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A Review of Vertical Farming Technology: A Guide for Implementation of Building Integrated Agriculture in Cities

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Abstract. Recently, the application of Vertical Farming into cities has increased. Vertical farming is a cultivating vegetable vertically by new agricultural methods, which combines the design of building and farms all together in a high-rise building inside the cities. This technology needs to be manifest both in the agricultural technique and architectural technology together, however, little has been published on the technology of Vertical Farming. In this study, technology as one of the important factor of Vertical farming is discussed and reviewed by qualitative approach. In the first, identifying existing and future VF projects in Europe, Asia, and America from 2009 to 2016. Then a comprehensive literature reviewed on technologies and techniques that are used in VF projects. The study resources were formed from 62 different sources from 2007 to 2016. The technologies offered can be a guide for implementation development and planning for innovative and farming industries of Vertical Farming in cities. In fact, it can act as a basis for evaluating prospective agriculture and architecture together. The integration of food production into the urban areas have been seen as a connection to the city and its residents. It simultaneously helps to reduce poverty, adds to food safety, and increases contextual sustainability and human well-being.

1. Introduction

"We live vertically, so why can't we farm vertically?"[1].

Due to the limited access to land for farming, there is a need for sustaining farming tasks so as to pave the way for adding to food needs [2]. Many aspects press on food industry and processing such as: growth of population and its growing needs accordingly, reduction of natural sources due to growing cities, earth erosion, different forms of contamination, advent of biofuels, restrictions imposed on food production techniques affected by customers and rule providers which requires better quality, less use of chemicals and many useful environmental attempts 'from farm to fork'[3]. Recently, environmental obsessions have been mixed with rising obsession with health as architecture design is concerned. Therefore, it has led to more interest in providing healthy food and incorporating it in the sustainable development project [4].

The answer to these issues is Vertical Farming (VF). VF has grown as a project which combines the design of building and farms all together in a high-rise building. VF is a system of growing crops in skyscrapers, to maximize the use of land by having a vertical design [2] whereby plants, animals, fungi and other life forms are cultivated for food, fuel, fiber… by artificially stacking them vertically above each other [5,6,7,8,9].Vertical farms are now used in a lot of countries. At present, these farms are largely grown and produce different types of crops inside cities [10,11].

There have been a great many publications on farming in cities and VF. However, little has been published on the technology of VF. So far, there has been no systematic analyses the design of the VF [12]. This research tries to review techniques and technologies that use in VF projects all over the world.

2. Method

In this study, a qualitative approach was chosen, for assessing and analyzing current VF practices. In the first step, identifying existing and future VF projects: related Websites, media and literature research from 2009 to 2017 resulted in a total of identified projects in Europe, Asia, and America. In the next step, a comprehensive literature reviewed based on an analysis of different documents published in accessible international resources on technologies and techniques that are used in VF projects. The study resources were formed from 63 different source types such as journals, conference papers, theses, books as well as standard, a report from Web of Science, Scopus, ProQuest as well as Google Scholar. They consist of 43 journals, 7 theses, 2 Books chapter, 2 conference paper and 9 websites of VF. Most of them are related to recent years from 2007 to 2017. Selected criteria presented in this paper include technology using in VF projects; spatial diversification; farming methods; VF products and activities. In the following section, VF technology will be explained thoroughly. Table 1 presents a review of different technologies of VF with their sources.

Table 1: Review of different technologies of Vertical Farming.

	Vertical Farming Technology	**References**
1	General structure of Vertical Farming	[8][9][11][12][13][14][15][16][17][18][19]
	Material	[13][20][21]
2	Lighting system	[6][8][12][16][18][22][23][24][25]
	Natural lighting (Sun energy) as a lighting system	[13][15][18][24][26]
	Solar cell as a lighting system	[12][26][27][28][29]
	LED system	[7][9][15][22][26][29][30]
3	Water required	
	Water retrieval by means of recycling	[7][8][12][13][15][16][18][22][23][24][25][29][31][32][33][34][35][36]
	Water retrieval by means of dehumidification	[7][8][9][13][15][16][18][24][34][35][36]
4	Renewable energy in vertical farming	[12][15][18][22][24][26][29][37][38][39][40][41][42]
	Replacing Electricity Energy with Solar Energy	[12] [18] [38] [41][42]
5	Farming system	
	Crop selection	[1][23][43][44]
	Hydroponic and Aeroponic	[6][7][8][10][13][15][18][19][23][24][26][29][37][20]
	Aquacultural Sub-system	[8][9][16][33][45]
	Livestock production	[3][9][44]
6	Control Environment System	
	HVAC sub-system	[2][5][9][16][19][24][26][29][33][35][36][37][42][46][47]
	Waste Management Sub-system	[8][9][13][24][29][34][35][48][43]
	Smart devices	[9][11][19][40][42][49][50][51]

