changes to society, through actors' negotiation of different possible development pathways (Petrović, 2024). In studies of societal transition, there is often a tendency to overlook the agri-food system, resulting in a limited number of comprehensive analyses of agri-food systems in a multi-level perspective or sociotechnical transition in general (Bilali, 2019). This section presents the theoretical understanding of transition theory that through the analysis will be combined with the agri-food system and expand the field of comprehensive analysis within this topic.

Multi-level perspective

The approach in the sociotechnical transition framework, multi-level perspective (MLP), is used to understand that a transition in the society is made through development at multiple levels and help identify what is implied in a regime shift. Three levels of concepts that MLP distinguish between are a level of niche innovation, a sociotechnical regime, and a sociotechnical landscape level. Figure 8 visualises the multi-level perspective that Frank. W. Geels has further developed from perspectives of previous transition theorists (Geels & Schot, 2007). This understanding of the multi-level perspective is used as reference for this thesis.

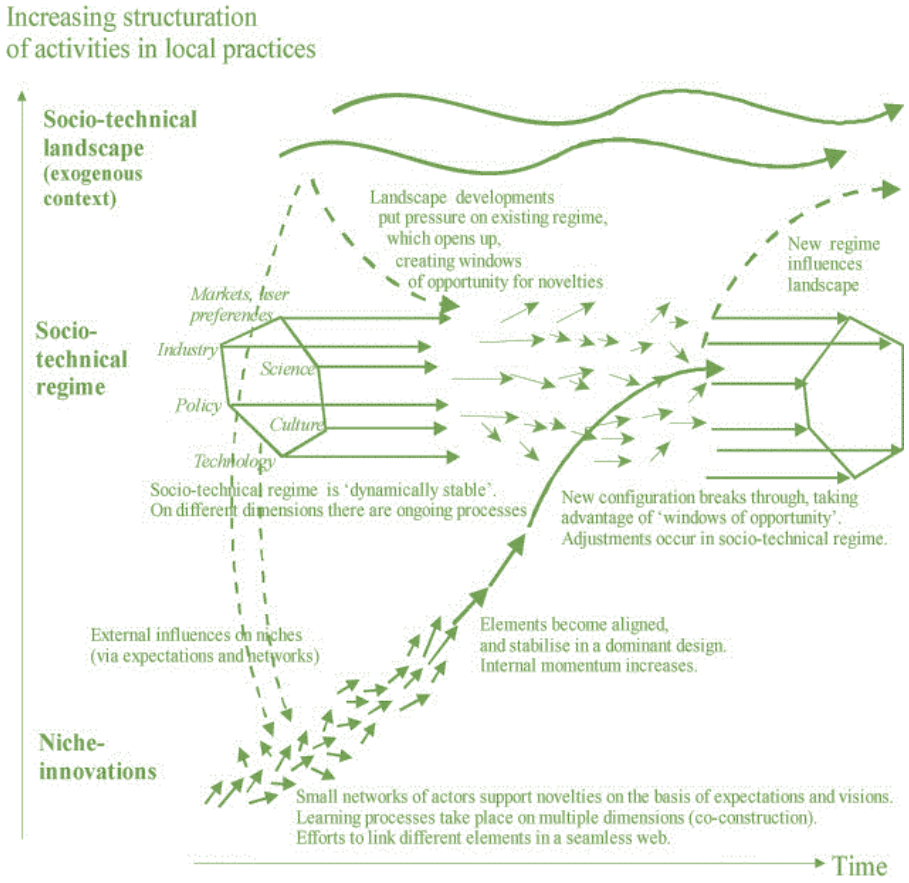

Figure 8: The multi-level perspective framework on sociotechnical transition (Geels & Schot, 2007, adapted from Geels, 2002)

In the multi-level perspective, it is argued that the transition of the society happens when the existing sociotechnical regime is impacted by either a niche innovation or aspects from the sociotechnical landscape, resulting in a new sociotechnical regime being created. It is the tension between the niche and the current regime's rules and institutions that define the potential of a transition into the society (Bilali, 2019). The transition process of the sociotechnical regime can happen over and over through new impacts from the other levels (Geels & Schot, 2007).

According to Geels, 2002, the existing *sociotechnical regime* is the result of the rules that guide and predict the actions in the society, along with the material aspects provided in the system, the embedded actors and the organisational networks that are in the current society. It is the broader community of different social groups, as policymakers, scientist, industries, and users that are all impacting and aligning their activities to the rules of the society (Genus & Coles, 2008; Geels & Schot, 2007;Geels, 2002). The dynamics in the regime affect, limit or strengthen the efforts one individual or a company can do, because of the composition of the regime (Petrović, 2024).

The sociotechnical landscape goes beyond the direct influence that actors, in the regime and in a niche innovation, can have on the regime. This is where large scale developments happen, for example a change in the geopolitical situation, climate, demographics or other situations that by its change can put so much pressure on the existing sociotechnical regime that it destabilises and a transition of the structure in the regime can occur (Geels & Schot, 2007).

Through the destabilisation of the regime, an opportunity for a *niche innovation* to enter the regime happen and it can help stabilise a new regime. The niche innovation is initially a radical innovation that emerged as a response or a supplement to the way things are done in the regime. Multiple niches from different industries can occur at the same time, supplementing or contradicting each other, and a niche can also entail subcategories of the concept. A niche innovation is often carried out by small networks or individual actors in a protective space away from the external factors of the current regime (Geels & Schot, 2007). This means that a niche often does not have a direct influence on the processes made by the sociotechnical landscape or the current regime (Bilali, 2019). It is first if a niche, or one of its subcategories, gets the opportunity to enter the regime that it must show its ability to stand against the pressure of the external factors in the regime. It will be tested whether the initial niche is built to scale, be integrated and operate as part of the regime, or it will fail (Geels & Schot, 2007). Even though subcategories of a niche innovation are subject to the same external factors as they arise from the same broader concept, the diversity of the subcategories may affect their transition potential into the regime. Despite its potentially small size, a niche can influence the reconfiguration of the regime (Bilali, 2019).

The process of pressure from other aspects of the sociotechnical landscape and a niche innovation can be both overlapping and act as a constant pressure. Depending on which dimensions of society the focus is on, new pressure can either take long time to emerge or it can happen often. A regime can therefore be considered “dynamically stable” (Genus & Coles, 2008).

A tool to generalise the shift from one regime to another is to use the S-curve (figure 9). In the study of sociotechnical transition, the process of the transition follows exponential or S-curve trends, when a niche is trying to integrate into a regime and establishing an adjusted regime (Petrović, 2024).

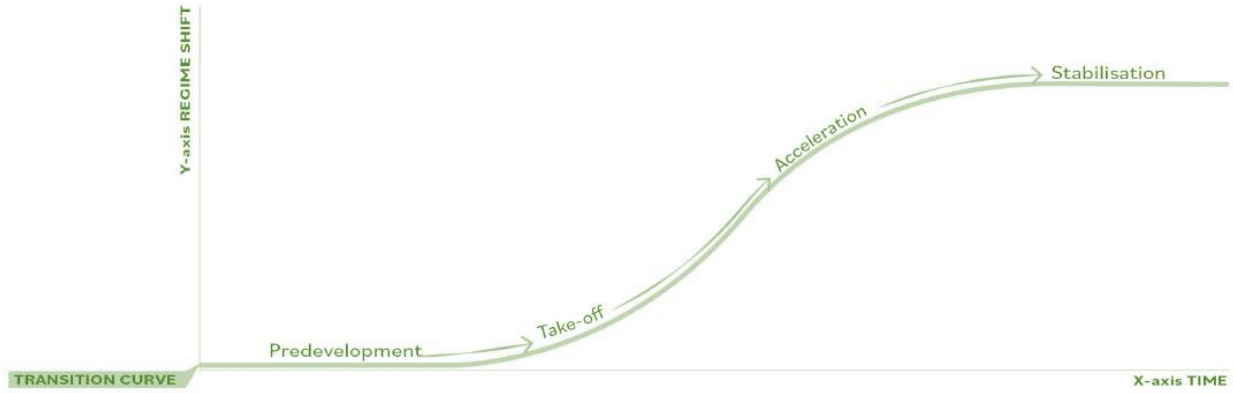

Figure 9: The transition S-curve with the stages; predevelopment, take-off, acceleration, and stabilisation that show a developing pathway that a niche can have over a range of time to shift the regime (Petrović, 2024)

The transition S-curve visualises the developing stages of the regime transition. A niche starts slowly in a *predevelopment* stage, also known as the formative stage, where the first steps, for how the technology should be, are made. When the niche starts to expand and get the current regimes attention it starts to *take-off* and an *acceleration* will happen until it results in a *stabilisation* where the niche is integrated into the regime and an adjustment of the former regime has happen. The start of the curve is the only known part of the curve as a niche can have different development pathways depending on which subcategory of the niche is being studied, resulting in varies points along the development that can transform the curve into a shape other than a S-curve. The uncertainties in what pathway a niche will follow, highlight that the purpose with transition management is to use the tools, MLP and the S-curve, to form long-term vision to try and understand the process associated with the transition through the investigation what factors affect the process of a transition. The focus is not on setting preconceived goals that are not certain cause of the different pathways that can happen (Petrović, 2024).

