Urban Vertical Farming as a Path to Healthy and Sustainable Urban Built Environment


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Received:10.06.2021, Accepted:03.07.2022
DOI: 10.17932/IAU.ARCH.2015.017/arch_v08i1004

Abstract: The issue of global warming and food insecurity are among the most problematic challenges of the 21st century. Meeting the current and future demands for food production and the willingness to survive is one of the recent problems the world is facing today. The fundamental concern of this article is to explore the significant role of urban vertical farms (UVF) in how they can pave the way for a healthy and sustainable built environment. Within this 21st century, issues such as climate change, bio-and environmental degradation, and other related man-made activities that lead to the loss of agricultural lands and vertical farms can be regarded as a sustainable alternative to conventional agriculture. Consequently, urban farming provides impeccable opportunities for the sustainable development of places such as urban cities and provides a form of moral support economically, socially and ecologically, and also addresses the recent changes brought to the general built environment by the COVID-19 Pandemic. The primary objective of this paper is to explore and introduce possible and various functions which support the ecosystem and how they affect assessable benefits for urban masses at different scales of solutions within the scope of urban vertical farming. In conclusion, this research has demonstrated that UVF can enhance the general well-being of the urban masses as well as ensure a healthy and sustainable urban built environment at different scales and capacities.

Keywords: *Urban Farming; Vertical Farming; Sustainable Development; Urban Cities.*

Sağlıklı ve Sürdürülebilir Kentsel Yapılı Çevreye Giden Bir Yol Olarak Dikey Tarım

Özet: Küresel ısınma ve gıda güvensizliği konusu 21. yüzyılın en önemli sorunları arasında yer almaktadır. Gıda üretimi için mevcut ve gelecekteki talepleri karşılamak ve hayatta kalma isteği, dünyanın bugün karşı karşıya olduğu güncel sorunlardan biridir. Bu makalenin temel amacı/ilgisi, kentsel dikey çiftliklerin (UVF) sağlıklı ve sürdürülebilir bir yapılı çevrenin yolunu nasıl açabilecekleri konusundaki önemli rolünü araştırmaktır. 21. yüzyılda, iklim değişikliği, biyolojik ve çevresel bozulma ve tarım arazilerinin kaybına yol açan diğer insan yapımı faaliyetler gibi sorunlar sonrasında/sonucunda dikey çiftlikler; geleneksel tarıma sürdürülebilir bir alternatif olarak kabul edilebilir. Sonuç olarak; kentsel tarım, kentleşmiş şehirlerin sürdürülebilir kalkınması için şüphesiz ki fırsatlar sunar ve ekonomik, sosyal ve ekolojik olarak bir tür manevi destek sağlar ve ayrıca COVID-19 Pandemisi tarafından genel yapılı çevreye getirilen son değişiklikleri ele alır. Bu makalenin temel amacı, kentsel dikey tarım kapsamında ekosistemi destekleyen olası ve çeşitli işlevleri ve bunların kentsel kitleler için değerlendirilebilir faydaları nasıl etkilediğini farklı çözüm ölçeklerinde araştırmak ve açmaktır. Sonuç olarak, bu araştırma UVF'nin farklı ölçek ve kapasitelerde sağlıklı ve sürdürülebilir kentsel yapılı çevre sağlamanın yanı sıra kentsel kitlelerin genel refahını artırabileceğini göstermiştir.

Anahtar Kelimeler: *Kentsel Tarım, Dikey Tarım,Sürdürülebilir Kalkınma, Kentsel Şehirler*

1. INTRODUCTION

Urban farming has an increasing demand and can be characterized as a global phenomenon. Its primary function is to feed the rapidly growing population. In some regions of the world, it relates to environmental issues and lifestyle [1]. Urban farming can be defined as a process of growing and distributing food products through the means of plant cultivation and animal husbandry in urban cities (Urban Agriculture Committee of CFSC, 2003). It is mainly characterized by food production, small urban farms, vertical farming, beehives, rooftop gardening, guerrilla gardening, allotments and other similar initiatives [2]. A common practice of urban farming in many cities is to engage people to produce food in limited and marginalized ways possible, and it varies between countries and cities. Examples of such cities practising urban farming are Chicago and the United Kingdom because they have done innovative projects to promote the sustainable development of urban farming.

Urban farming provides more opportunities for sustainable development of places such as urban cities and provides a form of moral support economically, socially and ecologically. However, there is a tricky striking balance between these three pillars of urban farming, directly related to sustainable city development [3]. The three pillars have a literal connection that reflects the potential influence of urban farming in urban cities. Socially, cities that are connected to the rural environment preserve a high level of environmental qualities that are due to the wide range of sociable spaces that are newly generated. The spaces serve as a meeting point for social activities concerning the urban natural environment, which adds a relative value. However, there is a radical change in multiple urban forms that are pragmatic and multifunctional. The growth of a city mainly relies on expanding extensive suburban peripheries, promising expressways, industries and significant commercial locations. Therefore, as a result, there is an increase in the growing consumption of food resources to manage and obtain a balance between food production and food consumption. Therefore, urban farming plays a vital role in the inflow and outflow of natural resources in a sustainable environment. Economically, urban farming enhances the new dynamics of land use, urban spaces, and innovative activities promotions in cities with high environmental competencies and economic value [4]. Urban farming has a positive aspect regarding sustainable city developments, including marketing stimulation initiatives, employment and tax income, productive land use and self-supply of food by urban farmers. Moreover, from an environmental perspective, urban farming provides and allows microclimate improvement and soil conservation, reduces pollution and increases biodiversity in environmental awareness, reduces pollution and global warming, and increases bio diversified environmental awareness [5].

Meeting the current and future demands for food production and the determination to survive is one of the most recent difficulties the globe is facing today. However, food is an essential need for the survival of living things and solely requires nutrition to grow. Most sustainability problems are due to the uncontrolled expansion of contemporary urbanized cities and their natural environment. The lack of urban planning practically results in more formal and informal rapid population growth of settlements. The excessive accumulation and consumption of soil, energy and mineral resources play an integral role in the urban environment. Undeniably, urban farming has a significant impact on sustainable city development. Therefore, urban farming has an increasing demand and can be characterized as a global phenomenon, which in some regions of the world, it has a relative relation to environmental issues like food security, farmland shortages, and urban population growth.

Urban Agricultural practices are simple and have a relevant potential to solve environmental issues partially. However, as the urban population rapidly grows and fertile land diminishes globally, a functional change in the food production sector is vastly needed, and vertical farming can be a new cultivating technique to positively contribute to both the people and their sustainable urban environment.

