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A REVIEW OF VERTICAL FARMING FOR SUSTAINABLE URBAN FOOD SECURITY

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Abstract

As the world population continues to overgrow, accompanied by substantial growth in food demand expected to emerge in the next 50 years, 70 % of the world census will live in urban areas. In order to feed the growing census, there is a need for sustainable urban food. Producing sustainable urban food requires considering all sustainability factors, including economic, social and environmental advancement. A new method was proposed to address the sustainability concern and meet the growing demand for food, implementing and designing vertical farms. This paper aims to review the vertical urban farming technological tools. Passing through defining vertical farming, what kind of crops can be produced by vertical farming, and why is it important. This study will review the significant challenges and opportunities of Vertical farming. It can increase and maintain high-quality food production and contribute to sustainable urban farming. Well-known benefits of growing food within the urban territory can be beneficial economically, socially and environmentally. Vertical farms can also provide results for increasing food security worldwide. The findings of this study indicate that vertical farming is an efficient tool that can supply food to cities sustainably and help urban areas survive overpopulation in a matter of providing food. This also depends on the location and design areas of future research identified.

Keywords:

Food security, Sustainable urban food, Sustainability, Urban farming, Vertical Farming.

1. INTRODUCTION

1.1. Background

By 2050, it is estimated that 70% of the population, equivalent to 9 billion people, will reside in urban centres as cities try to manage the challenges posed by the rapid increase in population (Eigenbrod and Gruda 2015, Abdelfatah, Dahab et al. 2022). Grapple with vicious sprawl, architects, urbanists and politicians have become increasingly interested in the vertical urban paradigm (Hewitt and Graham 2015). Unfortunately, cities worldwide are grossly unprepared to embrace vertical density as it may aggravate multidimensional sustainability encounters resulting in a "vertical sprawl" that could have worse consequences than a "horizontal" sprawl (Al-Kodmany 2018). One fundamental problem of future cities will be transporting a large amount of food to serve the dense population, and the vertical farm model offers a potential solution to this problem (Fischetti 2008). The second fundamental problem is that the city is dense, and land is costly, so if one wants to grow in the city, then growing vertically is the only solution (Hallock 2013).

Starting from 0.52 ha per person, the arable land worldwide is constantly shrinking in area, which is a matter of concern (Thokchom, Qiu et al. 2021). Further, water resource degradation and climate change aggravate the food shortage for the growing population. The adverse impacts of these two significant drivers on sustainable agriculture are critical for providing food for the future. (Gupta, Singh et al. 2021). The comprehensive influence of climate change is expected to positively impact crop production, possibly because of the collective effects of CO_2 radiation-use efficacy, fertilization, and extended growing seasons (Jin, Zhuang et al. 2017). The biggest consumer of water resources across the world is the agricultural sector. Thus water quality is one of the main determinants of crop productivity (Hoekstra and Chapagain 2007). Water quality and water availability degradation have historically impacted the agricultural system, representing a potential hazard to human health (Lu, Song et al. 2015). These factors, in addition to the internal immigration from rural areas to urban, led to a decrease in arable land, as shown in Figure 1.

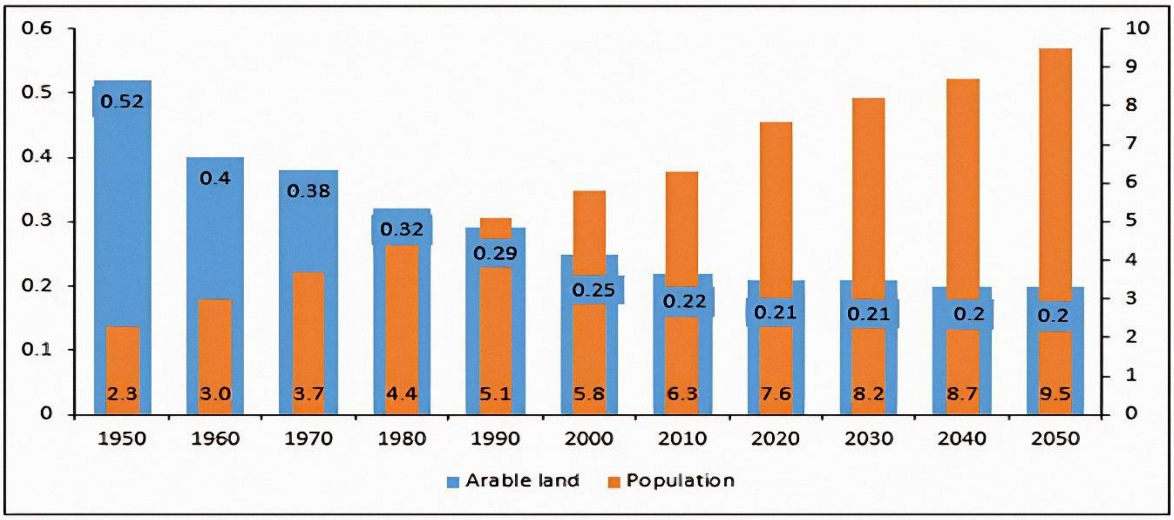


Figure 1: World population (billions) versus arable land (ha per person) 1950 – 2050 Source: (Gupta, Singh et al. 2021)

1.2. Scope of the review

As the urban census continues to increase and arable land is diminishing quickly worldwide, a significant change in food production is needed (Corvalan, Hales et al. 2005, Specht, Siebert et al. 2014). In particular, building-based urban agriculture is progressively needed in dense, compacted urban environments, and a review of existing cultivation projects and techniques would likely contribute positively to academic discussions (Despommier 2013, Touliatos, Dodd et al. 2016). This is particularly essential since vertical farming involves multiple disciplines of natural sciences, engineering, urban and architecture and affects both the environment and people (Al-Kodmany 2020). This paper endeavours to answer the following questions:

- What is vertical farming?
- What kind of crops are produced by vertical farming?
- Why vertical farming?

2 Methods

Studies on the topic come in multiple forms, including professional reports, academic papers and articles, as demonstrated in this paper's references. This paper combines various sources to endeavour to answer the above questions. Also, this paper examines a wide range of literature reviews related to urban agriculture, vertical farming and agronomy. It also reviews involved technologies and current cultivation techniques to review the future of farming technology.

This review adopts an informative qualitative approach. It conducted a literature review of existing studies, articles, and reports on vertical farming to understand the current state of knowledge in the field. This paper gathers complex technical information and makes this information accessible to non-specialists. By reviewing, organizing, and collating information from various sources, the paper hopes better to understand the theory and practice of vertical farming.

3 Types of Vertical Farming

3.1 What is vertical farming?

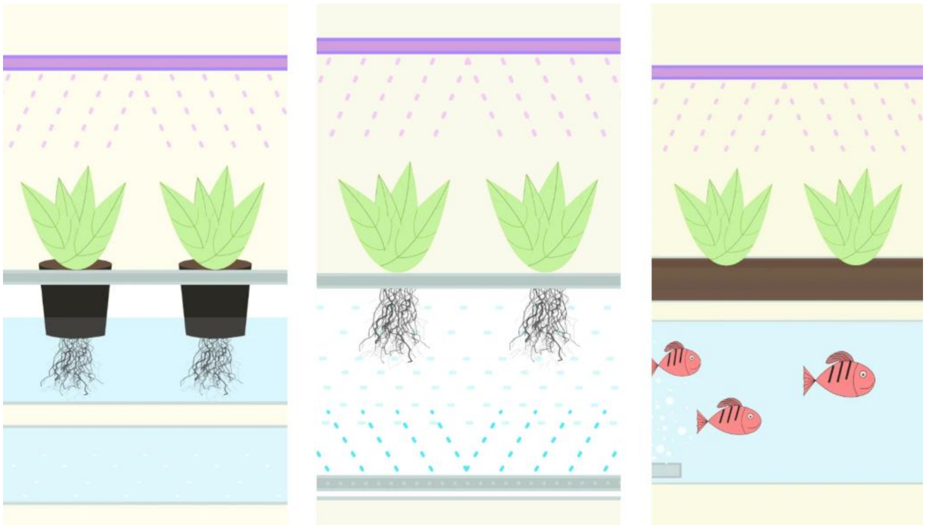
Vertical farming (VF) is growing crops vertically stacked layers or integrated with other structures (such as in a skyscraper or old warehouse) using less water and no soil (Kumar, Sharma et al. 2020). Modern vertical farming ideas use controlled-environment agriculture (CEA) technology and indoor farming techniques (Thomaier, Specht et al. 2015). All environmental factors, such as artificial control of light, temperature, humidity, and Biofortification, can be controlled, which breed crops to escalate their nutritional value (SharathKumar, Heuvelink et al. 2020), as shown in Figure 2.