Urban experimentation

An approach, to trialling initiatives with the aim to learn about how a societal transition can be made, is urban experimentation. The approach has different origins, but in this thesis the focus is the experimentation approach origin from the sociotechnical transition's theory. On this basis, the urban experimentation is linked to strategic niche management, which refers to managing the process of niche formation and development, through using the tool of a real-world urban experiment (Monstads et al., 2022). Introducing the concept of urban experimentation into the traditional way of planning

urban areas, can be a way to promote a transition of the urban system to include new or innovative systems that can potentially help solve problems arising from the rapid development of urban areas. Urban experimentation is a way of experimenting in a real-world setting, with the purpose of observing and reflecting on innovations made in an urban area (Ehnert, 2023). When investigating literature on urban experimentation it is stated that limited information is given on how the urban context is impacting and influencing the integration of the system or technology being tested in the urban experiment (Ehnert, 2023). This also links well with the information gathered though the literature review, when exploring existing knowledge on urban plannings impact on the development of vertical farming in urban areas (section 2). This may call for more research in this field, with the aim of incorporating more urban experiments into planning.

When using urban experimentation in a planning setting the following aspects can be used to define the work; situatedness, change-oriented and uncertainty (Karvonen, 2018; Karvonen & van Heur, 2014).

Situatedness is related to the specific situation that the urban experiment is made within. The knowledge generated, by making experiments in the specific urban setting, offers context specific information. The knowledge received from the experiment is therefore related to the situation of place and time for the experiment (Ehnert, 2023).

By situating an urban experimentation, the aim is to foster a more *change-oriented* way of planning that potentially make disruption or change in the traditional way of planning. It can lead to valuable knowledge on how to plan for the specific situation and it can impact the way of planning for situations similar, in the future. In some cases, an urban experiment will not lead to a change, but instead reinforce the status quo in an area (Bulkeley et al., 2019).

Urban experiments can be seen as a large-scale test environment that also aims to challenge the traditional boundaries of how planning is initially approached. The purpose is often to work in the *uncertainty* associated with urban transition to test more radical changes that potentially can fail. The failure should be viewed as opportunity to extract learnings and potential improvements to use for further developing the experiment or when trying to implement the system in society (Monstads et al., 2022). Urban experimentations more radical way of planning can be seen as a counter-reaction to the modern ways of planning (Ehnert, 2023).

The urban experimentation links well with the aspects of transition theory such as the concept of MLP, which also recognises that a niche or a more radical system can enter the society and potentially adjust parts of it. The urban experiment can eventually be framed as a "niche experiment" that begins as a temporal, shielded innovation and must scale-up from being a niche experiment to try and make its way into the regime, to potentially make a fundamental change in the society. One urban experiment can be, to trial a subcategory of a niche innovation. Multiple experiments can happen with that one subcategory, or different subcategories can be trialled at the same time or in relation to each other, for broader knowledge collection (Ehnert, 2023).

Urban experimentation and transition theory

Combining the idea of urban experimentation and transition studies, experimentation in the urban context can be used as a tool to scale an idea to have a wider impact on society, foster innovation in the urban area and potentially new markets to grow (Bulkeley, 2021;Monstads et al., 2022). Testing a niche in an experimental setting is where the niche can develop through a protective space, sheltered from external pressure as economy or social pressure. This allows the 'niche experiment' to provide contextual knowledge that can indicate the conditions for the niche. For example, does the planning of the area supports the development of the niche? Or has the experiment led to suggestions to adapt urban planning and its structures to better integrate the niche? (Ehnert, 2023). With the result of the experiment the niche can afterwards be scaled up and integrated directly into the society with the potential to challenge parts of the dominant social technical configurations of the society (Monstads et al., 2022).

Results that can be extracted

Depending on the niche, or subcategory of a niche, being tested in the urban experiment, it can result in addressing different dimensions of society, such as adaptation in rules, markets, norms or visions. It can lead to negotiation and learning and to some extent be used to understand if there is a need and how an adjustment in the way the urban area is planned should happen. As Geels positions it, a social technical transition also is a change in the society's practises, policies, infrastructure, or business models and not just a simple change in technology. These changes thrive in a dialectic relationship between the more stable regime and the changes from the niche and with the need for multi-stakeholder involvement, co-development, and public policy involvement (Bilali, 2019).

Although urban experiments are tested in a protective environment away from the external factors of the society, there is still valuable knowledge to be gained in the planning of the experiment (Ehnert, 2023). Categories of knowledge can be divided by the following concepts: embedded, scaling and translated, as visualised on figure 10.

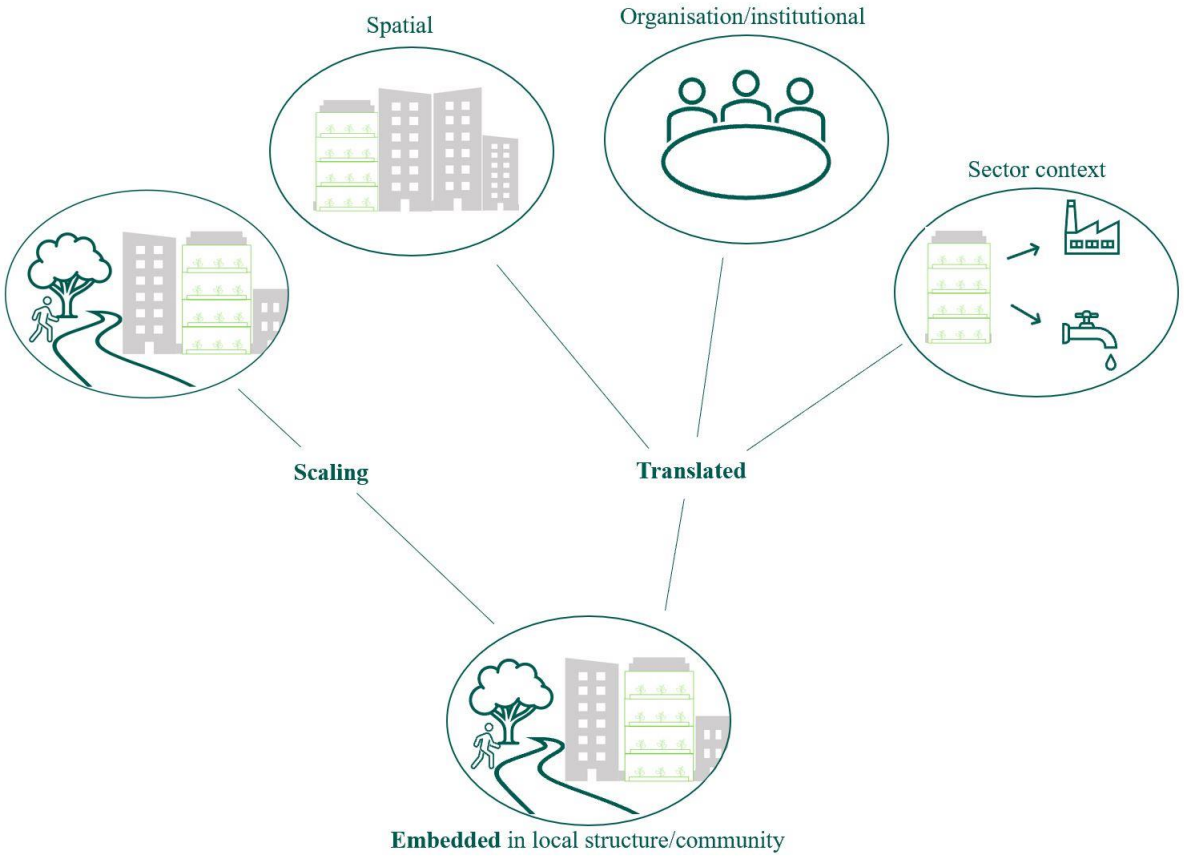

Figure 10: Categories of knowledge from urban experiment: embedded, scaling and translated (Own production, 2024, data from Ehnert, 2023)

When testing the experiment in an urban area the experiment is *embedded* into the local structures and community. From the experiment context-specific knowledge can be extracted and the results can possibly lead to internal development. Knowledge can come in the form of understanding how to build an experiment that can support the initial idea. Lessons learnt from the process and the final result can provide insight into what needs to be adapted if the experiment is to be integrated more widely in society and not just in a test form. Information can for example be regarding which stakeholders to include, how to overcome challenges with the inclusion of stakeholders and gain an understanding of which role is most suitable for the different stakeholders, for succeeding with the experiment. This can help *scaling* up the experiment so it potentially can be embedded into and adjusting the current regime of the society. Learnings from the experiment can also be *translated* into

other experiments that work as replicates of the original experiment. For example, lessons of how to spatially plan an area can be extracted from the original experiment and used as a way for planning other experiments. The organisational or institutional structures of the original experiment can also be replicated and used as a starting point or inspiration for developing the process of another experiment. The knowledge from the original experiment is not sector-specific, so the learnings can also be used to inspire other sectors to make similar changes, either within the traditional way of doing a process or the physical planning. It can also encourage synergies with existing parts of the society, to benefit both the integration of the niche experiment and the society (Ehnert, 2023).

A transition of the current society will often lead to changes to the established understanding and way of doing planning, but it can also bring beneficial aspects for the general society, such as improved coordination between urban dominants as a result of the adaptation that comes from welcoming a new niche into society (Monstads et al., 2022; Bilali, 2019).

6.2 Reflection on the theoretical framework

The multi-level perspective, and the model that displays the concept at figure 8, is presented in this thesis with the focus of using the concept and terminology associated with it as a frame for investigating the processes and interactions of the transition, for integrating vertical farming in the urban development. Transition theory and the concept of MLP contain several elements and perspective beyond, what is presented in this thesis. Elements that are highlighted are selected as a frame for the analysis as these elements from the theory contribute to what is wanted to be investigated in the thesis. With another perspective on the thesis topic, other elements could have been emphasised and thus relevant with a broader theoretical insight.

Using urban experimentation, to investigate a societal transition, is only one approach of many that could have been used to describe and create a transition in the society. Only focussing on this approach can lead to various risks of overlooking potential knowledge from other ways of adjusting society and the added value is not emphasised (Geels & Schot, 2007).