1.1. Objectives and Novelty of the Research

Nearly three-quarters of Europeans and more than half of the global population resided in urban areas in 2015. The United Nations predicts that by 2050, more than 66 percent of the world's population would live in urban regions, and 82 percent in Europe [6]. As cities get more dense, they don't always have better urban greenery. In addition to the loss of biodiversity, new regions are being developed, pollution is increasing, forests are disappearing, erosion is escalating, and fragmentation of ecosystems is occurring. When it comes to the ecological role of vegetation, a lot relies on the scale, resilience, ecological connections, and resistance of plant habitats to environmental changes. Even though urban ecosystems serve a vital function, they are vulnerable to the ever-expanding city's devastation. There is a pressing need to investigate the feasibility of incorporating greenery into new spatial systems in metropolitan environments where buildings and spatial planning are constantly changing. The world's population is currently expanding rapidly, particularly in developing regions like Africa, Asia, and South America. The United Nations predicts that by 2100, there will be more than 21 billion people on the planet. According to UN predictions, by 2050, 66 percent of the world's population would live in urban regions, and 82 percent of Europe's population will live in urban areas [58]. Food demand increases as the population grows. Most of the world's arable land has been exploited, with just 20% left as wasteland, where agricultural potential has essentially evaporated over the last several decades as a result of substandard land management practices. As a result of rapid urbanization, population shifts to cities, and a lack of arable land, new approaches to bio-architecture and agro-urban design are becoming more necessary [7, 8].

In order to preserve the environment's sustainability while simultaneously improving its quality, the human population must build a new quality of space. Currently, in the era of COVID-19, the broadly understood safety of urban residents has acquired a new meaning and sense in a multidimensional system. The implementation of modern smart solutions based on information and communication technologies may result in the emergence of new practical solutions in the field of shaping new, safe green areas, fulfilling a production function, but also important for recreation and leisure for urban residents. For this reason, we should consider the possibility of creating entirely new types of urban design systems.

The fundamental objective of this research is to determine the theoretical pattern of design principles involving vertical farming in urban environments. The study hypothesis is to believe that green in vertical systems may be a strategically planned network of multi-functional and multi- size green spaces, created and maintained in a manner that strives to deliver a broad variety of environmental and social services. The authors of the research think that urban vertical farming may promote connection between existing urban green zones, fight fragmentation, and boost ecological coherence. The study analysis in this article is aimed to illustrate if it is feasible to add diverse functions, supporting ecological and social services in a large-scale system of solutions in the area of vertical urban farming, and whether they influence demonstrable advantages for urban people.

1.2. Methods of the Research

The presented study is causal and involves a newly explored phenomena, vertical urban farming. The research technique was associated with case study analysis and comprised gathering and systematising data relevant to vertical urban farming, both empirical and theoretical, their structure, systematisation, and assessment. This research grew from subjective observations to thorough investigation of associated technology, existing and imaginative initiatives of vertical farming. In the preliminary stage, browsing the Internet (sites, blogs, movie clips) delighted and fueled the study by informing about contemporary projects that employ modern technology. This inspired rigorous analysis of general (secondary) and specialized (primary) literatures on vertical farming by utilizing several internet search engines and databases including Scopus, ProQuest, and Google Scholar. Researchers gathered almost 100 sources. These sources included 42 percent peer-reviewed academic journal articles, 28 percent books and book chapters, 6 percent theses, 9 percent conference papers, and 15 percent websites. Most of the evaluated material is quite recent, dated 2010–2022. The assessed projects came mostly from North America, Europe, and Asia.

The nature of the questions this study examines using a qualitative, constructivist research technique is exploratory. The qualitative feature of this research technique gives high emphasis to the context of the phenomena being examined, which led in the adoption of a case study approach (See Fig. 1). According to Yin (2009), a case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident in order to understand the phenomenon and pertinent context in depth [9]. While an argument might be made that the first research question is more deductive, the study overall is of flexible design and experimentally driven, resulting in an inductive research technique that draws upon the openness and receptivity of the researcher.

Additionally, the researcher knows that the emphasis of this research is on a context-bound urban agricultural system and does not attempt to generalize the results of this study. Rather, the main purpose is to give information that contributes to increased knowledge of the examined phenomena, increasing the study's repeatability. The publication compiles difficult technical material and makes them accessible to the non-specialists. Collectively, by examining, arranging, and integrating material of diverse sources, the study seeks to give a deeper understanding of the philosophy and practice of vertical farming. This research explores the elements that, according to the authors, are directly and indirectly connected to the quality of life in the city, i.e., economic, social and climatic/environmental support for vertical farming.

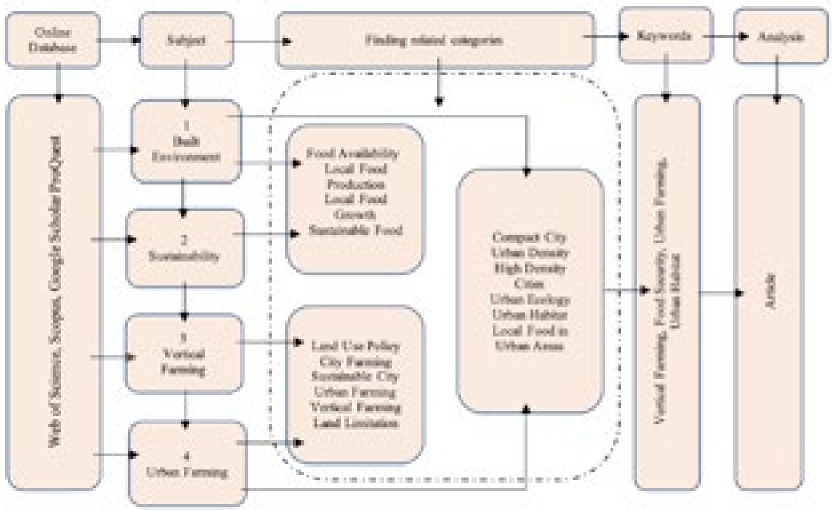

Figure 1: Research Process **(Improved by authors's)**

2. VERTICAL FARMING AND WHY VERTICAL FARMS?

Vertical farming (VF) seeks to employ the sustainable development of urban cities by addressing the rapid urban population growth. Therefore, vertical farming can be referred to as the construction of tall vertical structures with many levels of growing beds and artificial lightning serving as a form of energy or can be more defined as a multistorey vertical farm for food production. Thus, the vertical farm concept is farming up rather than farming out [10]. VF is a large-scale food production approach that uses cutting-edge greenhouse techniques and technologies to regulate ambient conditions and nutritional solutions for crops [11, 12]. VF is a farming technique that utilizes high-density food production in high-rise structures, allowing for controlled development and actual yields using advanced greenhouse techniques and fertilizer solutions. Food is the primary motivation behind the evolution of all living things. However, there is still little urban footprint and fewer water and energy resources left behind when fuel, fibre or comparable commodities or services are given by artificially piling them vertically over one another rather than using natural resources. There are many ways to grow crops inside, such as in towers, on the slopes of buildings, and so on, but vertical farming (VF) is one of the most efficient methods because of its vertical structure that can accommodate plants and animals, and so on. It may also be used to keep them stacked on top of the other [13].