Figure 2. Examples of vertical farming approach. Source (Verner, Vellani et al. 2017)

Different types of vertical farming are found all over the world. The first type refers to the construction type of tall structures with numerous levels of growing beds lined with artificial lights (Despommier 2013). This often mid-sized urban farm has been emerging around the world. Many metropolises have implemented this vertical farming model in old and new buildings, including warehouses that owners repurposed for agricultural activities (Despommier 2014). The second type of VF occurs on the rooftops of new and old buildings, residential structures, atop retail and grocery stores, and restaurants (Touliatos, Dodd et al. 2016). The third type of visionary vertical farm is the multi-story building (Mir, Naikoo et al. 2022). Several serious visionary proposals for this vertical farming type have arisen in the previous decade; It is essential to note the connection between these three types

(Petrovics and Giezen 2022). The accomplishment of modestly sized vertical farm projects and the evolution of their technologies will likely pave the way for tall farm buildings (Al-Kodmany 2018).

Public health experts, agronomists, architects, urban farmers, environmentalists, and others have joined this mini-revolution as partnering to work out a way to salvage an ultra-urbanized food-scarce future (García-Caro Briceño 2018). Many technology experts have converged on the concept of vertical farming, advancing the fields of hydroponics, aquaponics, and aeroponics (Ragaveena, Shirly Edward et al. 2021), as shown in Figure 3. Nonprofit organizations that promote local economic prosperity and environmentalism have backed the vertical farming concept. Similarly, for-profit ventures that pursue meet the need for local produce have supported this concept (Cohen and Reynolds 2015). Moreover, governments looking to enhance domestic food security have funded these endeavours. Numerous countries, including China, Korea, Japan, Sweden, Germany, the United Arab Emirates, France, India, the United States, and Singapore, have convened to discuss vertical farming (Al-Kodmany 2018). The concept has been endorsed as integral to the long-term sustainability of their metropolises (Deelstra and Girardet 2000).



(a) (b) (c)

Figure 3. Different types of Vertical farming
(a) hydroponics – (b) aeroponics– (c) aquaponics
Source: (Denisa 2022)

3.2 Systems of vertical farming

Vertical farming will use artificial light only or merging between artificial and natural light. The same issues need to be considered in designing the building. Two options are available: HPS (high-pressure sodium) or LED (light-emitting diode). When choosing the crops to grow, consider which plants can be better to bred indoors. Because of limitations imposed by height, plants that grow on trees, such as bananas, nuts, avocados, and olives, are hard to grow inside. This way, more than three dozen vegetables can be chosen to grow inside the building hydroponically (Ankri 2010). The most common products now produced in vertical farms are lettuce, Chinese cabbage, tomato, cucumber, green onion/chives, kale, spinach and eggplant (Rameshkumar, Jagathjothi et al. 2020, Shay 2021).

3.3 Hydroponics

Growing plants in a liquid nutrient solution, either with or without artificial media, is known as "hydroponics" (Jensen 1997). Commonly used mediums include expanded coir, clay, perlite, wood fibre, brick shards, polystyrene packing peanuts and vermiculite (Shrestha and Dunn 2010, George and George 2016). Vegetables like tomatoes, lettuce, cucumbers, peppers, and ornamental crops like roses, freesia, and foliage plants can all be grown successfully with hydroponics (Shrestha and Dunn 2010), as shown in Figure 4.

Hydroponics, the most common growth method used in vertical farms, involves growing plants in nutrient solutions without the use of soil (AlShrouf 2017). The fertilizer solution is regularly checked and rotated to maintain the proper chemical composition and is submerged beneath the plant roots (Rengel, Batten et al. 1999). The best possible nutrient combination may be given to every plant, yielding more consistent and superior yields (Jensen 1997). Additionally, it offers a less labour-intensive method of managing vast production regions and using no animal waste results in a cleaner procedure (Mir, Naikoo et al. 2022). A more uncomplicated technique to manage pH balance and nutrition levels (Jones Jr 1982). In 1950 commercial farms started in Europe, Japan, Asia, Africa, and America (Rameshkumar, Jagathjothi et al. 2020).

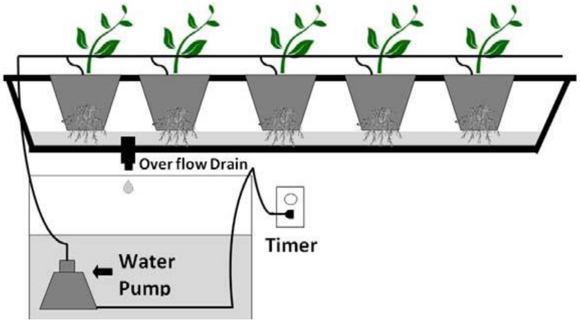


Figure 4. Hydroponic graphic. Illustration source (Birkby 2016)

Aggregate systems have a solid support medium, whereas Liquid systems have no medium for the plant roots to support (Jensen 1997). Hydroponic systems are further categorized as closed (surplus solution is replenished, recovered, and recycled) or open (once the nutrient solution is delivered and added to the plant roots, it is not reused) (Hussain, Iqbal et al. 2014), as shown in figure 5.

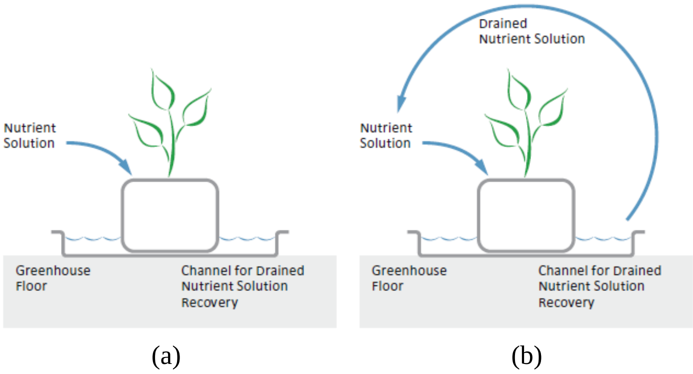


Figure 5. Scheme of an open cycle (a) and closed loop systems (b) the source (Maucieri, Nicoletto et al. 2019)

3.4 Deep Flow Technique (DFT)

Deep flow technique (DFT), also known as a deep water technique, is the cultivation of crops on hanging support (rafts, panels, boards) or floating in containers filled with 100–200 mm nutrient solution (Maucieri, Nicoletto et al. 2019). This can be up to 300 mm. Different application forms can be distinguished mainly by the volume and depth of the solution, and the methods of oxygenation and recirculation (Maucieri, Nicoletto et al. 2019), as shown in Figure 6.