Applying the sociotechnical transition framework in this thesis does help to indicate how a transition for integrating vertical farming into the urban development can look, including the aspects as who should initiative and participate in the process and how the process should be built to succeed with adjusting the society. What cannot be considered through the framework, are policies or uncertainties

in society that can directly affect and change the society, where the transition is trying to be made. A limitation in applying the framework is therefore predicting the future, but patterns to be aware of in the further process can eventually be identified.

The result from an urban experimentation is very context specific and even though the results can provide knowledge for an integration, it is not a one-to-one guideline for how to integrate a niche in the society. It cannot be directly replicated for all sorts of niches in the society or the same niche in a different context. The time for a transition to happen, as presented in the S-curve, is not definite and depends on the development pathways of a niche. The transition can either happen fast, slow or stall completely. However, a transition can often be expected to take place over a period of years (Petrović, 2024). The S-curve is also a simplified way of describing a development process, where development in reality is more dynamic with setbacks and progress mixed. In the predeveloping stage of the S-curve the niche innovation can be characterised by trying out many different structures of the niche where the model in its form is limited in showing the different developing pathways that a niche can have.

7. Analysis

To identify vertical farming's current position in society and analyse potential pathways for a transition of vertical farming into the urban development, vertical farming will be presented using Geels concept of MLP and the S-curve (section 7.1). To investigate if the way urban areas are planned affect vertical farming's transition into the urban development, challenges, related to and influenced by urban planning, are examined (section 7.2). In addition to the found challenges it is studied whether there are initiatives in the society to help overcome or minimise the risk of the challenges impacting vertical farming's transition process (section 7.3). The transition approach, urban experimentation, is presented as a tool to also help minimise challenges to come, in vertical farming's transition process, by testing the different structures of vertical farming in urban contexts before a real integration in urban development (section 7.4).
The analysis is carried out by the results from the literature review and supplemented data gathered using grey literature, interviews and communication with stakeholders within the field.

7.1 Vertical farming's position in society and potential pathways for transition into urban development

Vertical farming's current position in the Danish society can be derived from multiple sources. It has been stated that vertical farming is not a large industry in Denmark (section 1.2) and the outcome of the conducted literature review showed that limited scientific research has been conducted into vertical farming and urban context and the research made have recent publication years (section 2). Inputs from interviews with stakeholders, who work practical with vertical farming, also indicate vertical farming's position in society. From a broader global perspective vertical farming is viewed as, *"I think we are still in that early stage […] that different municipalities have their own potential in adapting the regulation, I think that is good. I think that it may enable these kinds of referencing projects to start."* (Dr. Wubben, 2024, appendix B.2, 13:23-14:52). Set in a directly Danish context comparable statements show that "*it [vertical farming] is also an industry or a technology that I think is going to develop a lot. I mean, there are many things that can still be optimised"* (Varbæk, 2024, appendix B.5, 04:14 - 07:04, translated) and "*In relation to vertical farming is it something we [Copenhagen municipality] consider if a demand comes from external stakeholders that has not themself found a suitable area for the purpose. But as it is not the case yet, is it not something that Copenhagen municipality has been working with."* (Schaffer, appendix C, translated). The

information combined indicate that vertical farming is an emerging industry in an early stage and adapted into Geels' concept of MLP, vertical farming can be classified as a niche innovation. A transition needs to happen for vertical farming to move from a niche innovation to be integrated and adjust the urban development (section 6.1). A simplified example of Geels' MLP model is shown at figure 11 and visualise how the niche innovation, vertical farming, potentially can transition and adjust the urban development, as a result of requirements coming from climate change and urbanisation, as highlighted in this example.

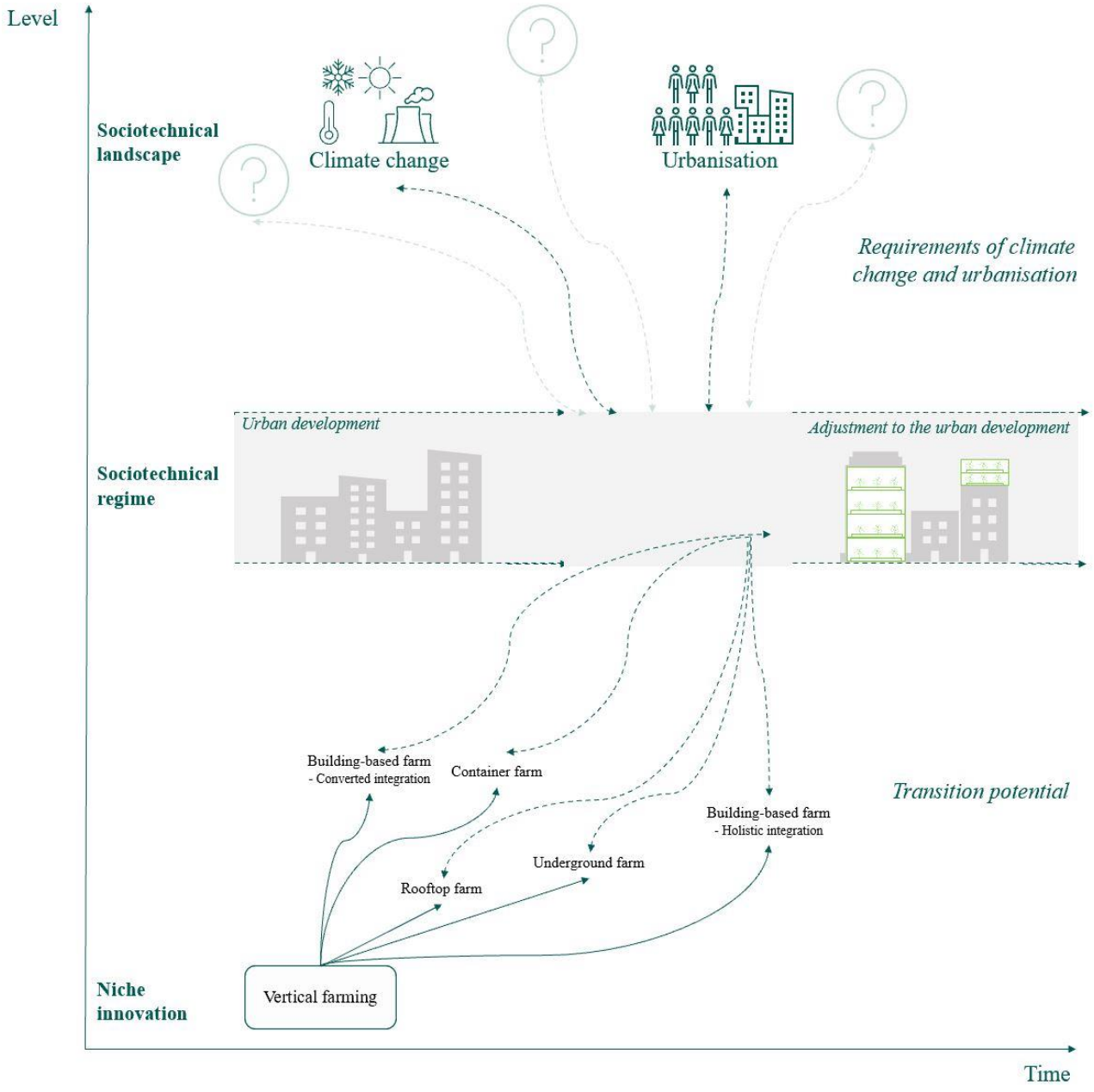

Figure 11: Visualisation of vertical farming´s (niche innovation) potentially pathways into adjusting the urban development (sociotechnical regime) as a result of the requirements from climate change and urbanisation (sociotechnical landscape) (Own production, 2024, inspiration from figure 8)

Figure 11 visualises how vertical farming is classified as a broad term of a niche innovation where the different structures of vertical farming (figure 2, section 1.2) are subcategories of the niche innovation. In general, the development of the niche - vertical farming - is a result of the pressure from the landscape level - climate change and urbanisation (section 1.1). Depending on which development pathways the different structures of vertical farming follow, some, or all of them, can potentially be integrated into the regime level - urban development - through a transition of the planning of urban development (Buscher et al., 2023).

The pressure or requirements from the landscape level is the condition within a transition of the urban development can happen. In figure 11, climate change and urbanisation are highlighted as elements from the landscape level that exerts pressure on the urban development as a regime. The pressure is in the form of a need for the urban development to address contributions to for example climate change adaptation and a growing urban population (Buscher et al., 2023). As an example, climate change is a slowly but steady progression on a global level that put noticeable pressure to act for the urban development regime. For climate protection and adaptation an engagement between the food system and urban development can be a mean to positively contributing to the challenge. A way to reinforce the engagement between the food system and urban development to assess the pressure, can be for the urban development regime to open up for niche innovations as vertical farming. Introducing vertical farming, is an innovation in the food system that based on its development can address some aspects of the landscape pressure since, *"we are facing a world, where large part of the areas where our food is produced, our vegetables are produced, are at risk of no longer being suitable for farming. […] So, in that sense it [vertical farming] can become a very, very relevant technology"* (Varbæk, 2024, appendix B.5, 07:34 - 09:04, translated). The global trade with food commodities can be another "pressure-point" from the landscape level, indicated as a question mark in figure 11, which also is related to climate change. The global marked can result in long food chains and a desire for more local production, where a technology as vertical farming can be an innovation that complies this requirement as when asked if vertical farming is a way to increase local production in Denmark the answer is,*" Yes, I would also say to ensure food security. That we are not dependent on things coming from Spain or Portugal, where it will be difficult to get our stuff from."* (Dyring, 2024, appendix B.3, 16:07 - 16:22, translated).