There are three types of vertical farming. In the first form, the construction of tall structures with many tiers of growth beds is frequently lined with artificial lighting. Several cities have embraced this strategy globally, and small-scale urban farms are cropping up for new and existing structures, including warehouses that owners adapted for agricultural activity [10]. The second form of vertical farming occurs on rooftops of old and new residential buildings, commercial and restaurants, and grocery shops [14]. Finally, the third form of the vertical farm is a multi-story structure designed with a broad concept. Many significant imaginative initiatives of this sort are emerging in the last decade. However, there has been no construction of any kind. However, it is crucial to highlight that the success of small-scale vertical farm projects and the maturing of their technology will undoubtedly pave the way for skyscraper farms in the future [15].

As far as the concept of vertical farming goes, it is not a new one. Some examples traced far back as Philon's seven ancient wonders of the world, Babylon's Hanging Gardens, are examples of this style dating from the prehistoric age built around 600BC [7]. American environmentalist and professor of public health Dickson Despommier enthusiastically revitalized the vertical farming idea in the early 1900s. He described Vertical farming as "the mass production of plant and animal life for economic reasons," as he described it. Hydroponics and aeroponics are two of the most sophisticated greenhouse technologies that may potentially be used to grow fish, poultry, fruit, and vegetables in the vertical farm" [16].

According to Al-Kodmany (2018), to respond to the aforementioned question, why vertical farms? It is significant to explore the following trends [17];

• Urban Density

In contrast to "horizontal" urban farming, vertical farming frees up areas for other urban activities (i.e., housing more people, services, and amenities). Demands for housing, health and hygiene services, work opportunities, and transportation will continue to rise as people move to cities. In addition to these challenges, an ever-increasing urban population raises the need for stable, readily accessible, and nutrient-rich food sources. As a result, the population of future megacities is predicted to be larger, poorer, and less developed than the current city population [18].

According to Ren et al. (2013), population density increases due to rapid and extensive city expansion. Therefore, the location of an urban farm is essential [19]. There are distinct regions in well-developed cities. As a result, they provide a wide range of city-based farming and food production [20]. Property is so expensive in metropolises that they tend to be densely populated. As a result, the development of structures for integrated manufacturing may assist in supplying residents [21]. Furthermore, VF may be performed year-round in a well-protected space, which is a huge benefit. Compared to traditional farming, VF enjoys several advantages, which elevate it to a higher and more influential position [13].

• Ecosystem

In order to sustain human and non-human life, the Earth's ecosystems must be maintained. Food, clean air, clean water, and a somewhat stable climate are necessities for human biology [22]. For millennia, humans have been intruding on natural ecosystems via agriculture. According to Despommier (2008), farming is the most harmful practice [23]. The ecosystems play a significant role in the recycling and redistribution of nutrition. Although this function underlies the health of plant and animal species globally, the interruption of nutrient cycling may degrade soil fertility and lower crop yield [22].

The location of an urban farm is significant. There are distinct regions in well-developed cities. As a result, there are several opportunities for city-based agricultural and food production [24]. Vertical farming has the potential to increase food production efficiency and sustainability, conserve water and energy, improve the economy, decrease pollution, create new jobs, restore ecosystems, and ensure that everyone has access to nutritious, affordable meals. Pesticide use, crop rotation, polluted runoff, and dust are less likely to affect crops grown in a regulated environment than those grown in an uncontrolled setting [25].

• Climate Change

Climate change has led to a loss of arable land. Damage to the global economy has been exacerbated by the loss of important farmland due to extreme weather events such as floods, hurricanes, storms, and drought. The shrinkage of arable land has been worsened by global warming. Flooding, hurricanes, storms, and drought have decimated vital farmland, resulting in a reduction in the global economy [26]. For example, climate change can stress agricultural production, and Weather-related disasters are expected to become more frequent and severe due to artificial global warming. Many acres of agricultural land will be rendered unusable due to these disasters. Crop insurance against natural causes is a systematic way for governments to fund traditional farming [27].

In the United States, conventional farming uses more than 20 per cent of all gasoline and diesel fuel used for agricultural operations (e.g., ploughing, applying fertilizers, sowing, weeding, and harvesting). Food miles refer to the distance crops must travel to reach urban inhabitants in a concentrated area. Even more so because of global urbanization's rising distance between farmland and cities. Climate change has been exacerbated by greenhouse gas emissions from food transportation and farming [28].

• Economics

The vertical farm's proponents also claim that it would provide food at competitive pricing. However, traditional farming's growing costs are fast decreasing the price gap. Moreover, in urban locations, vertical farms may be strategically situated to sell food directly to the customer, cutting transportation expenses by as much as 60% [2].

With the help of cutting-edge technology and intensive agricultural techniques, vertical farms can significantly improve their output. Researchers have been calibrating, tuning, and modifying various factors, including light intensity, light color, space, temperature, crop and root, CO2 levels, soil, water, and air humidity, to optimize indoor farming. Aside from supporting the local economy, vertical farming presents a unique innovation opportunity. For example, in urban areas where fresh produce is limited, abandoned buildings may be transformed into vertical farms that supply nutritious food. Indoor farming's high-tech setting might also add to the activity's appeal. As a result, a new generation of farmers is being groomed via technology. In addition, the development of new agricultural technologies is given a boost by vertical farming. Last but not least, urban farmers might help re-connect people with nature in the city [29].

• Health

Conventional agricultural operations often emphasize profit and commercial gain at the expense of the damage done to human and natural environment health due to these activities. Furthermore, the soil is eroded, contaminated, and much water is wasted. More than half of the world's farms still use raw animal manure as fertilizer, which may attract flies and carry weed seeds or illnesses that can be spread to plants.

This can have serious health consequences for humans. As a result, people's health is negatively impacted by eating such food [7]. In addition, precise irrigation and efficient scheduling are critical features of indoor vertical farming, which uses a fraction of the water regular farming does. Water consumption will rise as the urban population expands. Thus, this may be a huge help. Because metropolitan populations are developing and using more freshwater, farmers are losing the agricultural water source that they need to grow crops. As temperatures rise and more droughts occur, the water problem worsens [30].