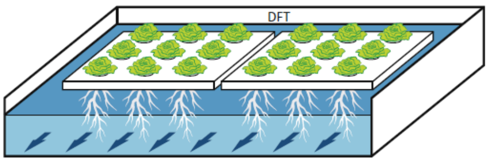
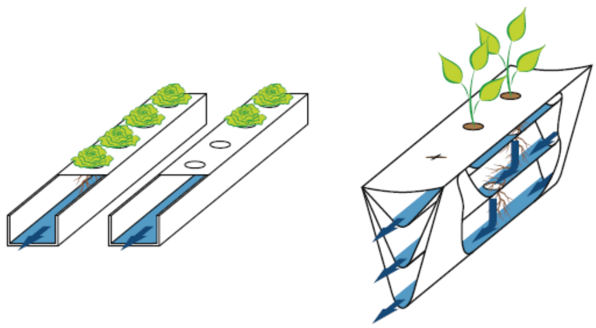


Figure 6 Illustration of a DFT system with floating panels. Source (Maucieri, Nicoletto et al. 2019)

3.5 Nutrient Film Technique (NFT)

The Nutrient Film Technique technique can be considered the classic hydroponic cultivation system, and it is used ubiquitously, where a nutrient solution flows along and circulates in troughs with a 10-20 mm layer of water (Maucieri, Nicoletto et al. 2019), as shown in figure 7. The absence of substrate and recirculation of the nutrient solution represents one of the main benefits of the NFT system. An additional benefit is its great potential for automation to save on labour costs (harvesting & planting) and the opportunity to achieve optimal plant density during the crop cycle. Furthermore, the low water levels and lack of substrate make the NFT vulnerable to the failure of pumps due to a failure in the power supply or clogging (Jensen 1997).



(a) (b)

*Figure 7. **(a)** Illustration of traditional NFT system and **(b)** a multilayer NFT trough, developed and marketed by New Growing Systems (NGS), Spain (Maucieri, Nicoletto et al. 2019)*

3.6 Aggregate Hydroponics

The most widely used medium in hydroponics is rockwool culture. It is ground-up basalt rock. First, it is heated; second, it is spun into threads making wool (Shrestha and Dunn 2010). Rockwool is often sold in very light cubes; Rockwool retains sufficient air space (at least 18%) to promote optimum root growth and can hold water (Rameshkumar, Jagathjothi et al. 2020). Plants are established on small rockwool slabs placed in channels containing recycled nutrient solutions (Mithare and Mundhe 2019). These systems are further categorized into two as shown in table 1:

Table 1. Aggregate Hydroponics' Passive and active systems description Source (Gruner, Orazi et al. 2013)

No	Category	Description
1	Passive systems	- Use a growing and wick media with very high capillary action; this enables water to be drawn to the plant's roots. - The Wick System is the simplest straight forward type of hydroponic system
2	Active systems	- Work by deliberately transferring a fertilizer solution over the roots of plants.

3.7 Aeroponics

Aeroponics is an advanced technological leap forward from traditional hydroponics. An aeroponic system is an enclosed water/nutrient and air ecosystem that fosters rapid plant growth with direct sun and little water without growing medium as soil as shown in figure 8. The significant difference between hydroponics and aeroponic farming systems is that hydroponics uses water as the growing medium, while aeroponics has no growing medium. Aeroponics uses nutrient solutions or mist instead of water, so it does not require trays or containers to hold water. It is an effective way of growing plants because it requires little water (95% less quantity of water than traditional farming methods) and minimal space. Plant stacks can be placed in a basement or warehouse in almost any setting.

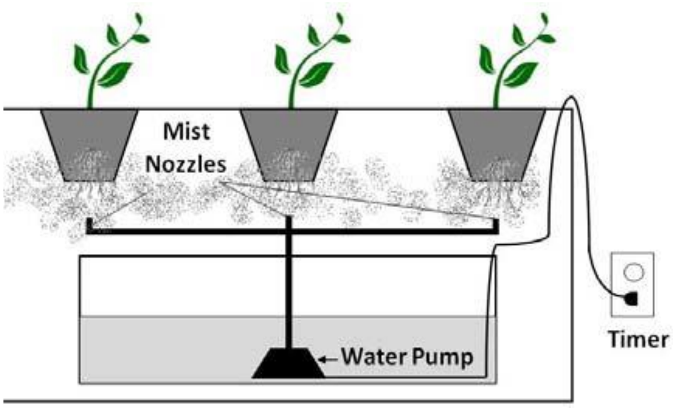


Figure 8. Aeroponic Graphic Illustration. Source (Birkby 2016)

Plants are suspended from the top and bottom of the stacking arrangement of plant boxes, allowing the crown to grow upward and the roots to grow freely below (Al-Kodmany 2018). A fine mist of nutrient-rich water-mix solution feeds plants (Jat, Tomar et al.). The fertilizer mix is completely recycled because the system is enclosed, which results in significant water savings (Savvas and Gruda 2018). Therefore, this technique is advantageous in areas lacking water (Mir, Naikoo et al. 2022). The aeroponic approach also has the benefit of not using pesticides or fertilizers. Additionally, studies have shown that this high-density planting technique yields more and facilitates harvesting (Buckseth, Sharma et al. 2016). For instance, a tomato experiment using aeroponics in Brooklyn, New York, quadrupled the crop over a year instead of the more typical one or two crops (Al-Kodmany 2020).

3.8 Aquaponics

When hydroponic and fish farming vegetable, flower, and herb production are combined, mutualistic relationships between plants and fish can be created (Özen and Çiçek 2018), as shown in Figure 9. Hydroponics and aquaculture are combined in aquaponics to produce food. Conventional soil-based horticulture uses about 10% as much water as an aquaponic system (Blidariu and Grozea 2011). These systems can benefit harsh rural environments or urban where land is poor quality or scarce (Mir, Naikoo et al. 2022). This benefit is also available using a recirculating aquaculture system or hydroponics (Halachmi, Simon et al. 2005).

Aquaponics can benefit considerably over traditional farming methods in countries where nutrient enrichment is a concern. Plants and fish in most aquaponic systems comprise 70% of the nutrients (Ranawade, Tidke et al. 2017). The remaining solid waste can be used to grow conventional horticultural crops or fruit trees (Al-Kodmany 2018).