To be able to understand the transition potential of vertical farming and the pathways the structures of vertical farming can take, the main focus should not only be on global or national landscape-level

processes affecting urban development. The processes in the specific urban development, where vertical farming attempts to transition and adjust the urban development should also be studied. For example, the market structure, the policy being practised or the scientific knowledge available in the specific urban context (figure 8, section 6.1). Vertical farming should thus be studied in the specific context of urban development with the landscape demands impacting that context (Petrovics & Giezen, 2021). Urban development is not the only regime that vertical farming should be studies in, but it is highlighted in figure 11, as the regime that vertical farming can transition into and adjust, since the focus of this thesis is to explore, how vertical farming can be integrated into urban development. In Geels' definition of MLP a regime is governed by the rules and institutes of society (section 6.1). The rules and institutions of society is directly linked to sector development, where vertical farming is affected by the development in the agricultural sector. The agricultural sector can therefore also be understood as a regime that vertical farming tries to integrate into. The rules that are embedded and developed within the sector, affect the transition potential of vertical farming into the agricultural regime and the development of this regime affects vertical farming's potential to integrate into urban development (Petrovics & Giezen, 2021).

The transition process from vertical farming as a niche innovation to establishing itself in the specific context of urban development can be studied using the S-curve (section 6.1). The S-curve can be used to examine the transition process of each of the different structures in vertical farming or study the transition process of vertical farming in general. The statements and information used to classify vertical farming as a niche innovation, earlier in this section, indicated that vertical farming in general is in an early stage and there are still things to optimise for further developing the technology. Based on this information vertical farming can be indicated to be in the predeveloping stage in the S-curve (figure 9). It is a general statement of the current global development position of the vertical farming industry. Derived from the conducted literature review and interviews, at this predeveloping stage or formative stage of vertical farming's development, several production methods and structures of vertical farming are trialled (appendix C). It can be related to different techniques of growing the crops, to what extend the production processes should be automated (Butturini & Marcelis, 2019; Parkes et al., 2022; Saad et al., 2021; Shahda & Megahed, 2023), selection of crops (Asseng et al., 2020; Specht et al., 2019) and in what type of structure and scale a production should be made in the specific context (Chaudry & Mishra, 2019; Jaeger, 2024; Lu & Grundy, 2017). It indicates that different structures of vertical farming, with additional different production methods, are trialled and no fixed development of vertical farming is defined. It can result in a competitive industry that can

either drive innovation or result in silos lacking cooperations. Interviews indicate a risk of the silo thinking at current state of vertical farming's development (appendix B.5, C).

Some cases of vertical farming companies are further in the transition stages. In a Danish context, Nordic Harvest, with its medium-scale building-based farm, can be in several of the forward-looking stages, depending on which aspects are considered in the assessment (appendix B.3). The company is established, producing, and expanding, which points towards a stabilisation of the s-curve, but external factors, such as continuous development of production methods within the industry or regulatory conditions, indicate that the vertical farming industry in general is not stabilised, so a company like Nordic harvest, can be assumed to be more between take-off and acceleration stage (appendix B.3, section 7.2). In a broader global context, which also apply for the Danish context, vertical farming is maturing as an emerging technology, through learning from the mistakes of the first generation of producers. For some pioneer producers their production has led to bankruptcies. The second-generation companies are starting to emerge and with the preexisting knowledge, the companies can eventually make the development take-off. For now, vertical farming is still classified as an industry in an early stage, with a mix of first- and second-generation companies testing, experiencing and learning from the mistakes of others (Boekhout, 2023).

The S-curve or the MLP cannot present which structure of vertical farming that will be integrated in the specific urban context. The models can only show that there is potential to do a transition and indicate that vertical farming might follow trends or being guided by earlier generations of vertical farming, or other industries that has been, or are in the first part of their developing. What structure of vertical farming that is suitable for integration in a specific urban context depends on what governs and determines the chosen urban context, such as the market structures, policies, or requirements from the global anchored structures, as showcased through Geels' MLP model. A tension between different interests can arise, either in favour of or against vertical farming, or certain structures, and can challenge the integration of vertical farming into urban development.

7.2 Urban planning challenges for integrating vertical farming into urban development

To understand what can affect the transition process of vertical farming in a Danish context, challenges for vertical farming's integration that can arise as a result of the way urban areas are planned are highlighted. Urban planning aspects that can challenge vertical farming's integration has

been grouped under two broader terms, each holding specific aspects. The groups are, functionality of the vertical farm (environmental aspects, logistics) and the enabling environment (land access, social aspect). As indicated earlier in this thesis, the literature review has shown limited research in the urban context's impact on the integration of vertical farming. In addition, there are a limited number of practical examples of vertical farms that have managed to stabilise in society (section 2). This reduces the insight into whether there are challenges in urban development for vertical farming integration. It also impact, which urban planning challenges can be highlighted in this section and to what extend differentiation can be made between different structures of vertical farming.

Functionality of a vertical farm

Environmental aspects

For a potential integration in the urban development, it may be relevant to consider whether there are environmental challenges associated with vertical farming that can be brought into the urban area. If so, it can be a crucial factor in deciding whether to open up for integrating the industry into urban development.

Based on the literature review it was highlighted that, "*The high energy requirement for running CEA systems is the biggest issue facing ag-tech, both economically and environmentally, according to this review, which is consistent with earlier research in the area*" (Parkes et al., 2022, p. 21). Vertical farming is an energy-intensive industry as the system is in a closed environment and the production needs energy, mainly electricity to power artificial light, ventilation and to use for the automated processes in production (Kozai, 2018; appendix B.2, B.3). Studies prove that the energy demand is the largest impacting process for all categories related to environmental impact in the production. Categories relates to for example land use, water use or greenhouse gases (Martin, 2024; Romeo et al., 2018). However, it should be noted that the share of energy consumption is also influenced by how the energy in the respective country is produced (Martin, 2024). A comparison of energy consumption in an example of a vertical farm with other near-urban industries, is visualised in table 2, to highlight the difference in energy needed. The calculations in the table are based on available data and assumptions, to try and indicate how a total energy consumption could look for an industry producing around 1,000 ton/year in different types of industries, all in the food and beverage sector.

Table 2. Comparison in total energy consumption (TJ/year) between a hypothetical example of a vertical farm producing 1000 ton/year and three other near-urban industries, all with similar production per. year

Vertical farm				Source
Size of production:	7000 m^2			(Appendix B.3)
Annual production:	1,000 ton/year	=	1,000,000 kg/year	(Appendix B.3)
Average energy consumption:	38.8 kWh/kg			(WayBeyond & Agritecture consulting, 2021)
Energy consumption per year:	1,000,000 kg/year * 38.8 kWh/kg	=	38,800,00 kWh/year	
kWh to TJ	1 kWh	=	$3,6*10^{-6}$	
Total energy consumption:	38,800,000 kWh/year * $3,6*10^{-6}$	=	139.7 TJ/year	

Svaneke Bryghus, Svaneke (Craft brewery)				Source
Size of production:	≈2700 m^2			(Danmarks Miljøportal, 2024)
Annual production:	1,700,000 kg/year			(Svaneke Bryghus, 2024)
Energy consumption per year:	250,000 kWh/year			(FORCE Certification, 2022)
kWh to TJ	1 kWh	=	$3,6*10^{-6}$	
Total energy consumption:	250,000 kWh/year * $3,6*10^{-6}$	=	0.9 TJ/year	

Nordic Kingfish, Hanstholm (Growing-facility for Yellowtail Kingfish)				Source
Size of production:	2500 m^2			(Christensen, 2023)
Annual production:	1,000,000 kg/year			(Christensen, 2023)
Average energy consumption:	4.5 kWh/kg			(Marøy, 2022)
Energy consumption per year:	1,000,000 kg/year * 4.5 kWh/kg	=	4,500,000 kWh/year	
kWh to TJ	1 kWh	=	$3,6*10^{-6}$	
Total energy consumption:	4,500,000 kWh/year* $3,6*10^{-6}$	=	16.2 TJ/year	

Greenhouse				Source
Size of production:	30.000 m^2			(Bergman, 2021)
Annual production:	1,560 ton/year	=	1,560,000 kg/year	(Landbrugsavisen, 2022)
Average energy consumption:	5.4 kWh/kg			(WayBeyond & Agritecture consulting, 2021)
Energy consumption per year:	1,560,000 kg/year * 5.4 kWh/kg	=	8,424,000 kWh/year	
kWh to TJ	1 kWh	=	$3,6*10^{-6}$	
Total energy consumption:	8,424,000 kWh/year * $3,6*10^{-6}$	=	30.3 TJ/year	

Own production, 2024, data from (Bergman, 2021; Christensen, 2023; Danmarks Miljøportal, 2024; FORCE Certification, 2022; Landbrugsavisen, 2022; Marøy, 2022; Svaneke Bryghus, 2024; WayBeyond & Agritecture consulting, 2021;appendix B.3)

The vertical farm has a significant higher energy consumption than the other types of industry, where the vertical farming example is about 4-8 times larger than the examples closest in energy consumption. The vertical farming example is considered to be a building base farm with a larger production to produce the kg/year, but other structures can vary in the energy consumption. Sufficient data is lacking to compare energy consumption of different structures, but one study indicated that farms under 1000 m^2, which could be a shipping container or underground farm, used significantly more energy per. kg related to larger production scales. A difference of 34.2 kWh/kg compared to 8.3 kWh/kg. Larger scales have often more efficient systems and larger ration of bedspace to surface area, so they are able to produce larger volumes per unit energy. When choosing the structure to integrate in an urban development it could be relevant to consider this perspective of energy consumption (WayBeyond & Agritecture consulting, 2021).