• Food Security

The problem of food safety is becoming more critical. According to demographers, urban populations are expected to multiply in the future decades. According to experts in land use (such as agronomists, ecologists, and geologists) [17]. Even in industrialized nations where fresh food supplies are scarce areas referred to as "food deserts" figuratively, food security is a significant concern. Food production methods are at the heart of the issue. As a result, urban farming receives more support to bridge the gap between food producers and consumers [31]. UN projects that the world's population will grow by 40% by 2050, reaching 9 billion. According to UN estimates, by 2050, 80 per cent of the world's population will be living in urban areas. A further 70 per cent increase in food production is expected to be required by 2050 when the world's population is expected to grow by 3 billion people [32].

The logic of vertical farming, you can grow more food in less area. VF may be run all year round Indoors in a well-protected environment. As a result of these advantages, VF farming is seen as superior to other traditional farming methods. VF can meet nutritional food needs [13]. VF is a significant source of food for a large local population. As a result, VF has made a significant effort to keep pace with the recent surge in the popularity of regional cuisine. Plants in VF may grow at any time of year. As a result, fewer crops are lost as compared to conventional farming. In addition, various kinds of plants grow on different levels of the usual form of city agricultural farm with the same square. In order to maximize the utilization of space, VF may be utilized everywhere in the city since it does not rely on weather conditions or soil conditions [13].

2.1. Vertical Farming Techniques

Vertical Farming (VF) is a large-scale agricultural system that allows rapid growth and planned production of crops by managing ambient conditions and nutritional solutions. With cutting-edge greenhouse techniques and technology [10, 11, 12]. Modern agricultural techniques have the potential to increase yields while using significantly less water. The form and arrangement of these high-tech farms will give each plant precisely calibrated nutrients while also ensuring optimum light exposure. Closed-loop farms would remove the need for toxic herbicides and pesticides while boosting nutrition and food value at the same time [33]. VF can be classified into three methods of production: hydroponics, aeroponics, and aquaponics [17].

2.1.1. Hydroponics

The hydroponic technique is a method of growing plants in water, either with or without sand or gravel as support, and is an environmentally friendly way to grow food without soil [17]. The water acts as a channel for distributing and absorbing mineral nutrition solutions. Due to its many advantages and low-maintenance nature, hydroponics has become the primary technique of food production in vertical farms today. Deep-water culture (DWC), nutrient film technique (NFT), and media bed technique (MBT) are all components of the hydroponic system [34] (See Fig. 2).

Hydroponics is now widely used in industrial agriculture and offers various benefits over conventional soil-based production. Soil-related cultivation issues might be eliminated or at least reduced by using this strategy (i.e., the insects, fungus, and bacteria that grow in soil). Because no animal excrement is utilized, it may also be a cleaner method. Additionally, hydroponics gives a more convenient technique for controlling fertilizer levels and pH levels time [33].

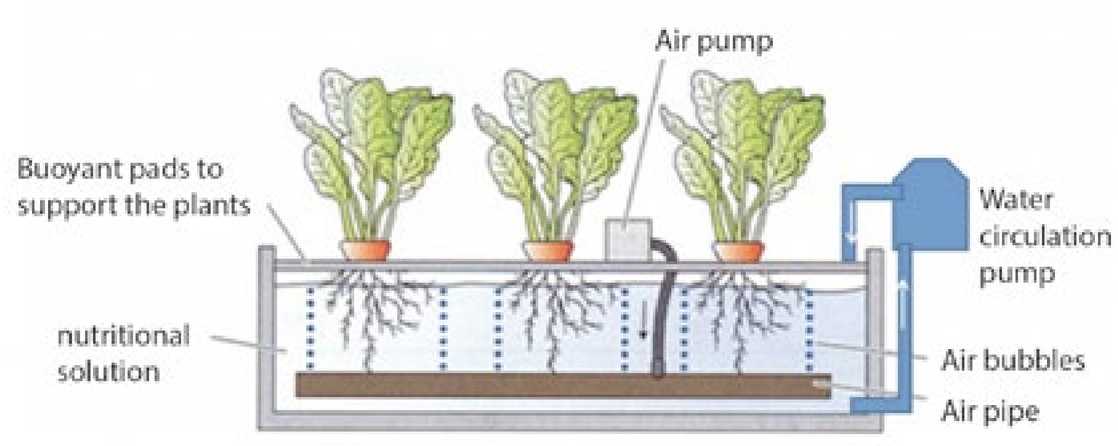

Figure 2. Basics of Hydroponic system [35].

2.1.2. Aquaponics

The hydroponics method is integrated with fish farming, producing a symbiotic link between the fish and the plants. The fish excrement flows into the hydroponic beds, providing nutrients for the plants. Hydroponic beds remove gases, acids, and chemicals from the water circulating between the fish tanks and the hydroponic beds (e.g., ammonia, nitrates, and phosphates). An essential part of this process is substrates, which offer nitrifying bacteria an ideal water filtration and nutrient recycling environment. Researchers believe that aquaponics has the potential to be a model for sustainable food production because of its efficient circular flow of resources (See Fig. 3). For example, water filtration by crops, waste products of one system serving as nutrients for the second, efficient water use, and reduced need for fertilizers and artificial chemicals [36].

This method has the potential to become a model for sustainable food production by meeting the 3Rs, according to researchers (reduce, reuse, and recycle). Many advantages include:

- It provides organic liquid fertilizers that support healthy plant growth;
- The waste products of one biological system serve as nutrients for another;
- It saves water because water is filtered and recirculated;
- The waste products of one biological system are used as nutrients for another. Particularly appealing in countries where water is scarce, this trait reduces or eliminates the need for herbicides and synthetic fertilizers [36].

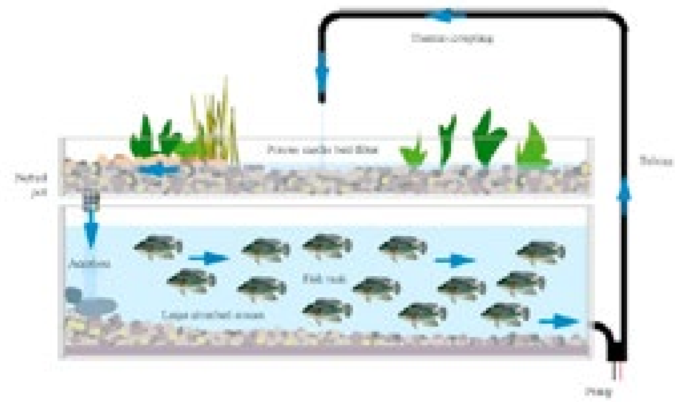

Figure 3: Basics of an Aquaponic System [17].