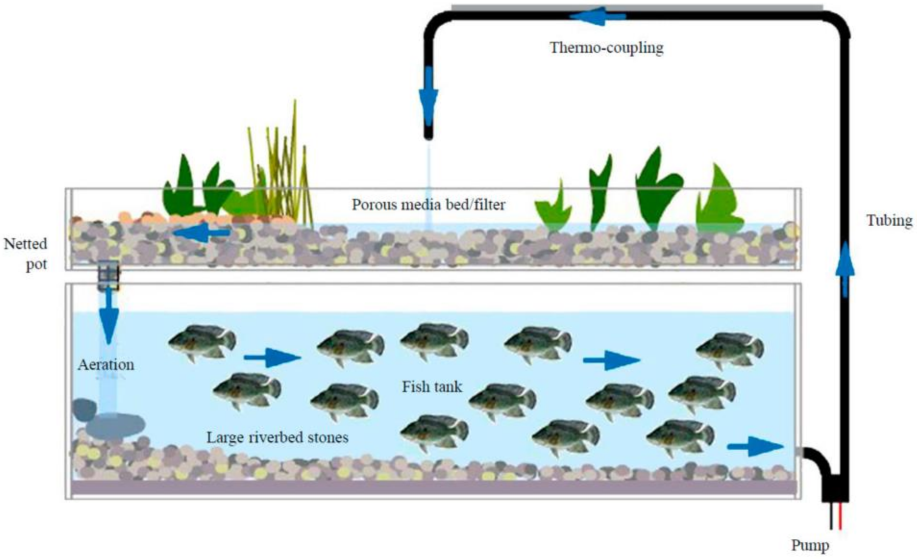


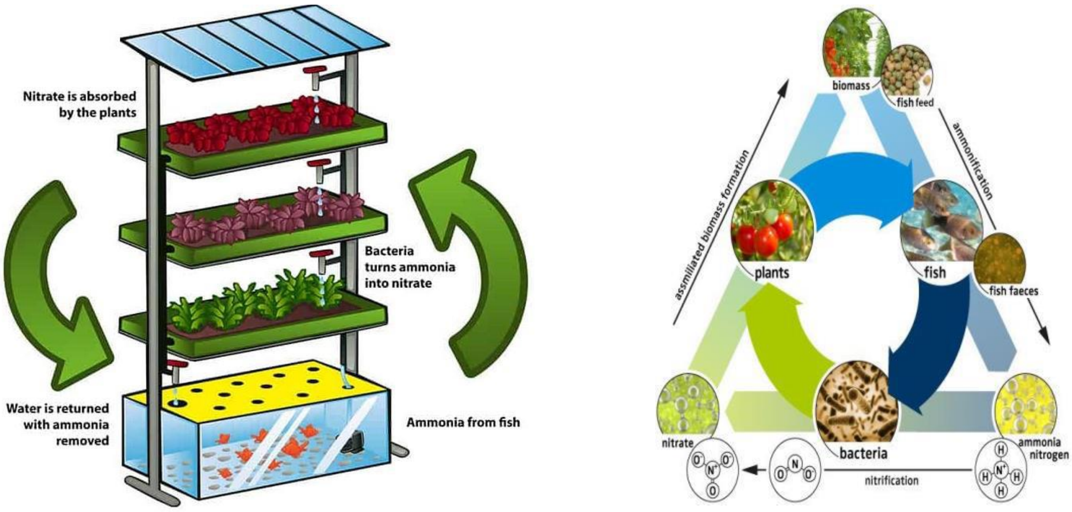
Figure 9. An aquaponic system. Source (Martin, Clift et al. 2016)

Aquaponics is a technique for growing plants and several types of fishes close to one another (Rakocy 2007), as shown in Table 2. When fish consume food, they excrete metabolites into the water (Ako 2014). After being further metabolized by bacteria, the plant growth medium is pumped with the end products of this metabolism, which are absorbed by the plants and used as food (Rakocy 2007). To grow hydroponic plants, fish effluent must be treated to remove ammonia, nitrate, nitrite, phosphorus, potassium and other micronutrients from the waste stream (Danaher, Shultz et al. 2013), as shown in Figure 10. Aquaponic systems are well-suited to lettuce, herbs, and speciality greens (such as spinach, chives, basil, and watercress) (Barnhart 2017). Using fish tank effluent to fertilize hydroponic production beds is known as aquaponics (Barnhart 2017). Plant roots and rhizobacteria move nutrients from the water, which is suitable for fish (Ranawade, Tidke et al. 2017).

Table 2. Types of fish grown using aquaponics Source Authors' compilation.

1	Aquaponics	Fish	Pacu, prawns, carp, catfish, barramundi, goldfish, salmon, trout, mussels, crayfish, Murray cod, koi, white bass, sardines, carp, sunfish, shrimp, silver perch, blue gill, tilapia

The fertigation of hydroponic production beds with nutrient-rich waste from fish tanks achieves symbiosis (Ranawade, Tidke et al. 2017). For hydroponics, fish waste should be processed to remove ammonia, nitrate, and other micro-nutrients from the waste stream so plants can thrive. Herbs, lettuce, and speciality greens (like watercress, chives, basil and spinach) can be grown in aquaponic systems (Diver and Rinehart 2000). Aquaponics is the practice of using fish tank leachate to fertilize hydroponic production beds (Goddek, Delaide et al. 2015). Rhizobacteria and plant roots help fish by removing nutrients from the water. Hydroponic production beds are "fertigated" with fish waste to create a symbiotic relationship between fish and plants (Diver and Rinehart 2000).



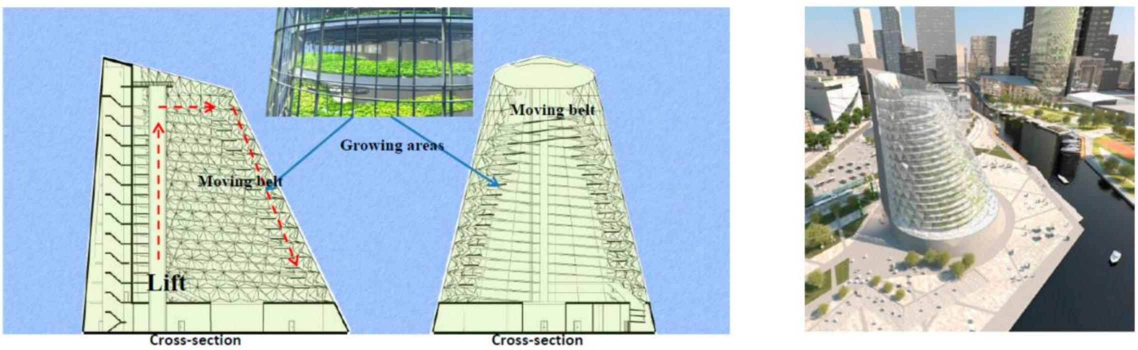
(a) (b)

Figure 10. The basic process of an aquaponic system
(a) Diagram showing Aquaponic System – (b) Aquaponics processes
source (Mir, Naikoo et al. 2022)

Aquaponics, therefore, outperforms hydroponics in this area (Suhl, Dannehl et al. 2016). On the other hand, aquaponics systems are still experimental and have only recently achieved some measure of commercial success (Turnšek, Morgenstern et al. 2019). Several processes in constructing aquaponics systems call for using various agricultural products (Palm, Knaus et al. 2018). As a result, aquaponics requires conservative management (Mir, Naikoo et al. 2022).

3.9 Vertical farming proposed structure (Standalone)

The standalone vertical farms are dedicated exclusively to the industrial production of food. Plantagon, a Swedish food-tech company, has created a prototype. The prototype, known as "Plant scraper," is a structure suggested for downtown Linköping, located south of Stockholm, the capital of Sweden. This building was constructed to create a reference structure that might serve as a model for vertical farming. The "Plant scraper" is a 12-story, mixed-use building with office space for potential urban farming research and an indoor farm (The PlantaWall) along the southern façade, as shown in Figure 11. The building will receive additional cash by renting out office space. The Plant scraper is anticipated to produce between 300 and 500 metric tonnes of leafy greens annually, primarily pak choi. Chinese vegetable pak choi, commonly called celery cabbage, can be consumed either raw or cooked. The reason for emphasizing this leafy green is that Plantagon intends to use this structure as a prototype for Asian towns. Additionally, all wastewater will be collected and reused, and all pesticides, fertilizers, and soil degradation will be automatically tracked and managed. Interestingly, Plantagon intends to integrate the vertical farm with the city's municipal infrastructure, including the electricity, gas, water, and sewage systems.



(a) (b)

Figure 11. One of Planta gon's standalone prototypes for the vertical farm
(a) Cross section – (b) perspective shot showing the outer skin
source (Al-Kodmany 2018)

In the second concept, architects from the Australian company CK Design works have created the world's first spherical vertical street, as shown in Figure 12. It is a 35-story high-rise to be constructed in Melbourne, in which gardens with trees up to 10 meters tall would be planted on every sixth floor. Crystal Gardens marks the first time five communal gardens have been attempted in a single high-rise, claims project architect Robert Caulfield. Unique structural supports that can withstand the weight of the soil and trees will be employed, along with specially constructed planter boxes that will allow tree roots to thrive in the cramped 120m2 gardens (Poole 2011).

(a)

(b)

Figure 12. First spherical vertical farming in Melbourne. (a) shot 1 - (b) shot 2. Source (Poole 2011)

According to Robert Caulfield, the structure will be made almost entirely of pre-cast concrete and have 200mm thick vertical fins on its floors rather than columns. The fins also serve as the building's interior walls, minimizing interference with the usable floor area while offering excellent strength. The garden floors will also include stronger reinforcement than other floors (Poole 2011).