Integrating vertical farming can with its general high energy consumption lead to "*scarcity of grid capacity. So that may be an issue for an industrial site to accommodate energy needs of vertical farms*" (Dr. Wubben, 2024, appendix B.2, 17:25 - 22:32). There is a shift in urban development that also requires increased electricity for the transport sector and other industries in and around the urban area. Competition for electricity may arise, and an assessment of whether to open up the possibility of integrating additional businesses in the urban development that are energy-intensive, such as vertical farming, can be considered (Raun, 2020). If there is not enough renewable energy available

on the market, there is a risk that an integration of vertical farming in urban development will negatively contribute to the consumption of fossil energy, where in a Danish context '*if we actually import fossil-based electricity to meet that need [for vertical farming], then it will be against our climate goals. For example, within scope 1 and 2, if we do energy-intensive production within our own geography, it will suddenly be negative in relation to our climate plan. So, it can very quickly become that it will be something that will be difficult to accommodate*." (Kristensen, 2024, appendix B.1, 14:07-16:19, translated). This challenge will thus be related to development and changes in other sectors, such as the energy sector. On the other hand, developments in energy planning can minimise fluctuations in energy availability and costs associated with energy (appendix B.3). Energy costs for vertical farms can eventually be minimised by making use of renewable energy through the main grid and batteries as well as avoiding electricity peaks and change production time to night (Kozai, 2018; Avgoustaki and Xydis, 2020). The challenge with vertical farming's energy consumption is very context-based, where a factor can be the energy mix for the area, where vertical farming is planned, or the structure of vertical farming is necessary to consider (Martin, 2024; Parkes et al., 2022)

Despite the energy aspect of vertical farming, other aspects of a vertical farm can be assessed when investigating the environmental impact. A life cycle assessment can be used. Unfortunately, there are limited empirical data from real cases, so the data is most based on theoretical projections mainly limited to carbon assessments. The same goes for conventional food production, so a comparison on the environmental sustainability with production in a vertical farm is challenging (Martin, 2024). Looking into the carbon assessments, vertical farming's CO2 footprint is calculated to be between 5.6 - 16.7 times higher than for conventional production, which mainly is from the energy used for electricity (Ottosen, 2022). It is very depended on the technology used, structure of the farm, location and so on, combined with no standard assessments or market standards (appendix B.2). Another perspective is that the environmental challenges depend on the system boundaries for example whether material inputs, energy supply, lifetime of products or transportation of the crops are included in the calculation of the environmental status. When trying to improve processes, for example the energy consumption through technological development, it can lead to either positive or negative trade-offs in other areas in or outside the chosen system boundary. An example is resource depletion or expansion of infrastructure that create competition for land and what to develop (Martin, 2024).

Logistic challenges

The urban area is an inherent part of the food supply and distribution system, and the planning and management of the urban area impact the functioning of the system. The placement of infrastructure in form of roads, grids, as energy or water, and buildings, as distributions centres and supermarkets, impact how the supply and distribution of food can be made in an area. Logistic challenges with integrating vertical farming in the urban development can arise, depending on the urban flows and how urban space is planned (Alfaro et al., 2023; appendix B.4). The distribution of crops from a vertical farm with the purpose of sale, follows the same distribution system as other types of food, which means that in most cases the crops are transported to a distribution centre and then distributed to consumers. That the crops are grown in the urban area, transported out of the urban area to be distributed back to a consumer in the urban area, defeats the purpose of having vertical farming as an urban production (appendix C; Martin, 2024; appendix B.3, C). Integrating a vertical farm into an existing urban area must fit in the urban structures and priorities may need to be made in regards of the location, for example, distribution opportunities, accessibility to water and electricity, building regulations and in general availability of land, which in urban areas is a scarce resource (Allegaert, 2019). The location and what to prioritise, depends on the chosen structure of a vertical farm, where a company with a small-scale container farm might prioritise an accessible levelled location on the street over proximity to large distribution infrastructure that are more relevant for large-scale building-based farms (appendix B.3; United Nations Development Programme & Vertical farming institute, 2023). Another aspect is what structure is possible to locate in the areas as with a new building-based farm it can be challenged by, *"the infrastructure is already settled on the old time. And whenever we want to build a new building, it has to somehow lie in the exact pattern and the change will be not so easy"* (Dayh, 2024, appendix B.4, 13:50 - 16:13)

The enabling environment

Ensure land access

The land access is another big challenge for integrating vertical farming in the urban development as the space for vertical farming compete against other land uses in the urban area such as housing and infrastructure. The reality is "*It is hard for me to say whether it [vertical farming] is something that can compete with a high-rise building, with some insanely expensive apartments, where you have a good rental income. I do not think so"* (Dyring, 2024, appendix B.3, 10:07-12:09, translated) and "*I think the main driver with any investor is money. […] If you have absolutely no driver, and the*

infrastructure is super expensive, and the regulations even are kind of contradictory to what is needed. Then nobody will do it." (Dayh, 2024, appendix B.4, 34:48-37:03). The challenge requires government decisions on how urban areas should be distributed as they decide what to plan for in an area, where the urban planners in the municipality then develop a local plan that can accommodate the wishes (Appendix B.3, B.4, C). Whether land access is a major challenge also depends on the structure of vertical farming, chosen in the specific context. A small-scale container farm and a building-based farm that is converting into a vertical farm does not significantly change the amount of land used and the structures may be more easily adjusted into urban development if the challenge for integration is based on lack of space (Jaeger, 2024).

The executive Order of the Planning Act (Danish: Bekendtgørelse af lov om planlægning) establishes the overall rules for public authorised to follow to ensure a coherent way of planning in Denmark (Bekendtgørelse af lov om planlægning, 2024). Land zoning is determined by The Planning Act, which means the division and regulation of rural and urban zones and what is considered part of industrial areas. A local plan for an area must work within this framework (Bekendtgørelse af lov om planlægning, 2024, §26, §34, §35). Industrial areas are reserved, but not restricted, for industrial companies doing activities listed in the Order of environmental Permitting, annex 1 and 2, with an environmental permit (Bekendtgørelse af lov om planlægning, 2024, §12; Godkendelsesbekendtgørelsen, 2023, appendix 1,2). Vertical farming is not an activity included in annex 1 or 2 and the explanation for this, can be found in the classification of vertical farming. The definition of vertical farming is not broadly defined yet, as per section 1.2, and it is questionable whether vertical farming is an activity to be classified as an agri-business or as industrial business, "*It is, very difficult to categorize. But so far it is more categorized as in industry. And being located also at industrial locations, industrial sites. […] And that is strengthened by the absence of subsidies from European common agriculture policies, for instance. […] typically, I see the more as a high tech industrial application"* (Dr. Wubben, appendix B.2, 11:10-13:19) or "*For me, it is a type of gardening. I mean, it is a highly specialised production. And if you look at modern greenhouse gardening, it is also an industry, it is also an industrial production*" (Varbæk, 2024, appendix B.5, 09:15-10:23, translated). Although vertical farming is more often related to the definition of industry, a more fitting definition might be more along the lines of 'high tech industrial application/highly specialised production'. A classification like this is not directly included in regulatory context, as regulations are more fixed in its division between businesses. The unclear definition is considered a barrier as regulation fails to consider vertical farming's dynamic reality and thereby the definition

challenge which regulations vertical farming should follow that can limit vertical farming's ability to scale up and be in certain areas, such as an industrial area (Geneletti et al., 2017). For example, problems with insurance and investors have been proven in practice within the global vertical farming industry. An insurance company for fire insurance said no to insure a farm due to complications in the regulation and investors would not provide business loans because they questioned if a farm could guarantee to run for multiple years based on current regulation (appendix B.2; Allegaert, 2019). Questions regarding the regulation can arise as, is it allowed to retrofit a building to a vertical farm, such as a rooftop farm, or is it only in dedicated buildings and what are suited zoning or building regulation that the different structures of vertical farming should follow? (Allegaert et al., 2020). Navigating this bureaucratic landscape may be a barrier to integrating vertical farming into the urban development in Danish context (Akintuyi, 2024). It can impact which structure of vertical farming will be implemented, as for example a shipping container farm can be a more portable structure and viewed as a temporary building that is flexible in placement and thus an easier implementation. Wanting to convert a building into a farm can become challenging due to the existing system and regulations, which cover the building (United Nations Development Programme & Vertical farming institute, 2023; appendix B.4)

One example where the legal aspects have challenged vertical farming was with a farm classified as an industry and therefore had to follow the regulations set for industrial production. It was a vertical farming company in Dronten, The Netherland. Due to the classification as an industry, the company had to follow specific safety requirements for industrial production, such as an obligation to have a more sprinklers in the building beyond what was needed to operate the vertical farm, but a necessity because they were located in an industrial area. The farm could not financially afford the additional requirements and had to close their production (appendix B.2). The example emphasises that since vertical farming does not belong directly to the traditional understanding of industrial production, challenges can arise that can have fatal consequences for the scaling of vertical farming. It is not in all cases that the classification of vertical farming affects the farms integration in the urban area, as for example in the Danish case of Nordic Harvest where, "*There are local plans that we must comply with, and that has not been a problem here. There are no requirements that we specifically must comply with, not at all. There have been no restrictions of that kind*" (Dyring, 2024, appendix B.3, 24:06-24:27, translated). Differences in regulation between countries and the specific context can make the variation.