2.1.3. Aeroponics

The Aeroponics method is a substrate-free, air, water, and nutrient-based form of food production that promotes crop growing with minimal water or sunshine. One of the most successful and efficient food production methods is the utilization of mist to transfer nutrients throughout the root systems when water is not available [7]. It uses 95 per cent less water and takes up a fraction of the area of traditional agricultural techniques (See Fig. 4). However, the maintenance of aeroponics systems is a challenge. Aeroponics production requires a hands-on approach since the mist nozzles must be clean of bio-debris. However, the production system must be constantly monitored and maintained to ensure that the roots of the plants are not damaged by even the most minor changes in their surroundings.

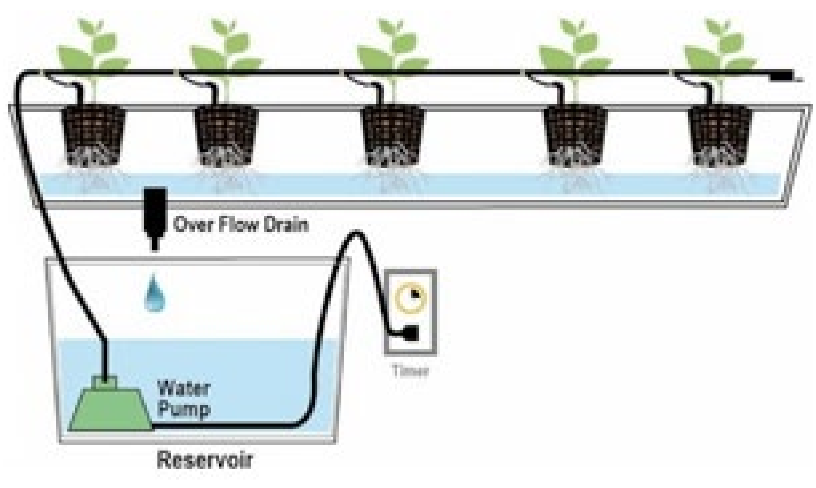

Figure 4: Basics of Aeroponic System [37].

Table 1. An over view of vertical farming methods adapted from Al-Kodmany, 2018.

Farming Method	Characteristics	Benefits	Drawbacks	Applicable Technology
Hydroponics	Soilless; water is used as a medium for growth.	Eliminates soil-related cultivation concerns, reduces the usage of fertilizers and pesticides, enables faster plant development.	The use of foreign inputs and pesticides, as well as a lack of oxygen to the roots of crops, may lead to tasteless produce.	Monitoring and computerized systems There are smartphones, laptops, and tablet computers. Apps for growing food; Systems and software for remote management (agricultural systems that are operated remotely); racks with moving conveyor belts and huge towers of automated racking; LED lighting systems that can be programmed; Solar, wind, geothermal, and other forms of renewable energy Anaerobic digestion; closed-loop systems Nutrient systems that can be programmed; AC/HVAC systems for climate control methods for reusing and recycling water Collectors for rainwater; The use of insect killing systems and robots.
Aquaponics	The integration of aquaculture and hydroponics	The symbiotic interaction between plants and fish is used to create a closed nutrition system. Fish 'waste' is rich in nutrients and provides food for plants, which in turn cleans the water for the fish.	A lack of oxygen reaching the roots might result in a tasteless product.	
Aeroponics	Hydroponics with nutrient solution mists is sprayed over the roots of plants during the Soilless method.	In addition to the advantages of hydroponics, it uses less water and promotes more aerobic plant development.	Algae and biofilm forming in the mist nozzles may quickly jam them. The system requires a lot of attention. System temperature changes are rapid because there is no medium or substrate to slow them down.	

2.2 Approach to Vertical Farming and Urban Gardening

The vertical farm is a modern city's counterpart, providing stability while accepting change rather than a single building. The vertical farm is a complex system for growing agricultural produce in an urban setting while also being a functional part of the urban system. The vertical farm is about hidden circuits of energy and materials, labour and resources, capital and infrastructure that modern cities rely on, not just a skyscraper with agricultural plots and food production. Food is only one aspect of the vertical farm that consumers see, and it is the most apparent portion, while the rest of the industrial process is hidden [38].

On the planet, 80% of the land accessible for agriculture has already been farmed. The indication that natural expansions are dwindling in favour of agricultural areas. According to NASA, the increasing population has necessitated the provision of food, which the agricultural industry can provide. Every day, the total area of agricultural land in the world expands. Agricultural exploitations are displacing natural regions all over the world. By 2050, approximately 80% of the world's population will be living in cities. Therefore, If existing farming practices continue, an estimated 109 hectares of new land (about 20% more land than in Brazil) will be required to cultivate enough food to feed them [38].

The public's perception of the vertical farm is a ballet of food visibility. Food is the most dynamic and complicated system in the twenty-first century, necessitating a complex web of interconnections. "Eating is an act of agriculture", as Wendell Berry puts it. As a result, the vertical farm's primary function is to mediate the visibility of food production. Furthermore, the vertical farm teaches that interaction with the world has consequences, especially what an individual consumes.

A vertical farm design by Eric Ellingsen and Dickson Despommier shows a sustainable vertical farm design approach. The pyramid farm was a predecessor of the vertical farming concept [23]. It is designed to save space while reducing trash and providing food for an ever-increasing population. Harvesting edible fruits and vegetables are done on this vertical farm. It also uses waste to create an indoor fishery and aids in developing a chicken farm. Figure 5 presents a vertical farm design in Dubai. Looking closer at the design, some programmatic shelves contain a graze of colours. Despite this, some energy evaluations have indicated that urban agriculture can be a viable alternative to non-renewable and imported resources in urban growth initiatives [39]. According to Maassen (2017), increasing the participation of local renewable resources and assuring local inputs will promote sustainability [40]. Additional recommendations include increasing resource recycling and reuse, supporting renewable energy sources to replace fossil fuels, and improving input efficiency [41].