As Caulfield notes, gutters will be installed on every sixth story of the exterior façade to collect rainwater that will flow into vertical pipes inserted into the fins' edges and storage tanks in the basement. Rainwater is pumped up to a rooftop distribution tank for irrigation purposes, where it will then fall naturally to the neighbourhood gardens. (Poole 2011)

The building is covered in reflective glass to reflect summer heat, and rooftop solar hot water collectors are used to heat water on the top six stories as part of extensive attempts to reduce the demand for air conditioning and lower heating costs. In order to decrease pipe lengths to each apartment and lower heating and cooling losses along the route, air conditioning units in the community gardens will only service the three levels above and below. As a result of transpiration from the trees on these floors, the ambient air temperature will likely drop by one to five degrees. Caulfield continues, "[The gardens] will also boost the efficiency of these compressor units" (Poole 2011)

4 Crops produced using vertical farming

A suitable plant-growing medium must be friable, reasonably fertile, well-drained, and have good air circulation (Calcino, Schroeder et al. 2018). Pure topsoil is not advised for use as a seedling and transplant media due to disease issues, weed seeds, drainage, aeration, and unstable physical conditions. The farm will need a constant supply to run the system unless it generates its seeds or seedlings (Gleba, Borisjuk et al. 1999). For a given climate, specialized vegetable seed varieties with a range of disease resistance are required (Specht, Siebert et al. 2014). For instance, due to their hardiness, Roma plum tomatoes thrive in hot climes and are less likely to sustain damage during packaging, storage, and shipping. For particular vegetable species, there are many different types of plastic trays with different cell sizes. The transplants need to be fertilized. There are numerous ways to water transplants, including mechanical and manual approaches (Despommier 2013).

Certain crops can be produced depending on the system's size (Despommier 2014), as shown in Table 3. Crops like leafy greens and herbs are typical in smaller locations, such as those used for residential usage (AlShrouf 2017). These plants expand rapidly, can be picked regularly, and do not need much room. A more advanced system may be utilized in more significant areas, such as a greenhouse, garage, or patio, to grow voluminous plants that need trellises and deep root support. Some crops do better in commercial hydroponic systems than others (Abel 2010). Large-scale greenhouse facilities do exceptionally well with tomatoes, lettuce, bell peppers, and cucumbers. Herbs and leafy greens thrive in vertically arranged warehouse buildings. The viability of the commercial hydroponic business will largely depend on the type and quantity of crops that can be produced (Hewitt and Graham 2015).

Table 3. Crops produced using Vertical Farming (VF) Souce Authors' compilation

1	**Fruit**	Tomatoes, watermelon, cantaloupe, strawberries, blackberries, raspberries, blueberries, grapes, dwarf citrus trees (lemons, limes, oranges), dwarf pomegranate tree, bananas
2	**Vegetables**	Leafy greens, parsnips, celery, cucumbers, potatoes, yams, peppers, wheatgrass, onions, leeks, carrots, radishes, squash, zucchini, peas, bok choy, kale, swiss chard, arugula, watercress, chives, broccoli, beans, squash, corn, cauliflower, beets, carrots, onions, radishes, cabbage, microgreens
3	**Herbs**	Chives, oregano, mint, basil, sage, rosemary
4	**Grains**	Rice, barley

5 Urban Vertical Oasis

5.1 Superblock

Superblocks are urban design concepts that promote mixed-use buildings, integrating different functions such as residential, commercial, and recreational spaces within a single block. They encourage efficient land use, create vibrant communities and foster economic growth, while reducing the dependency on automobiles for transportation (Kan, Forsyth et al. 2017). A key feature of superblocks is their pedestrian-friendly design, which prioritizes walking and cycling while limiting car access (Nieuwenhuijsen 2021). This helps to create safe, pleasant environments that encourage social interactions among residents and visitors as shown in figure 13. The combination of mixed-use spaces within superblocks ensures that daily needs such as shopping, dining, and leisure activities are conveniently accessible (Cervero, Guerra et al. 2017). Mixed-use buildings within a superblock typically consist of residential units on upper floors and commercial or recreational spaces on lower levels. Retail shops, restaurants, cafes, offices, gyms, and childcare facilities are examples of the diverse functions that can be incorporated into these structures (Wiryomartono and Wiryomartono 2020).

By integrating various purposes within a single building or block, mixed-use developments offer several benefits:

1. Enhanced walkability: With different services and amenities located close to each other, residents can easily access them on foot or by bike.

2. Increased livability: Combining residential units with commercial spaces reduces commuting times for residents who work nearby and fosters a sense of community engagement.

3. Efficient land use: Mixed-use buildings maximize the efficient use of available land by incorporating different functions together.

4. Greater housing options: The inclusion of various types of residential units within these developments accommodates the diverse needs of the population.

5. Environmental sustainability: Reduced reliance on automobiles contributes to lower greenhouse gas emissions and air pollution levels in urban areas.

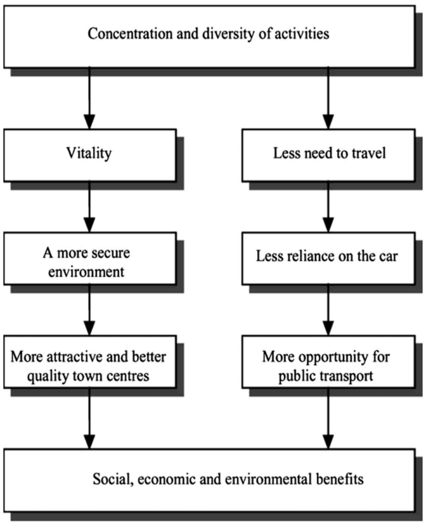


Figure 13 Benefits of mixed-use development Source (Hoppenbrouwer and Louw 2005)

In conclusion, superblocks that incorporate mixed-use buildings offer a sustainable approach to urban development. By combining different functions within these structures, developers can create vibrant cityscapes that effectively utilize land resources and cater to the diverse needs of residents while promoting environmental sustainability.

5.2 Sustainable building design principles

It is estimated that by 2056, global economic activity will have increased fivefold, global population will have increased by over 50%, global energy consumption will have increased nearly threefold, and global manufacturing activity will have increased at least threefold globally, the building sector is arguably one of the most resource-intensive industries (Panel, Consumption et al. 2011). Compared with other industries, the building industry rapidly growing world energy use as shown in figure 14. The use of finite fossil fuel resources has already raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts—ozone layer depletion, carbon dioxide emissions, global warming, climate change. Building material production consumes energy, the construction phase consumes energy, and operating a completed building consumes energy for heating, lighting, power and ventilation (Brook, Buettel et al. 2021).

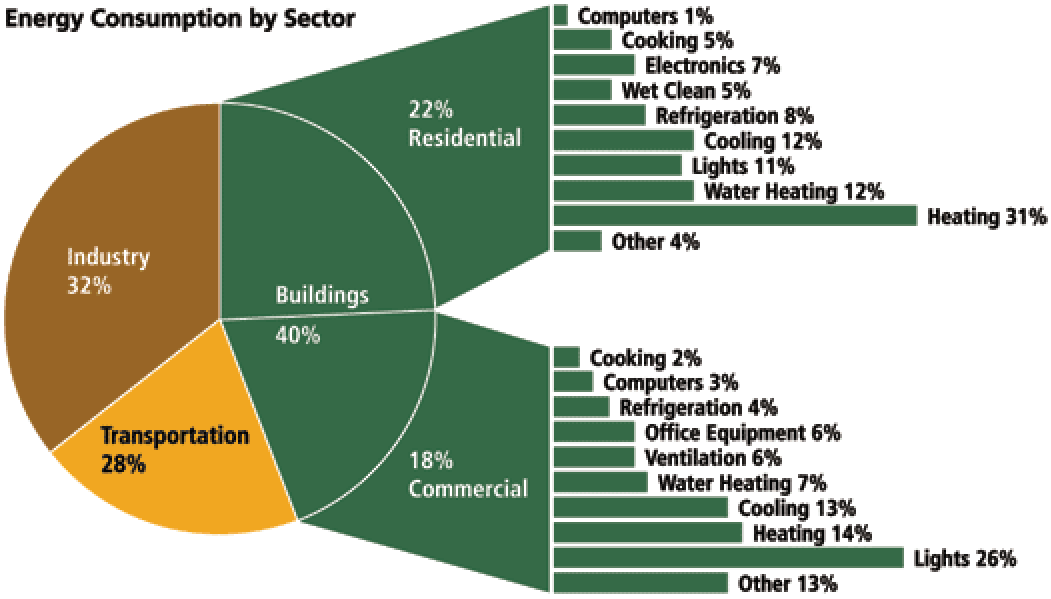


Figure 14 Energy Consumption By different sectors, Source (Cheng, Wang et al. 2014)

In addition to energy consumption, the building industry is considered as a major contributor to environmental pollution, a major consumption of raw materials, with 3 billion tons consume annually or 40% of global use and produces an enormous amount of waste. The principal issues associated with the key sustainable building themes (Hussain and Kamal 2015).