Social aspect

The urban development is directly or indirectly influenced by the needs of its citizens and an integration of a vertical farm in an urban area, can also be affected by public perception (Akintuyi, 2024). The social aspect can be grouped into people actively engaged in the production of the vertical farm, as workers, and people, who impact the vertical farming development in society and politics (Thomaier et al., 2016). The second group can create a social barrier towards integration vertical farming in urban development. In literature a negative perception of vertical farming is highlighted, where vertical farming is described as not natural, too artificial or as a laboratory plant factory (Al-Chalabi, 2015; Kalantari et al., 2017b; Thomaier et al., 2016). If the perception leads to a resistance of integrating a vertical farm in an area, it can lead to a cancellation of the integration. The resistance can come from multiple stakeholders in the urban area, as real-estate owners, architects, local politicians, urban planners, or the citizens, as the stakeholders are confronted with integrating a farming practice in an urban setting (Thomaier et al., 2016). That a resistance towards new technology or a technology that is planned for an area, has been seen in other cases. For example, from citizens perspective, the not-in-my-backyard (NIMBY) effect, where solar parks or larger wind farms has not been implemented (Steen, 2024). It demonstrates that although the integration of vertical farming is determined by the technological supply and by law, the population is such a large part of the urban area that their voices can be a barrier to integration. The vertical farm, Nordic Harvest, describe that in their case, they do not face resistance from consumers regarding their product, but instead a demand (appendix B.3). Their location in an established industrial area outside the urban centre can positively contribute to why they have not met resistance in their implementation of production (appendix B.3). In other cases, a social barrier from citizens may arise if production is located closer to the urban centre or chosen over other land use activities that citizens would rather see in their area. Another type of resistance might come more from local politicians, urban planners, or architects. Vertical farming's aesthetic, regardless of structure, has an indoor closed production, which does not directly contribute to a green development of the urban area, which is a vision for urban areas in Denmark (Regeringen (2019-2022), 2021; Thomaier et al., 2016). This is where vertical farming differs from other urban agriculture methods and if the green production that happens behind closed doors cannot be reflected outwardly, the value of having vertical farming as a local production may not outweigh the value of greening the city. It depends on the actors and what value is emphasised.

Throughout the section multiple urban planning challenges have been presented and investigated. Table 3 summarises and provide a comprehensive overview of the urban planning challenges for integrating vertical farming into the urban development.

Table 3. Challenges for integrating vertical farming in the urban development

Challenge	Why?
Environmental aspects of vertical farming - Energy intensive industry - CO2 footprint	Vertical farming's energy consumption can create scarcity of grid capacity and increase the need for energy supplied to urban areas, to a degree that may not be desired. Limited research into the environmental factors of vertical farming. Negative environmental aspects may influence if a vertical farming type is desired in urban development as CO2 footprint or trade-offs.
Ensure land access - Vertical farming's classification	Vertical farming's position in the decision-making process compared to other land use activities, can challenge if it will be chosen for integration into urban development. No defined classification of vertical farming between agri-business or industrial business. The regulation to follow can affect if an integration of vertical farming into urban development can happen and under which conditions.
Logistic - Distribution - Location of the farm	Urban flows and how urban areas are planned in terms of infrastructure, can challenge the distribution of crops from vertical farms. Likewise, the urban structure can challenge what location is suitable for a vertical farm. It can vary depending on the chosen structure of a vertical farm.
Social acceptance - Resistance - Aesthetic	The perception of vertical farming can lead to resistance of an integration into the urban development from multiple stakeholders in the society. The closed indoor system of a vertical farm, regardless of structure, is not ideal for contributing to a green development of urban areas.

(Own production, 2024, based on outcome of section 7.2)

7.3 Initiatives to help overcome urban planning challenges affecting vertical farming's transition process

The challenges presented in section 7.2 indicate that there are aspects related to the way urban areas are planned that can affect the transition potential of vertical farming into the urban development. In this section initiatives are studied that are being developed, or suggestions to further initiatives that can be made, to support vertical farming's transition potential.

For a transition to happen, there must be stakeholders to create and drive initiatives for integration of vertical farming in urban development. Stakeholders, who have insight into the challenges facing vertical farming or insight in the pressures coming from external factors, such as climate change and urbanisation, as highlighted when vertical farming was put in a multi-level perspective in section 7.1. Applying vertical farming into the MLP does indicate how a transition can happen, but the role of the stakeholders, such as who should drive the transition process is ignored (Petrovics & Giezen, 2021). When asking interviewed stakeholders, who is responsible for vertical farming's potential transition, the answers differentiate, where the municipalities highlight the private stakeholders, *"for business activities, planning typically only takes place when we experience demand from external, typically private stakeholders, after which we as a municipality enter into such a dialogue"* (Scharff, 2024, appendix C, translated) (appendix B.1). In most cases the local politicians must also be involved in the decision of an integration as, "*It is the citizen representation in the City of Copenhagen that decides what to plan for, which means that if we [Copenhagen municipality] receive an application for a local plan for vertical farming, it [vertical farming] will only be adopted if there is a political majority in favour."*(Scharff, 2024, appendix C, translated). This can be avoided if the structure of the vertical farm fit within the frame of the local plan for the chosen area (appendix C). From a private stakeholder's perspective, governmental engagement for a transition potential is also highlighted, *"... it may be a government matter, so it is not something that an investor should use, but if you chose from the political side that we simply have to do something for the green transition and part of it is that we can put a vertical farm here..."* (Dyring, 2024, appendix B.3, 12:30 - 13:33, translated).

Potential governmental initiatives originate from the Ministry of Food, Agriculture and Fishery as vertical farming is managed by this ministry (Ministeret for Fødevarer, Landbrug og Fiskeri, 2023). As presented in section 6.1, vertical farming's potential transition into urban development is also affected by the development in the agricultural sector and even though the transition potential of vertical farming, as a niche, is often created by a tension of the niche with the existing regime rules

and institutions, it is also possible for a niche to receive support from the regime actors for a transition. In this case, it is the actor of the "agricultural regime", in the form of the Ministry of Food, Agriculture and Fisheries of Denmark, as the ministry is in the process of making a link or collaboration with the vertical farming. An initiative within the ministry that is under development as decided in the Agricultural Agreement, October 4th, 2021, is a taskforce for vertical farming (Ministeret for Fødevarer, Landbrug og Fiskeri, 2023). The purpose is to collect existing knowledge and experience with vertical farming, national and international, to cover future potential for growing crops in vertical farming in a Danish context. The results are presented in an explanatory report (appendix C). The taskforce is cross-ministerial and include the Ministry of Industry, Business, and Financial Affairs and stakeholders as businesses, associations for vertical farming and research institutes (appendix C; Ministeret for Fødevarer, Landbrug og Fiskeri, 2023). The outcome of the taskforce will not directly lead to new regulation or subsidies for vertical farming, but based on the identified future potential it may lead to further investigation into the industry (appendix C). The outcome may have implications for opportunities for vertical farming in urban development and how the technology as a business should be defined.

Even though this collaboration is in process, it is not a direct indicator that vertical farming as a niche is moving closer to making an actual transition of the regime. The link between the regime and the niche occurs as the ministry seeks knowledge about vertical farming to understand its potentials and whether it can support the traditional way of farming in Denmark. At the same time stakeholders related to vertical farming, want to raise awareness of the technology and hear from politicians about prospects for vertical farming. Stakeholders, who are part of the niche, as the businesses and network of vertical farming, is also in an economic or technical situation that they depend on the regulatory elements that are in the current regime. It can increase that they want to connect and coexist with the stakeholders of the regime, to be able to get the necessary support, for trying to transmit the niche-derived practices into the regime (Bilali, 2019). As regulation is now, vertical farming does not receive subsidies, as the technology does not belong to the categories as conventional or organic farming and does not get funding for research into the farming practice. From the business side of vertical farming there is a request for initiatives that can support the development and process of running a vertical farm (appendix B.3). It is questionable whether there will be a regulation on a global scale as, *"that is nice to have, that is often what we of course think that regulation will then enable everything. I think there is insufficient urgency in Western Europe, especially Northwestern Europe now, while also in the South and East. So, I think it is not feasible. You cannot expect that*

there will be European regulation" (Dr. Wubben, 2024, appendix B.2, 13:23 - 14:52). However, on a global scale there is thus an increasing focus on urban agriculture practices. The Food and Agricultural Organisation of the United Nations (FAO) is working on a study on urban agriculture, as vertical farming, and what investment and policy is needed for development. The outcome of the report can eventually push for a greater focus on vertical farming (FAO Investment Centre, 2021).

Initiatives to support vertical farming's developing might therefore have to be found in national initiatives ranging from funding programmes that business can apply to, a sector regulation, simplifying regulations or temporary subsidy programmes to use for the technology, to move from its predevelopment stage to take-off and accelerate towards stabilising in society (section 6.1; Butturini, 2023; Nordic Harvest, 2022; appendix B.3).

It has been established in section 7.1 that vertical farming is a niche innovation that has not yet transitioned into the regime and adjusted the way of planning in the urban development. As an addition to the presented initiatives for minimising and help overcome the challenges for vertical farming to become a more permanent innovation in the urban development, a transition method or approach can be useful. A transition approach can be a tool for also creating additional initiatives, based on the outcome when applying the tool in practice. In the process of collecting data on how vertical farming can potentially be transitioned into urban development, an approach was independently referenced by multiple stakeholders. The approach described, for integrating an early initiative like vertical farming into urban development, has elements of the transition approach, urban experimentation, since the approach is described as *"... often with emerging activities, that local adaptation and local initiatives and then creating reference projects is the way to go in earlier stages."* (Dr. Wubben, 2024, appendix B.2, 13:23-14:52). When explaining the theory and whether urban experimentation can be a tool for integration in response to stakeholder statements, it was agreed by multiple stakeholders that there is potential in creating experiences from urban experiments to use for integration of vertical farming in the urban development. One to highlighted is that, *"there are actually some tools and the way of thinking, that is started to occur, so it is possible to work with it [vertical farming] on an experimental level, a pilot project level"* (Kristensen, 2024, appendix B.1, 02-56 - 05:15, translated) (appendix B.3, B.5). The following section will therefore investigate the use of urban experimentation as a tool for integrating vertical farming into the urban development.