Figure 5. Showing vertical farm design in Dubai [23]

The vertical farm pyramid design has many different mixed-use purposes for people to live and enjoy the links between food and the city because it has an interwoven network of relationships in the twenty-first century. The anaerobic digest is a critical component of the vertical farm megastructure. Waste from humans and animals is used as a source of energy. All waste in the form of animal manure will be remediated through the plant's roots system and reused as fertilizer at the complex, including chicken and hog production and aquaculture tanks for raising shellfish to tilapia. All waste in animal manure will be Phyto remediated through the plant's roots system and reused as fertilizer. Water recycling into a wastewater treatment facility and a potable urban reservoir from plant evapotranspiration and aquaculture tanks. Finally, the year-round vertical farm will produce fruits and vegetables, and the complex will feature residential units, restaurants, and commercial operations. On the exterior parts of the vertical farm, a public park will have a relationship between nature and public space. Figure 6 presents a section of various components of the vertical farm that will collect, filter, merge and redistribute urban energy [42].

Figure 6. Showing a section of various components of the vertical farm [23].

3. URBAN FARMING AND SUSTAINABLE DEVELOPMENT

For decades, the rural built environment was linked to the traditional model of a compact, social, complex and efficient city, thereby preserving high levels of environmental quality. Moreover, the model generated spaces for sociability, that is, the boundaries that are ideal for economic activities of the urban natural environment. However, Viana-Cárdenas (2013) stated that the model has drastically changed since the second half of the twentieth century through the functional character of the city's urban form [43]. However, towards the end of the twentieth century, new urban realities were characterized by low-density industrial estates, with most residents living near highway and expressway intersections. The new model has a path to greater consumption of water, energy, materials, and soil resources. Thus, this path is contrary to sustainability, and only a few cities manage to balance inflow and outflow and consumption and production of natural resources. Due to the significant expansion of contemporary urban cities, most of the sustainability problems have a direct extension to the natural environment. For example, formal and informal settlements result from territorial expansion and a lack of planning. Therefore, in the same vein, mobility and traffic are part of the ecological problems contemporary urban cities are facing today. Moreover, the new urbanizations are generating abused landscapes that undervalue rural and natural heritage and primary activities such as agriculture.

However, to stop the unsustainability of urban cities, there are several national, regional, and municipal government projects worldwide. These initiatives address traffic control, trash management, sanitation, and water purification, among others. The outline of a network or green matrix in the interior and perimeter of cities stands out among these operations. The rebalancing of urban systems is based on a network of green spaces surrounding urban centers made of rings and vegetable corridors that link and meld agricultural and forestry areas with inhabitants and neighborhoods. Within this green matrix network, urban and peri-urban farming plays a vital role as one of the essential strategies for urban sustainability. Consider the future city as a resilient and self-sufficient city that achieves "ecosystem" status by committing to urban agriculture [44]. However, cities that generate new land-use dynamics modify urban spaces and promote innovative activities such as urban and peri-urban agriculture become cities with high economic, social, and environmental competencies [44]. Hence urban farming can have a positive impact on sustainable urban cities. Urban farming can contribute to social development by providing urban food security, access to fresh and healthy food, personal well-being and direct involvement in (UA) which can result in physical, intellectual, and psychological benefits, personal skills (example, horticultural and communication skills), and a sense of place preserving the national rural image. In addition, urban faming benefits the environment by preserving urban soil, improving microclimate, reducing pollution (waste and nutrient recycling), increasing biodiversity, and increasing environmental awareness [5, 45] (see Fig.7). When the Pandemic broke out in March 2020, most cities were left with empty food store shelves, adding to the already high level of anxiety. The reason for this is because of the considerable distance between the farm and the market. Because of the disruptions to air travel and the closure of international borders, food supply networks were unable to function, which resulted in this predicament [47].

It takes lettuce, for example, around 30 to 45 days to mature in an open field, which means it has to travel about 2000 kilometres. While it takes just 12 days for urban indoor lettuce to develop and travel less than 50 miles, urban food production can reduce the supply chain gap and prevent future crises [47].

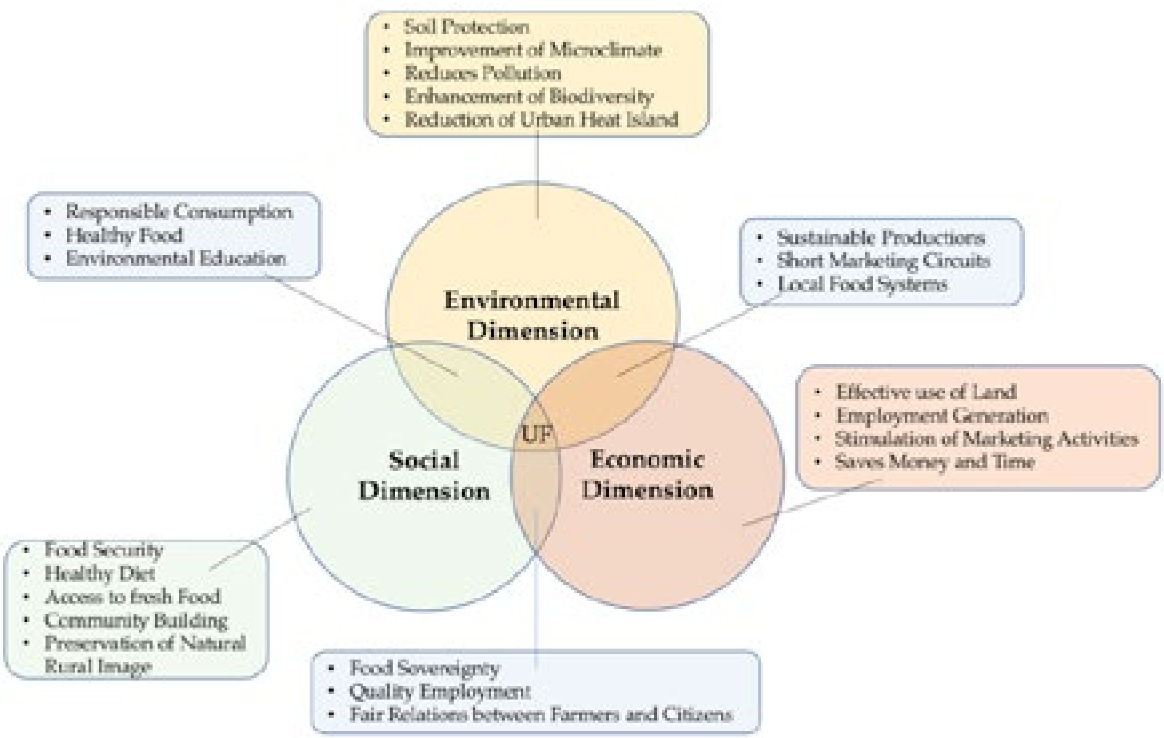

Figure 7. The vertical farm may offer opportunities in the three pillars of sustainability: social, economic and environmental (Improved by authors)

Social Dimension

Urban farming contributes to social development in a variety of ways by providing urban food security, a healthy diet, and access to fresh and healthy food; promoting community building (promoting integration and participation), cultivating personal skills (e.g., horticultural and communication); and preserving the national rural image [3, 5]. Employment possibilities may also be provided by the vertical farm. A team of architects, engineers, scientists, farmers, horticulturists, environmentalists, marketers, and economists is needed to build a vertical farm. Industrial, mechanical, and electrical engineers are required to develop water recycling systems, lighting systems, heating, ventilation and air conditioning (HVAC), seed and plant growth monitoring, and harvesting systems. Building databases and software applications will need the services of computer professionals [5]. As a result, the vertical farm creates new job prospects in fields such as biochemistry and biotechnology, as well as building, maintenance, marketing, engineering, and research and development to improve the technologies involved [48].