5.3 Redefining Urban Living

5.3.1 Integration of Vertical Hydroponic Farming in Superblock Buildings

A superblock vertical hydroponic building can be designed to incorporate a range of sustainable features, including rainwater harvesting, solar panels, and green roofs. The building can be divided into different levels: a podium for retail on the ground floor, typical floors for vertical farming, and a residential floor on the level before roof. The roof floor can be designed as a recreational area for residents, with various amenities such as a swimming pool, gardens, and outdoor seating areas as shown in figure 16.

The effect and impact of the architecture of the building can be significant. The use of vertical farming on the third level can provide residents with a source of fresh produce, reducing the need for transportation and storage of food and other features as shown in figure 15. Green roofs and rainwater harvesting can help reduce the building's environmental impact by reducing storm water runoff and lowering the building's energy consumption.

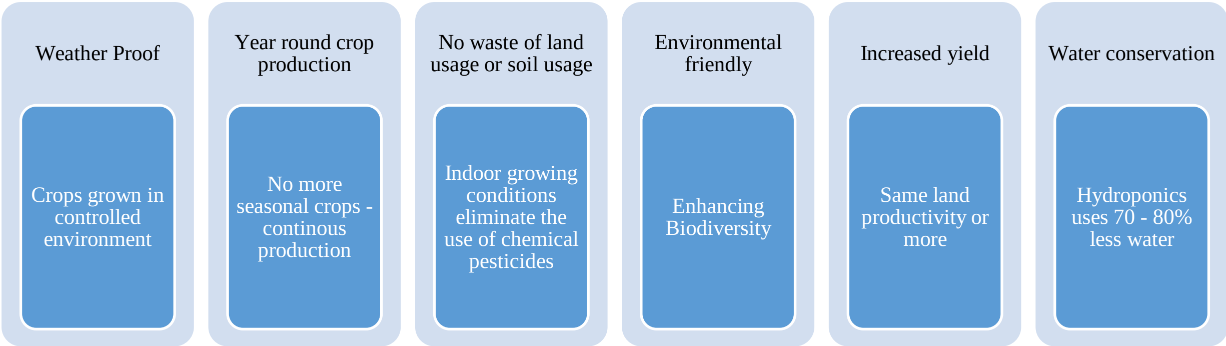


Figure 15 Advantage of Vertical farming inside a superblock – Source Authors' compilation

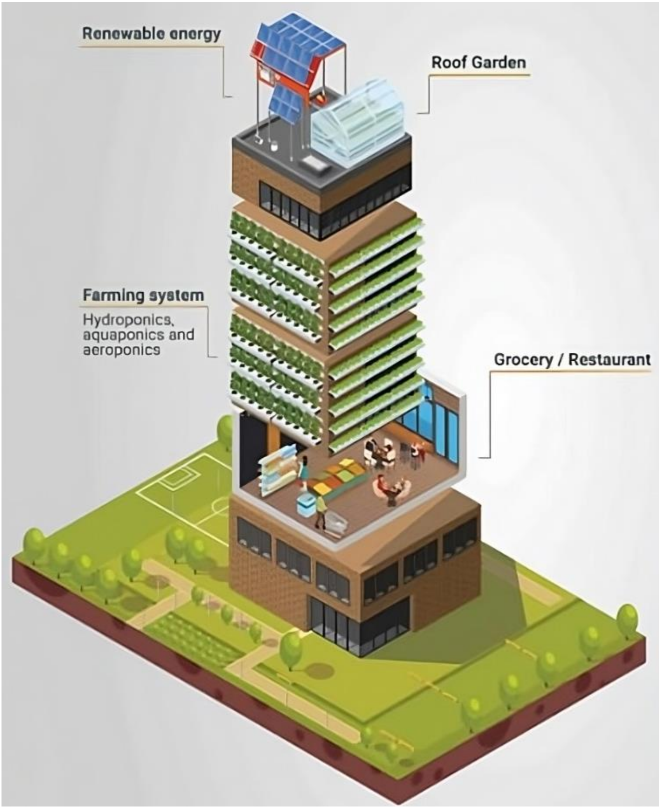


Figure 16 Superblock that have different function through levels - Source Agri, (2021)

In addition, the recreational area on the roof floor can provide a space for residents to socialize and enjoy outdoor activities. This can help promote a sense of community and well-being among residents. The retail podium on the ground floor can also provide residents with convenient access to essential goods and services.

Overall, a superblock vertical hydroponic building can provide various benefits, including increased sustainability, reduced environmental impact, and improved quality of life for residents. The design and impact of the building will depend on a range of factors, including the specific location and the community's needs.

In summary, the integration of superblocks, sustainable building design principles, and vertical hydroponic farming has the potential to revolutionize urban living by creating a vertical urban oasis. This innovative approach addresses the challenges of rapid urbanization, resource constraints, and environmental concerns while enhancing the quality of life for residents.

The vertical urban oasis concept combines the benefits of mixed-use developments, pedestrian-friendly design, and sustainable building practices to create a harmonious living environment. By incorporating vertical hydroponic farming within superblock buildings, residents gain access to fresh, locally grown produce, reducing the need for transportation and storage of food. This not only contributes to a healthier lifestyle but also minimizes the environmental impact of food production and distribution.

6 Why vertical farming?

By addressing food security, vertical farming is an example of proactive thinking that attempts to ensure the sustainability of cities (Albajes, Cantero-Martínez et al. 2013). The urban population already experiences food shortages, and as a result of rising oil costs, water scarcity, and the depletion of other agricultural resources, food prices are soaring (Abel 2010). Food is now delivered to urban areas using procedures that negatively affect the environment and the economy, such as inefficient long-distance transportation (Eigenbrod and Gruda 2015). The vertical farm will grow food effectively and sustainably to address these issues by conserving energy, water, and fossil fuels, lowering pollutants, regenerating ecosystems, and creating new job possibilities (Abel 2010). Modest-scale vertical farming has a rapid growth rate, and these initiatives have produced good examples of adaptive reuse of abandoned industrial structures (Eigenbrod and Gruda 2015).

Therefore, the vertical farm will offer opportunities in the pillars of sustainability: economy, society, and environment, as shown in Table 4. It may provide a model for sustainable food production that produces crops all year long, uninterrupted by seasonal changes or unfavourable natural occurrences (e.g., hurricanes, droughts, and floods) (Safikhani, Abdullah et al. 2014). Additionally, depending on the crop variety, it can offer a higher yield per space unit (1:4–1:6 ratio). Also, the vertical farm's high-tech production techniques reduce the need for potable water. They are frequently effective plant irrigators by concentrating water on plant roots and reducing evaporation (Albajes, Cantero-Martínez et al. 2013). They could also collect rainwater and recycle wastewater (including grey and black water) (Safikhani, Abdullah et al. 2014). When fish farms are combined, the fish cleans up the waste (esp. fish filet) (Sivamani, Bae et al. 2014). The methane from compost can be used to create energy for the vertical farm. For instance, trash is turned into electricity at the Republic of South Korea's VF factory and the Plant Vertical Farm in Chicago (Al-Kodmany 2018).