7.4 Urban experimentation as approach for vertical farming's transition into urban development

As presented in section 6.1, urban experimentation is an approach that tests initiatives in a protected space in a real world setting, with the aim of observing and reflecting on the initiative, to use for how to implement the initiative in society. In this section, vertical farming is put in the setting of urban experimentation and the process of making urban experimentation with vertical farming, is investigated. It is examined whether urban experimentation is an approach that vertical farming can benefit from, when it comes to making a transition into the urban development.

In recent years, urban experimentation has proliferated and put pressure on the tradition urban governance and fixed planning structure, to develop more hybrid ways of learning and planning. The pressures of climate change on society create entirely new challenges to plan for and the fixed definitions and ready-made solutions that often characterise modernist and state planning practices do not fit all cases. There is a need for a more iterative approach and inclusion of multiple stakeholders to imaging and test for new planning practices, to create solutions for the varies new challenges for example posed by climate change (Torrens & von Wirth, 2021). On a municipal level in Denmark, a general understanding has emerged to work more experimentally, such as with pilot projects, and for instance with the development-department in Aarhus municipality, *"We start to use the approach, that we need to create projects that can be used to quickly find out, is there something in this project or not?"* (Kristensen, 2024, appendix B.1, 02:56-05:15, translated). It has been indicated that planning for vertical farming is not on the agenda in municipalities (section 7.1) and no current urban experience with vertical farming is identified in Danish context. A test to integrate vertical farming at the port of Aalborg was initiated, but never realised (appendix C). Nevertheless, it is not denied that an urban experimental approach can be used to drive the development and potential integration of vertical farming into the urban development as, *"Some of the tools, some of the procedures, and the desire to do pilot projects and things like that, can be used to actually say, how can you organise, for example, some first steps in doing some vertical farming in the urban area"* (Kristensen, 2024, appendix B.1, 05:29-07:12, translated). An indication that urban experimentation can be applied in the case of vertical farming raises the question on how can the process of the experiment be made successful, to give an outcome that can be used for a potential integration in the society? First, a stakeholder should indicate that an experiment should be made. As presented in section 7.3, the initiative for a potential transition does not come from the municipalities, but rather from private stakeholders, where a dialogue then can be made with the municipalities. The same can be expected

with testing vertical farming in an urban experiment. The *situatedness* of an urban experiment, as per section 6.1, is constituted through the agenda of different stakeholders and how the urban experiment is positioned in regard to the urban development. To investigate further which stakeholders to include in the experiment, is therefore relevant (Bulkeley & Broto, 2012). The stakeholders and their function depend on what local setting the experiment is *embedded* in (section 6.1). To include the network for vertical farming, formed by the Food and Bio Cluster Denmark, or stakeholders that contribute to the ministerial taskforce, can provide insight into what can work in the local context, based on practical or technological experience from other companies or research institutions (appendix B.5, C). Governmental institutes need to be involved, so the governmental rules not become isolated from development happening in the field. The government does not have to be an active stakeholder necessarily, but they should be aware of the outcome of an urban experiment, for societal rules and regulations not to be outdated (appendix B.4). The municipality, where the experiment is conducted, is a stakeholder, who can help drive the experiment and their inclusion can allow them to follow the process and to understand the possibilities of vertical farming. It can potentially lead to the results of the experiment being taken more seriously than without the participation and that the municipality advocate for the structure of vertical farming that is being tested, to be considered integrated into the urban development. Additionally, it can lead to that the knowledge from the experiment can be used to conduct other experiments, for example with other structures of vertical farming, to collect more data, before a potential integration of vertical farming (section 6.1). A way to include the municipality, where they are actively part of the experiment, can be as a consulting role where in Aarhus municipality this has been used in another case where, *"a department in the municipality is connected [to the experiment], so the department in some way can help build and develop [the experiment] … In principle, it could be something that could be used in relation to vertical farming to uncover the first business potentials…"* (Kristensen, 2024, appendix B.1, 02:56 - 05:15, translated). In the case, the municipality financially supported the experiment (appendix B.1). When developing a niche innovation and trying the find the right constellation to take-off and accelerate the development, as per section 6.1, multiple testing must be made. This is often very costly and "*no one will be able to do this from the research area. And the companies would not be able to cover that either, because he will know that he has to go through a very long endless marathon in the end to be able to get it in the market"* (Dayh, 2024, appendix B.5, 40:57 - 44:15). Getting financial support from the public sector, either the municipality or governmental support, are crucial for the success of an urban experiment

as well as further in the transition process when a case of vertical farming should get into the real market and try and stabilise in the urban development (appendix B.4).

The urban experimentation approach is a way of managing the process of niche formation and development (section 6.1) and as indicated with vertical farming as a niche, the term consists of several structures of vertical farming that can follow different pathways, and not all structures may succeed in transitioning into an urban development (section 7.1). It is relevant to consider, which structures to study in an urban experiment, based on what is desired in a specific context. Applying the urban experimentation in a Danish context, the structure of vertical farming to choose is very depended on the stakeholder asked. The structure to choose range from building based farms *"one of our dreams is […] if you imaging that we [Nordic Harvest] is centred in a building with apartments around the farm, where the excessed heat then is transferred to the use in the apartments. The residents can, when they open the door, look into the pretty view of our farm*" (Dyring, 2024, appendix B.2, 06:33-08:21, translated) to smaller scale container farms, *"I don't think, on the other hand, that in Denmark it will start at all. Unless you have more like standard units like container based. Because of the investment"* (Dr. Wubben, 2024, appendix B.2, 14:53-16:08). The structure that will be chosen for a specific urban area will depend on how well the structure fits with the development desired for the area or the broader society. This means the value the farm can bring to the area. It can be related to greening in the urban area. A smaller production is more flexible in location and can be placed in an area around elements that contribute to a greener urban area, where a farm can interact with the more visually green elements (section 7.2). The value of a larger production might be more in the form of a larger amount of crops that can be produced. Regardless of structure, there is an opportunity by doing urban experiment to test if and how a vertical farm, despite its closedness in production, can bring value into the urban area, towards a greener development of an urban area. A vertical farm does not directly, as a closed system, contribute to the greening of an area like a park would, but can contribute towards a greener development in terms of bringing food production into the urban context and creating more local production (section 7.1). It should be noted that additional value, other than just being local, will benefit a vertical farms integration potential as there in some cases can be disadvantages with placing food production in the centre of the urban area (section 7.2; appendix B.1). It is also important to remember that even though the desired outcome with an urban experiment is to make a *change-oriented* way of planning, there is an *uncertainty* in the setting where the experiment is made. It can impact that the outcome potentially will not be positive for vertical

farming's integrating, but instead reinforce the status quo of the area, if the vertical farm cannot bring sufficient value for the area (section 6.1).

Through the section it has been proven that using the urban experimentation approach is valuable in the context of vertical farming as it can provide insights to which stakeholders to include and their role, but also which structure(s) fit best in the local context. However, expectation of what results an urban experiment can produce and if the results can lead to an integration in society can differ from what happens in practice. Experiences from an urban experiment are thus not a direct guide to how a structure of vertical farming can be integrated in urban development and it is emphasised that, *"... there is a gap between on one hand, the small scale, where experience is gained, to the larger scale, where it [vertical farming] is implemented based on planning aspects or is framed in a planning-context."* (Kristensen, 2024, appendix B.1, 02:56-05:15, translated) In the discussion this gap, between conducting and gaining experience from an urban experiment, to integrating a tested system in a planning context, will be explored. This happens through a discussion of whether the constellations of stakeholders in society support integration of vertical farming in urban development and if the full potential of vertical farming is expressed when trying to outline its development.

8. Discussion

As presented in section 7, from a sociotechnical transitions perspective multiple stakeholders and constellations of stakeholders, are necessary to drive the transition of vertical farming both when testing a system in an urban experiment and further along the development in the S-curve to a vertical farming system is integrated and stabilised in an urban development case. It can be discussed if the constellations of stakeholders that are made to investigate and hence drive the development of vertical farming in a Danish context support an integration of vertical farming in urban development and is vertical farming full potential expressed?

To discuss if constellations of stakeholders support an integration the network for vertical farming, formed by Food and Bio Cluster Denmark, and the stakeholders invited to contributing to the ministerial taskforce, are highlighted. The purpose with the vertical farming network is to bring compagnies in contact with each other and especially bring scientists and companies in contact with each other. The network does not include other professions as, "*For the time being, I would say that I think I have had enough to do with ensuring that the different groups do not step on each other's toes."* (Varbæk, 2024, appendix B.5, 15:15-16:29, translated). A similar constellation is evident in the included stakeholders in the ministerial taskforce for vertical farming, where businesses, the network for vertical farming and research institutes are included (section 7.3). To bring different stakeholders together that can share and jointly develop the vertical farming industry is an advantage, so that opposing developments do not occur, but the inclusion of stakeholders may be too narrow. A consistent tendency in the interviews was that interviewees were able to give perspectives within their own field more easily than if they were challenged with questions that also reached into other fields as the urban context. It indicates a more silo-based thinking on the vertical farming industry. Professions as urban planners, architect, energy- or climate planners are missing from the constellations of stakeholders for vertical farming's development and in their absence, important knowledge may be lacking, to understand the opportunities or challenges of vertical farming for example aspects presented in section 7.2 and appendix B.4. Regulation or recommendations for the industry may end up being inadequate for the complexity of the vertical farming industry and challenge a transition into the urban development. Testing vertical farming structures in urban experiments can help overcome silo thinking as experiments are conducted in the intersection between sector development and the urban area as a system. For the tested structures to be realised in a real urban development, they must thus both support the sectorial development of vertical farming,

but also provide added value to the urban area, for example by helping to solve urban challenges that are reinforced by climate impacts.