Economic Dimension

In terms of economic development, urban farming has the ability to use the land effectively; provide self-supply; generate employment; generate revenue; save time and money (reducing ‘food miles’); stimulate marketing activities, and save time and money [5]. VF may also be able to use rainwater and recycle wastewater (grey or even black water), and Compost from the vertical farm may potentially be burned to generate electricity. Examples include the Plant Vertical Farm in Chicago and the VF plant in the Republic of Korea [49]. The vertical farm’s cutting-edge production technologies minimize the need for potable water. By focusing on the plant’s roots and limiting evaporation, they may be quite effective at irrigating plants [50].

Environmental Dimension

Urban farming provides a wide range of environmental benefits, including soil protection, improved microclimates, pollution reduction (waste and nutrient recycling), biodiversity enhancement, and an increase in environmental consciousness [40]. It can provide a year-round food supply that is unaffected by climate change, seasonality, or unfavorable natural disasters (e.g., hurricane, drought, and flood). Integrated fish farms eliminate waste (especially fish filets) from the environment [47]. Urban Heat Island (UHI) may be reduced, and climate change can be combated with the help of the vertical farm [24]. As a result, less energy is required to cool interior rooms during the summer, which reduces emissions of carbon dioxide. In addition, vegetation minimizes sound reflection. Therefore, the vertical farm may aid in noise absorption. Soil and vegetation may act as a sound insulator [32].

Agro-urbanism is predicated on the premise that urban areas can be repurposed to grow food in three distinct ways: intensively, by constructing vertical farms in skyscrapers using cutting-edge agricultural and construction methods, like Singapore’s Sky Greens; extensively, by constructing farms in underdeveloped or degraded areas that are no taller than the surrounding structures; and dispersedly, based on existing structures and infrastructure that may be used for agricultural applications without the deployment of costly and complex new technology [51]. Multi-scale vertical farming was considered while looking at the application of agro-architecture in three dimensions (intensive, extensive, and dispersed). The chapter’s findings show that vertical farms may operate in a city or a neighbourhood at different sizes based on a city’s demands and financial possibilities.

Table 2. General principle Sustainable benefits of vertical farming (Improved by authors).

NO.	BENEFITS	SOCIAL	ECONOMIC	ENVIRONMENTAL
1.	Reducing the number of miles that food travels (travel distances)	improving air quality has a positive impact on both environmental and human health. Fresher, locally sourced cuisine is served to customers	Reduce the amount of energy, packaging, and fuel needed to move food	Reducing air pollution
2	Reduce water use for food production via the use of high-tech irrigation systems and recycling processes	Providing more people with access to safe drinking water	Cost reduction	Reducing the amount of water that runs off of traditional farms.
3	Organic waste recycling	Improve the quality of food and better health of consumers	Turn waste into a valuable resource	Reduce the amount of waste that must be disposed of in landfills to save the environment.
4	Creating employment opportunity	Involve farmers and their employees in a local community and social network.	Economic benefit to the community	People won't have to travel far to go to work, hence reducing their environmental impact.
5	Reduced fertilizers, pesticides and herbicides	Improve the quality of food and better health of consumers	Cost reduction	Improve the well-being of the environmental
6	Improve productivity	Time may be saved by reducing the amount of work that is repetitive and redundant.	Increase greater yields	Less space needed
7	Protect crops against flooding, drought, and storm damage from overexposure to the sun or other seasonal factors.	Food security improvement	Preventing an economic loss	Reduce environmental damage and agricultural clean-ups after a disaster
8	Product/produce control regardless of the season	Increasing accessibility all year round and meeting the needs of the local community	Provide year-round support for economic activity	Seasonally appropriate products may be made.
9	Usage of renewable energy	Air quality improvement	Cost reduction	Reducing fossil fuel
10	bringing nature into the urban environment	Health improvement, stress reduction, and improved mental health	Create employment in the city	Increase in biodiversity

11	promoting green and high-tech industries	Encourage higher education and the creation of highly-skilled employees	Providing employment opportunities for engineers, biochemists, biotechnologists, construction and maintenance workers, and researchers	minimize environmental damage and increase environmental performance by using "green technology."
12	Reduction of traditional agricultural activities	Improve the health of the citizens	Environmental harm can only be remedied through cost reduction	Natural ecological systems preservation
13	restoring and reusing dilapidated structures	Create chances for people to socialize with one another	Boost the economy	Enhance the atmosphere. Neighbourhoods should be cleaned up of blemishes and stigma.

4. MACRO, MESO, MICRO SCALE OF GARDENING

4.1. Macro Scale: City Vertical Farming

Presently, there are two distinct kinds of urban projects using vertical farming. Firstly, buildings and warehouses from the post-industrial era have been modified, while investments made with design principles are implemented from the start of the process. The structure and technology of planned buildings are created to allow for the development of plants, and the function of the building is already established. Engineering and environmental protection standards must be combined with the economic and utilitarian functions of buildings, but also aesthetics and widely known spatial order concerns must be considered in the design. Transport, storage, and packaging are part of the supply chain for fresh fruits and vegetables in contemporary cities [52]. During each phase, contaminants are created that impact waste generation and public health. Some communities are stepping up to meet the future challenges of an ever-increasing population and the requirement for an adequate food supply. These solutions are being created all over the globe. Examples of such solutions are the Forest City in Malaysia and Sunqiao in China. The whole 31.000 m2 post-industrial neighbourhood in Strasbourg is covered with vertical gardens. Because of this, the development of a contemporary multifunctional area, which will include housing, services and workplaces, is imminent. Using an integrated rainwater system, lush, irrigated gardens will be developed on the terraces of the residences [6].