Table 4 Key sustainable benefits of the vertical farm. Source Authors' compilation

No	Sustainability Pillar	Benefits
1	**Economic**	Reduce costs, Create jobs in the city, Reduce energy, packaging, and fuel to transport food, and Turn waste into an asset.
2	**Social**	Create a local community of labourers and social networks with farmers, Improve food quality and, subsequently, consumers' health. Improve food security.
3	**Environmental**	Needs less space, Produces regarding season, Reduces fossil fuel, reduces embodied energy, Increases bio-diversity, and Reduces cities' carbon emissions.

7 Conclusion

Vertical farming has emerged as a critical solution for addressing food sustainability challenges in urban areas, particularly as the global urban population continues to rise. This innovative approach to agriculture offers numerous advantages over traditional rural farming, as evidenced by its alignment with the three pillars of sustainability: economic, social, and environmental. The integration of cutting-edge cultivation methods, such as hydroponics, aeroponics, and aquaponics, has revolutionized the agricultural landscape, challenging the necessity for soil-based farming for a variety of crops.

Hydroponics, the most prevalent system worldwide, involves growing plants in a liquid nutrient solution, with or without artificial media. Aeroponics, a more advanced iteration of hydroponics, employs nutrient solutions or mist in place of water, resulting in a 95% reduction in water usage compared to traditional hydroponics. Aquaponics, on the other hand, establishes a symbiotic relationship between plants and fish by incorporating fish farming into the conventional hydroponic system.

The convergence of advancements in greenhouse technology and supporting systems, such as multi-racking mechanized systems, wind power, recycling systems, LED lighting, solar power, storage batteries, drones, computing power, databases, software applications, and the Internet of Things (IoT), is poised to create highly efficient production systems in the near future. As the field of vertical farming continues to evolve, there is an increasing need for interdisciplinary research and collaboration, fostering collective thinking among the myriad disciplines involved in the development and implementation of vertical farms. This holistic approach will be instrumental in realizing the full potential of vertical farming as a sustainable solution for urban food production.

The concept of an urban vertical oasis, when combined with the superblock model, presents a compelling vision for sustainable architecture in the future. An urban vertical oasis refers to the integration of green spaces, such as vertical gardens and green roofs, within high-rise structures. This approach not only enhances the aesthetic appeal of the built environment but also contributes to improved air quality, reduced urban heat island effect, and increased biodiversity. The superblock model, which entails the creation of large, pedestrian-friendly zones with limited vehicular access, promotes walkability, social interaction, and a sense of community. By incorporating vertical farming and green spaces within superblocks, architects can design self-sufficient, sustainable neighborhoods that minimize the ecological footprint of urban areas. This fusion of vertical farming, urban oases, and superblocks has the potential to revolutionize urban planning and architecture, paving the way for more resilient, environmentally conscious cities that prioritize the well-being of both their inhabitants and the planet.

8 Recommendations

8.1 Urbanists

This subject, 'vertical farming', needs to be performed by doing an additional questionnaire to the customers and the companies already settled. A more detailed questionnaire would describe in depth what the people could think about the concept of different products from different production systems. It will help to understand people's minds better and draw an overview of what must be changed.

8.2 Architects, structural and mechanical engineer

The vertical farming standalone building will require collaboration among different engineering disciplines. The building should consider the principles of architecture, which are durability, utility and beauty, to create a green landmark that helps future food security. Architects and engineers should set design guidelines for this new building concept to satisfy to principles of architecture.

8.3 Municipalities

Vertical farming is a futurist concept that already has a place in people's views in 2050. Many cities would like to turn green in the coming decades, but a reasonable choice must be made to make the better choice. These cities have many warehouses and structures that can adopt the vertical farming concept and grow vegetables and other kinds. Moreover, many sites have natural products, such as beehives, in some hostels. Vertical farming can bring another image to the city and improve its inhabitants' quality of life. Using its characteristics and benefits, the vertical farm could make the city more inclined to futurist concepts.

8.4 Entrepreneurs & investors

Investing in farming became easy with the concept of vertical farming. This made the future of agriculture an excellent investment to start inside urban areas with different technological techniques. Customers have the power to choose their food, products and shops. Creating a need for vertical farming, describing in detail how it works and why this concept came up, will help entrepreneurs & investors adopt and invest in it.

References

Abdelfatah, M. T., et al. (2022). "Spatial Enclosure Assessment toward More Livable Urban Communities; Salah El-Din Street, Aswan-Egypt." Scientific Journal of the Faculty of Fine Arts: 38 - 52.

Abel, C. (2010). "The vertical garden city: towards a new urban topology." CTBUH journal **2**(1): 20-30.

Ako, H. (2014). "How to build and operate a simple small-to-large scale aquaponics system." Center for Tropical and Subtropical Aquaculture (CTSA). College of Tropical Agriculture and Human Resources, University of Hawaii At Manoa, Honolulu, Hawaii. Publication **161**.

Al-Kodmany, K. (2018). The vertical city: a sustainable development model, WIT press.

Al-Kodmany, K. (2018). "The vertical farm: A review of developments and implications for the vertical city." Buildings **8**(2): 24.

Al-Kodmany, K. (2020). "The vertical farm: Exploring applications for peri-urban areas." Smart Village Technology: Concepts and Developments: 203-232.

Albajes, R., et al. (2013). "Building bridges: an integrated strategy for sustainable food production throughout the value chain." Molecular breeding **32**: 743-770.

AlShrouf, A. (2017). "Hydroponics, aeroponic and aquaponic as compared with conventional farming." Am. Sci. Res. J. Eng. Technol. Sci **27**(1): 247-255.

Ankri, D. S. (2010). Urban kibbutz: Integrating vertical farming and collective living in Jerusalem, Israel, University of Maryland, College Park.

Barnhart, E. (2017, 30/1/2023). "Fish & Water." A Primer on New Alchemy's Solar Aquaculture 30/1/2023. from http://www.aces.edu/dept/fisheries/education/documents/Primeronsolaraquaculture_aquaponics.pdf.

Birkby, J. (2016). "Vertical farming." ATTRA sustainable agriculture **2**: 1-12.

Blidariu, F. and A. Grozea (2011). "Increasing the economical efficiency and sustainability of indoor fish farming by means of aquaponics-review." Animal science and biotechnologies **44**(2): 1-8.

Buckseth, T., et al. (2016). "Methods of pre-basic seed potato production with special reference to aeroponics—A review." Scientia horticulturae **204**: 79-87.

Calcino, D., et al. (2018). "Australian sugarcane nutrition manual."

Cohen, N. and K. Reynolds (2015). "Resource needs for a socially just and sustainable urban agriculture system: Lessons from New York City." Renewable Agriculture and Food Systems **30**(1): 103-114.

Corvalan, C., et al. (2005). Ecosystems and human well-being: health synthesis, World Health Organization.

Danaher, J. J., et al. (2013). "Alternative solids removal for warm water recirculating raft aquaponic systems." Journal of the World Aquaculture Society **44**(3): 374-383.

Deelstra, T. and H. Girardet (2000). "Urban agriculture and sustainable cities." Bakker N., Dubbeling M., Gündel S., Sabel-Koshella U., de Zeeuw H. Growing cities, growing food. Urban agriculture on the policy agenda. Feldafing, Germany: Zentralstelle für Ernährung und Landwirtschaft (ZEL) **43**: 66.

Denisa (2022). "Hydroponics vs. Aquaponics vs Aeroponics: Common Features & Differences." 1. Retrieved 23/1/2023, 2023, from https://ponicsarea.com/hydroponics-vs-aquaponics-vs-aeroponics/.

Despommier, D. (2013). "Farming up the city: the rise of urban vertical farms." Trends Biotechnol **31**(7): 388-389.