It is debatable if the constellations of stakeholders actually are intended to drive the development of vertical farming or whoever is in charge. Fostering networks and supporting a scaling of vertical farming is not the goal of the ministerial taskforce, and even though the network for vertical farming brings stakeholders more in contact with each other, it is stated in the interview that it is up to the individual company to drive vertical farming's development, if necessary, with governmental support (appendix B.5, C). The constellations of stakeholders, presented in this example, are not, according to them, responsible for driving the development of vertical farming. The views of other stakeholders also point in different directions with a lack of accountability, where municipalities points towards private stakeholders and inclusion of local politicians, private stakeholders' points towards governmental engagement and a governmental point of view hints that stakeholders in the field can cooperate towards scaling the industry (section 7.3). in the interviews, each stakeholder describes elements of the development they cannot solve themself, but need other stakeholders to bring in their expertise for the further development of vertical farming. The connection between stakeholders in practice is missing.

The elements highlighted that each stakeholder would like help solving are related to challenges exclusive to the vertical farming industry, such as the need for additional financial support for the industry or further technological knowledge about the potential of vertical farming. This suggest that in the development of vertical farming, there is a strong focus on understanding the internal challenges and opportunities in the industry, but an absence of the industry's interaction with other industries and the urban flows. It can then be questioned whether vertical farming's full potential is expressed in the constellations, where vertical farming's development take place. A common definition of vertical farming and how the industry itself is perceived, is valuable to agree on between stakeholders to be able to drive a development together, but with requirements for the society for example coming from climate change, that call for holistic and interdisciplinary innovations, there is also a huge need for thinking broader than a sector or industry itself and make synergies within the urban context. The potential for understanding vertical farming's synergies with the urban context is complicated by a lack of inclusion of stakeholders, other than those with direct contact to the vertical farming industry. Some challenges presented in the urban context, as per section 7.2, could benefit from creating synergies, for example investigating potential for industrial symbiosis to drive the processes within a vertical farm. Interviewees also hinted that vertical farming can become part of

the urban ecosystem, beneficial for both vertical farming as an industry and the urban context (appendix B.1, B.3). Including an evaluation of synergy opportunities for vertical farming can impact the perception of whether to focus on integrating vertical farming in urban development.

Combining all the information indicate that the current constellations of stakeholders, who are made to investigate and hence drive the development of vertical farming, lack a system approach with multiple stakeholders communicating and drive the development of vertical farming together, also with the inclusion of other professions. Through that collaboration, a more comprehensive perspective on how an integration can happen might be achieved, leading to a greater potential for vertical farming to transition into and stabilise in society.

9. Conclusion

The purpose of this master thesis is to investigate the transition potential of vertical farming into the urban development in a Danish context, by studying the aspect of whether the way urban areas are planned influence the transition potential.

Knowledge that has already been gathered and researched in the field of vertical farming and the way urban areas are planned, was studied though a literature review of scientific literature with the outcome presented in the state-of-the-art (section 2). A limited selection of 41 publications was derived with relevance to vertical farming and the urban development from 41,430 publications found through three different search databases. Reviewing the 41 publications indicated a predominance of newly publications, consisting of smaller sections on vertical farming in an urban context, presented in broader publications on urban farming and food security. The sections mostly hinted at a lack of knowledge about challenges and how to help overcome them within the field, but limited information to draw from practical examples or broader studies of the field. A knowledge gap for understanding vertical farming's transition potential in urban development was therefore indicated, and lead to shaping the research question:

How is vertical farming's transition potential into the urban development in Denmark from an urban planning perspective?

The research question was studied within a sociotechnical transition framework, meaning that the transition potential of vertical farming into urban development was examined through a systemic change in society.

An overall lack of data and studies to compare with has been confirmed throughout the thesis, such as the presented limited amount of scientific literature, that agri-food systems are often overlooked in comprehensive sociotechnical transition analyses and limited practical examples of vertical farms stabilised in society. The lack of data influenced the outcome that was possible to derive from the analyses.

To investigate vertical farming's transition potential, vertical farming's current position in society was first identified to understand where the industry is in its development that can influence how a transition should take place. Outcome from the conducted literature review and interviews indicated that vertical farming, both globally and in a Danish context, is in its early stage. Placing vertical farming in the sociotechnical transition framework by using Geels' MLP concept, vertical farming

can be classified as a niche innovation. In this thesis vertical farming was used as a broader term of a niche innovation and with the different structures of vertical farming being subcategories of the niche innovation. Each structure of vertical farming can take different developing pathways in trying to transition into the urban development. A transition is conditioned by pressure or requirements coming from the landscape level, as climate change and urbanisation, which are put on the current regimes solutions, where the marked structures, policy, or available scientific knowledge determine the urban context. Vertical farming can alleviate some aspects of landscape pressure, such as being an urban food production with minimal land use that can be beneficial for increased urbanisation and being controlled production without the use of pesticides to benefit the climate. The landscape pressure can open the regime up for vertical farming, or some of its structures, to transition into the society and adjust the urban development. The transition process is thus still long before vertical farming is stabilised into the urban development in Danish context. Visualised using the S-curve vertical farming is in its pre-developing stage, meaning an emerging technology that still test various developing pathways and has to learn from mistakes and experience from first- and second-generation companies before becoming a stabilised industry. Developments in individual companies must be considered as they may deviate from the general situation of the vertical farming industry (section 7.1).

To investigate if the way urban areas are planned affect vertical farming's transition process from the industry's predeveloping stage in a Danish context, an analysis of urban planning aspects that can challenge vertical farming's transition process towards stabilisation, was made. The challenges were derived from the literature review and data collected through interviews and grey literature and lead to an identification of four categories of challenges with urban planning. Two related to the functionality of the farm, which are environmental aspects and logistics challenges, and two categories referring to the enabling environment that are, land access and social aspects. It is a combination of the way the urban area is planned and the farm as a system that can lead to the challenges. Whether challenges arise when integrating a vertical farm depends on the structure and the urban context of the particular area (section 7.2).

Different initiatives were indicated that can help overcome or minimise the risk of urban planning challenges impacting vertical farming's transition process. Current governmental and international initiatives to map the potential of vertical farming, indicate an opening in the regime, but the outcome of the explanatory reports will determine the extent, to which the vertical farming as an industry can benefit from the newfound governmental interest in the field (section 7.3).

Another tool that can be used to mitigate urban challenges in the vertical farming transition process is to test the system before integration. The sociotechnical transition approach, urban experimentation, was presented as a tool to trial different structures of vertical farming in urban contexts. The approach supports the predeveloping- or formative stage that vertical farming is in as the experiments are carried out to test vertical farming's different structures and connect them with the urban development with awareness of the challenges the area is facing. The findings on what to include in the process of an urban experimentation for vertical farming is in a general setting, as no practical examples of urban experimentation with vertical farming was found. An inclusion of multiple stakeholders was identified, as for example a private stakeholder to initiate the experiment, the municipality to help drive the process, stakeholders with technological knowledge to support the process and financial support from public organisations, to be able to trail enough experiments to get the knowledge needed for vertical farming's transition process into urban development. Experiences from an urban experiment are not a direct guide on how to implement vertical farming in urban development, as structures being trialled can vary, leading to different knowledge, and there is a gap between gaining experience and then implementing in a real planning context (section 7.4).

The reason for the gap has been discussed and by studying vertical farming's transition potential into urban development from an urban planning perspective, it has been indicated that there is a of lack of systemic approach with communication and wider inclusion of stakeholders to research and drive the development of vertical farming, as urban planners, architect, energy- or climate planners. Additionally, a lack of understanding of whether a synergy and a co-existence between vertical farming and the structure of the urban area can strengthen vertical farming's transition potential into urban development (section 8).

10. Further study

The findings in this thesis are determined by the delimitations and aspects chosen to investigate the research question. This section has the purpose of introducing other perspectives that can be further studied to support and nuance the findings of this thesis.

This thesis disseminates knowledge and perspectives in the field of vertical farming's transition potential into urban development, by focusing on whether the way urban areas are planned impact this transition. Vertical farming's general transition potential into the urban development is not just influence by urban planning practices, so to broaden the research field can lead to a greater understanding of vertical farming's transition potential in a Danish context. A further study can include for example a more extensive investigation into whether vertical farming is an economic sustainable industry as the vertical farming industry is characterised by high investment costs (Kabir et al., 2023; Kalantari et al., 2017b). Another example is to explore whether Denmark is the right market for vertical farming, based on the country's share and production type of agriculture (appendix B.2). The findings in this thesis are characterised by a lack of sufficient data and insight into the field of topic among researchers and in practical examples. The thesis can thus also be used as a starting point to further investigate the urban context in relation to vertical farming's transition potential into urban development.

The presented aspects to keep in mind when practicing urban experiments in relation to vertical farming in this thesis are more broader considerations, as they are not directly linked to a conducted urban experiment. To derive more specific knowledge about, for example the integration potential of a particular structure of vertical farming in a specific urban context, to use for either scaling or translating the knowledge to conduct other experiments, a real urban experiment can be performed and the findings studied. Conducting an experiment requires resources and time beyond what is allocated for a thesis, but it is possible to study an urban experiment already taking place, for example in another country. By following the process of the experiment, it is possible to study and derive knowledge that can be used for a transition of vertical farming into the urban development in a Danish context. Making a design of how the system, that is being tested, will look like in a specific urban context can complement the more explanatory study and the design can be presented to stakeholders, such as citizens or public authorities, as a tool for understanding how the urban context will change with the introduction of the vertical farm.

The citizens, consumers, organisations specialised in environmental- or energy considerations are stakeholders in the urban environment that also can give perspectives on the chosen thesis topic. A further study that includes perspectives from these stakeholders can suppliant or contradict the statements presented in this thesis and lead to a nuance of the findings of this thesis.

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Figure list

Appendix list