The forest city, Malaysia, almost four times the size of Central Park in New York, four artificial islands in Singapore are being developed as a joint venture between the Chinese developer Country Garden and Esplanade Danga, a Malaysian property company (99.9 per cent of which is owned by the Sultan of Johor). It will be the most densely inhabited human settlement on the planet, with 700,000 residents. According to the vision plan, large structures would be covered entirely with greenery. In order to achieve the new city's high density, concrete high-rise towers will be used to create residential and office buildings, as well as malls and hotels. However, the negative environmental effect of the investment climate may exceed the advantages of establishing a new economic engine in Malaysia. Shipped-in sand used in construction may irrevocably impact the surrounding marine ecosystem [53].

In Sunqiao (China), Urban farming in the form of skyscrapers began construction on a new housing complex in 2017. According to an initial estimate, more than half (56%) of Shanghai's population consumes leaf vegetables, which do not need special care and can be grown in hydroponic and aquaponic systems. The district visualization shows floating greenhouses, green walls, and vertical façades are shown in the district visualization. Sunqiao's vertical farming system can help sustain the city's food supply chain and govern food distribution inside the city itself. The 100-hectare new housing development is located between Shanghai's international airport and the city's central business district [54].

4.2. Meso Scale: Neighbourhood Vertical Farming

In 2012, Singapore's Sky Greens became the world's first large-scale vertical farm to begin commercial operations. The 3R principle (reduce, reuse, and recycle) is followed in production because of the reuse of waste generated throughout the manufacturing process. Automation and ultra-modern lighting systems are used in subsequent municipal farms, assuring high yields and high-quality goods while minimizing environmental effects. Various farming concepts and economic strategies are being used in vertical farms across the globe.

Aero Farm, one of the biggest, is located in a decrepit New Jersey Hall. Aero Farms (USA), which has a total area of roughly 10,000 square meters, has begun commercial operations in the United States. The vertical farms have been designed so that the cultivation cycle is as short as possible while still ensuring high-quality products with the least negative environmental impact, using a patented aeroponic cultivation system in a completely controlled atmosphere with an ultramodern lighting system. There are 250 varieties of leafy green crops, such as arugula, kale, and spinach, layered 6 meters high on dedicated shelves. LED lights enable photosynthesis to occur (the intensity, length, and spectrum of which are designed to the individual needs of each species). Fresh veggies produced in this manner are sold to local businesses, restaurants, supermarkets, and educational institutions [55].

The Plantagon World Food Building in Linköping, Sweden, is a 16-story skyscraper intended as a vertical agriculture urban farm in urban environments with integrated solutions for energy, excess heat, trash, CO2, and water recycling. The greenhouse's trash will be composted at a nearby biogas facility, where it will provide the plantation with the energy it needs to continue operating. It is estimated that the World Food Building will produce 550 tons of vegetables per year, save 1100 tons of CO2 emissions, and use 13,000,000 gallons of water per year, enough to feed about 5500 people. An indoor farm will occupy a third of the structure, which will feature offices, restaurants, and a market selling vegetables and fruits [51].

The main idea of indoor farming is growing more with less, farming up rather than out [10]. Growing crops indoors was to create a suitable location for the crop that farmers were cultivating. As a result, crops grow better, faster, and without being affected by the weather outside in this controlled environment. The concept dates back to the first century when Romans who grew their vegetables did so in carts to shift them from outside to inside when the weather turned cold [56, 57].

Local vertical farms use a wide range of green architectural solutions, such as green roofs, green walls, and other small-scale projects. In addition, investors from all around the world may purchase micro-farms equipped with the newest technology. Some of them include multi-story systems for cultivating plants in a garden on balconies or rooftop terraces and a Cubic Farming system that is fully insulated from the environment [58, 59].

Gotham Greens, a commercial hydroponic vertical farm in New York City, is one example of a micro- and midi-scale investment in a single green roof. Constructed in 2011, Gotham Greens is a commercial hydroponic rooftop farm that provides food for New York and Chicago residents without pesticides [58].

Two-story structure in Greenpoint, New York, houses Gotham Greens, a 1394 square foot rooftop facility. Irrigation systems for Gotham Greens are based on reusing water, which is part of the city's recycling system and adds to the notion of a closed-loop environment. Innovative technology regulates the flow of water and fertilizer for crops on urban farms. The hydroponic Gotham Greens commercial farm employs modern controlled environment agriculture (CEA) technology to provide a year-round supply of fresh veggies to the local market, regardless of the weather conditions outside [60, 61, 62].

5. CONCLUSION

One of the world's most pressing issues today is the need for food, which has been examined in this research. When it comes to the three pillars of sustainability, environmental, social, and economic, urban farming may be a game-changer. Compared to traditional farming methods, vertical farming offers significant benefits over traditional methods. In the 21st century dilemma, the vertical farm provides an iconic production method and a new architectural type. The dominion of space in the future is also an element of it. Learning how to optimize indoor farms on Earth and ultimately transfer this technology to prospective space colonies is likely the first step in developing Vertical Farms. For a wide range of crops, new high-tech production techniques such as hydroponics, aeroponics, and aquaponics are challenging soil-based agricultural needs. Multi-tracking automated systems, recycling systems, and other greenhouse and supporting technologies will be developed in the future.

Modern cities are impacted by sustainable development and environmental care. In recent years, the idea of a green economy has gained traction. As cities grow, so does the concept of local production. Imports of items that may be produced locally are urgently needed in today's cities, stimulating the local economy and providing new opportunities in urban agriculture. Remote working and the COVID-19 epidemic have impacted the environment and alleviated the strain on cities, which has resulted in a shift in people's lifestyles and a greater appreciation for local goods. Now, the issue is how contemporary cities will be able to adapt to the changing social and environmental needs. Researchers set out to find a method of vertical farming that may help cities cope with the fast rise of their populations while also producing food that would be environmentally friendly. As a result, urban farming is becoming more popular and is now considered a worldwide phenomenon. The associated benefits and reasons for integrating organic architecture green techniques into our built environment will provide a massive collection of appropriate plant information and extensive plant directories for rooftop gardens and vertical greenery systems. Urban farming is not a replacement for conventional farming, but rather a supplement to the alternative agricultural production system, providing a product with precise specifications developed under regulated circumstances in a controlled environment. Depending on the present and evolving demands of city people, this product will evolve. Most cities that rely on food imports and have limited agricultural land are currently working to increase the efficiency of vertical cultivation and plant production methods, as evidenced by the research conducted for this paper. This work is being done at various scales, from city scale to building scale. With the help of urban vertical farms, it is possible to simulate a variety of designs for cities that are continually evolving. Aside from increasing yields and lowering production costs, newly constructed vertical urban farms will also enhance the quality of agricultural goods given to urban people, reducing the environmental damage that urbanization causes.

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