Despommier, D. (2014). "Vertical farms in horticulture." Book Encyclopedia of Food and Agricultural Ethics; Thompson, PB, Kaplan, DM, Eds: 1860.

Diver, S. and L. Rinehart (2000). Aquaponics-Integration of hydroponics with aquaculture, Attra.

Eigenbrod, C. and N. Gruda (2015). "Urban vegetable for food security in cities. A review." Agronomy for Sustainable Development **35**: 483-498.

Fischetti, M. (2008). "Growing vertical." Scientific American **18**(4): 74-79.

García-Caro Briceño, D. (2018). Vertical farming sustainability and urban implications.

George, P. and N. George (2016). "Hydroponics-(soilless cultivation of plants) for biodiversity conservation." International Journal of Modern Trends in Engineering and Science **3**(6): 97-104.

Gleba, D., et al. (1999). "Use of plant roots for phytoremediation and molecular farming." Proceedings of the National Academy of Sciences **96**(11): 5973-5977.

Goddek, S., et al. (2015). "Challenges of sustainable and commercial aquaponics." Sustainability **7**(4): 4199-4224.

Gruner, R. L., et al. (2013). "Global versus local: An exploration on how vertical farms can lead the way to more sustainable supply chains." IEEE Engineering Management Review **41**(2): 23-29.

Gupta, P., et al. (2021). Impact of climate change and water quality degradation on food security and agriculture. Water Conservation in the Era of Global Climate Change, Elsevier**:** 1-22.

Halachmi, I., et al. (2005). "A novel computer simulation model for design and management of re-circulating aquaculture systems." Aquacultural engineering **32**(3-4): 443-464.

Hallock, L. S. (2013). "Vertical farms, urban restructuring and the rise of capitalist urban agriculture." Agrarian and Environmental Studies (AES). Retrieved from http://hdl. handle. net/2105/15226.

Hewitt, L. and S. Graham (2015). "Vertical cities: Representations of urban verticality in 20th-century science fiction literature." Urban Studies **52**(5): 923-937.

Hoekstra, A. Y. and A. K. Chapagain (2007). "Water footprints of nations: water use by people as a function of their consumption pattern." Water resources management **21**: 35-48.

Hussain, A., et al. (2014). "A review on the science of growing crops without soil (soilless culture)-a novel alternative for growing crops." International Journal of Agriculture and Crop Sciences **7**(11): 833.

Hussain, A. and M. A. Kamal (2015). "Energy efficient sustainable building materials: An overview." Key Engineering Materials **650**: 38-50.

Jat, G. S., et al. "Vertical Farming of Leafy Vegetables under Protected Conditions."

Jensen, M. H. (1997). "Hydroponics." HortScience **32**(6): 1018-1021.

Jensen, M. H. (1997). Hydroponics worldwide. International Symposium on Growing Media and Hydroponics 481.

Jin, Z., et al. (2017). "The combined and separate impacts of climate extremes on the current and future US rainfed maize and soybean production under elevated CO2." Global change biology **23**(7): 2687-2704.

Jones Jr, J. B. (1982). "Hydroponics: its history and use in plant nutrition studies." Journal of plant Nutrition **5**(8): 1003-1030.

Kumar, S., et al. (2020). "Vertical farming: new agricultural approach for 21st century." Agri Mirror: Future India **1**(1): 27-30.

Lu, Y., et al. (2015). "Impacts of soil and water pollution on food safety and health risks in China." Environment international **77**: 5-15.

Martin, G., et al. (2016). "Urban cultivation and its contributions to sustainability: Nibbles of food but oodles of social capital." Sustainability **8**(5): 409.

Maucieri, C., et al. (2019). "Hydroponic technologies." Aquaponics food production systems **10**: 978-973.

Mir, M. S., et al. (2022). "Vertical farming: The future of agriculture: A review." Pharma Innov. J **11**: 1175-1195.

Mithare, P. and U. Mundhe (2019). "Hydroponics: An Innovative Approach for Doubling Farmers Income in Modern Agriculture." AGRONOMY: 103.

Nieuwenhuijsen, M. J. (2021). "New urban models for more sustainable, liveable and healthier cities post covid19; reducing air pollution, noise and heat island effects and increasing green space and physical activity." Environment international **157**: 106850.

Özen, A. and N. Çiçek (2018). "A sustainable innovative agriculture technology aquaponic systems and potential use in Turkey."

Palm, H. W., et al. (2018). "Towards commercial aquaponics: a review of systems, designs, scales and nomenclature." Aquaculture international **26**: 813-842.

Panel, U. N. E. P. I. R., et al. (2011). Decoupling natural resource use and environmental impacts from economic growth, UNEP/Earthprint.

Petrovics, D. and M. Giezen (2022). "Planning for sustainable urban food systems: an analysis of the up-scaling potential of vertical farming." Journal of Environmental Planning and Management **65**(5): 785-808.

Poole, R. (2011). "Vertical farming paves way for future of agriculture." Retrieved 1/2/2023, 2023, from https://eandt.theiet.org/content/articles/2011/10/vertical-farming-paves-way-for-future-of-agriculture/.

Ragaveena, S., et al. (2021). "Smart controlled environment agriculture methods: A holistic review." Reviews in Environmental Science and Bio/Technology **20**(4): 887-913.

Rakocy, J. (2007). "Ten guidelines for aquaponic systems." Aquaponics J **46**: 14-17.

Rameshkumar, D., et al. (2020). "Vertical Farming-Agriculture of the Future." Indian Farmer **7**(11): 1013-1017.

Ranawade, P., et al. (2017). "Comparative cultivation and biochemical analysis of Spinacia oleraceae grown in aquaponics, hydroponics and field conditions." International Journal of Current Microbiology and Applied Science **6**(4): 1007-1013.

Rengel, Z., et al. (1999). "Agronomic approaches for improving the micronutrient density in edible portions of field crops." Field crops research **60**(1-2): 27-40.

Safikhani, T., et al. (2014). "A review of energy characteristic of vertical greenery systems." Renewable and Sustainable Energy Reviews **40**: 450-462.

Savvas, D. and N. Gruda (2018). "Application of soilless culture technologies in the modern greenhouse industry—A review." Eur. J. Hortic. Sci **83**(5): 280-293.

SharathKumar, M., et al. (2020). "Vertical farming: moving from genetic to environmental modification." Trends in plant science **25**(8): 724-727.

Shay, S. (2021). "THE IMPACT OF THE WORLD CLIMATE FOLLOWING THE GROWTH OF THE DESERTS AND THE SOLUTION TO THE EXTERMINATION OF THE DESERT GROWTH Article id: INV110." AGRICULTURE & FOOD: e-NEWSLETTER: 1.

Shrestha, A. and B. Dunn (2010). Hydroponics, Oklahoma Cooperative Extension Service.

Sivamani, S., et al. (2014). An OWL-based ontology model for intelligent service in vertical farm. Advances in Computer Science and its Applications: CSA 2013, Springer.

Specht, K., et al. (2014). "Urban agriculture of the future: an overview of sustainability aspects of food production in and on buildings." Agriculture and human values **31**: 33-51.

Suhl, J., et al. (2016). "Advanced aquaponics: Evaluation of intensive tomato production in aquaponics vs. conventional hydroponics." Agricultural water management **178**: 335-344.

Thokchom, B., et al. (2021). Water Conservation in the Era of Global Climate Change, Elsevier.

Thomaier, S., et al. (2015). "Farming in and on urban buildings: Present practice and specific novelties of Zero-Acreage Farming (ZFarming)." Renewable Agriculture and Food Systems **30**(1): 43-54.

Touliatos, D., et al. (2016). "Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics." Food and energy security **5**(3): 184-191.

Turnšek, M., et al. (2019). "Commercial aquaponics: a long road ahead." Aquaponics food production systems **18**: 453-485.

Verner, D., et al. (2017). "Frontier Agriculture for Improving Refugee Livelihoods."