3. Vertical Farming Technology

3.1 General Structure of Vertical Farming

The vertical farms differ from one city to another [17]. More general tips on the structure as well as more designs and concepts of VF are explained in the following section. For an instant as to supply 15000 people with food, this high-rise building is designed with these properties: size of the vertical farm: 93 ha (about the size of a block), 37 floors, 25 of which are just for producing crops and 3 for aquaculture. Moreover, 3 floors of the same distribution are for adjusting the environment and 2 located underground are used for keeping the waste. Furthermore, one floor is allocated to the cleansing of growth trays, showing as well as germination. One floor is for the packing and processing of the vegetables or fish. One other floor is for the selling of the products located underground. This makes the overall height of the building 167.5 meters and its length and width equal to 44 meters. The aspect ratio will be 3.81. The building is equipped with a spacious elevator in the middle big enough to space a forklift truck. This helps to transport the harvest down to other floors. Each day, about 217000 water is needed for the system. 14000 of that amount is absorbed and leaves the building with the water waste. The water not absorbed by the vegetables is then circulated again in a system in charge of recycling water. It is processed and sprayed once more and the loop is closed[8].

Also, illustrated by Cikeli and Barlas's design, they mentioned the structure as some floors for example production floor, laboratory floor, carousel floor, system floor, poultry floor, and supermarket [9].

So as to obey a key role in local food production, the ground floor of a vertical farm needs to be a grocery store or a restaurant in which the products are sold to the public. What makes such products unique is their freshness since they are provided for the customers upon being harvested. They are also much cheaper than ordinary crops because the cost does not include that of transportation or storage[13,14,15].

Fig. 1: Interior view of Vertical Farming [9].

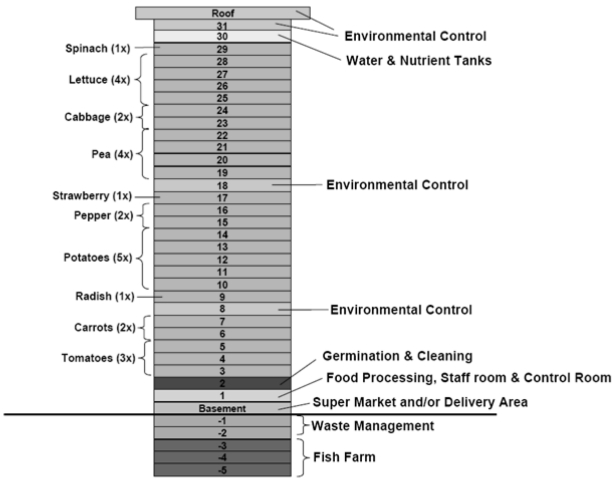

Fig. 2: General Structure of Vertical Farming with its layout. [8]

3.1.1 Material

Usually, the skin façade of the building is made of a self-cleaning and clear material for example ETFE (Ethylene Tetra Fluoro Ethylene). Also, a material with fantastic transparency and the thermal rate are needed to raise the amount of sunlight that arrives the building. ETFE has just 1% of an equal-sized piece of glass weight but permitting for 95% light transmission. Between the ETFE layers have a different pressure, these pressures help the screens close and open to change the sunlight transmission [13]. As a standardized construction material, ETFE has covered a vast surface of ethereal domes in the Eden Project located in the south of England [20,21].

3.2. Lighting

Lighting is a key issue in VF. To manage the production line, whether the vertical farm is planned to be totally using artificial light or both artificial and natural light should be taken into account. The same issues need to be considered in designing the facility [22]. There are two options available: LED (light emitting diode) or HPS (high-pressure sodium) [12,18]. The range of light intensity needed for enhancing the growth of vegetation is contingent on the setting and time, product, heat and CO2 content of the air around plants. Considering all these, the normal range of light intensity utilized is 50-200 mol/m2/s or about 4100-16400 lx including high-pressure sodium lamps. The light required in closed space for vegetation growth is about 18 hours a day. In order to maximize how much light enters (and at the same time minimize how much light needed to be produced), they use light shelves. Every window has got the tallest height up to 3.5 meters which are actually the height of each floor [12, 22].

3.2.1 Natural Lighting

The design of the building is such that absorbs as much light as possible. Especially the roof can be designed so as to get the highest amount of energy from the sun in all seasons in places where the weather is moderate.Other parts of the building can receive sunlight too which is a viable option [15, 18].

In standardized one-floor greenhouses, the main source of energy for lighting is the sun. In a vertical farm, any decrease in the density of stacking inside the building is accompanied by an increase in building cubature. Although natural daylight is the main source of energy received from the outside, there needs to be daylight concentration, direction and distribution strategies conceived so as to use sunlight effectively throughout seasons. The idea of the vertical farm can be applied to many different places and types of weather with divergent amounts of light. Since this concept is quite flexible, it usually leads to modular construction plans and uses diverse ideas in architecture. It also takes advantage of multiple façade modules that integrate ideas that guide lighting. Clearly, sticking solar panels on top of each other has not been suggested by anyone before. Similarly, layers of plants cannot be stacked on top of each other if there is not a reasonable replacement for the light required. When stacked above each other even when the farm has transparent walls and lets the most light in, there is not enough light reaching all layers especially those below. During the day, the amount of light entering many windows of a room might hurt our eyes but this amount is not even part of what a plant needs to grow. Much of the light energy is reflected when touches the glass. So less light can enter to reach plants unless the sun is low enough (particularly when two stacks of plants are inserted in one floor). Even at that time, the light touches plants at a low angle and therefore less light are absorbed in any square inch of the leaf as compared to when the light shines from straight above. Consequently, there needs to be artificial lighting used to supply the energy of vertical farms [26].

In front of that, building angle and shape to follow the sun through the day can control that the wherever the extreme solar gain can be received in the year (see the Fig.3 and Fig.4) [13]. For example, there is a preview of the dynamic construction program of Plantagon in Sweden. This plan was expected to be finished in 2015 and it used a modern helix design which has a globular design the focus of which is one making automatic systems which grow crops until they are harvested. These systems maximize the amount of light absorbed and distributed. The aim of the rotating design of the system is to decrease or remove the need for artificial light supplies [15].

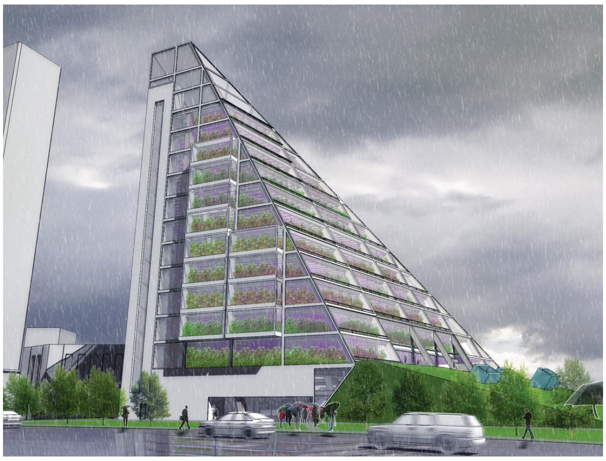

Fig. 3: Vertical farming Tower use the maximum of sunlight [13].

Fig. 4: Conceptual Design of Plantagon greenhouse use the maximum of sunligh [2].

3.2.2 Solar Cell

All operations within the system need to be highly efficient especially the photosynthesis of plants. In order to use the energy of the sun maximally in vertical farms, non-PAR waves (Photo-syntactically active radiation) should be filtered since they are not absorbed by chlorophyll. These waves need to be filtered by selected solar cells and need to be used for producing photovoltaic energy. Recently different semi-transparent cells are made. But fewer attempts have been made to make such cells particularly transparent for photosynthetically active wavelengths [27]. The employing red/purple colors with the highest degree of absorption (535 nm) as the basis of dye-sensitized solar cells can be a useful way to produce selected solar cells [28]. Since in VF the area of the vegetation growth is multiplied by the number of stories, PAR, as obtained from natural sources, is not adequate. In order to cut down on the need for supplemental artificial light, solar energy needs to be gathered by a system of mirrors from the buildings around the city. This would help to raise the outcome of selective photovoltaic generators and also promote PAR in a vertical farm [26].

What was gained from the energy model showed that sufficient energy was obtainable from certain aspects of the site in order to satisfy the needs for energy (light and water both) within one month? The results show that adequate amounts of energy can be gained from solar panels inserted on roofs or the façade of the building where they can absorb sunlight and there are pumping facilities too. The third dimension needed lighting and was quite practical. The eventual three dimensions led to the lack of energy that is there was a need for more panels that the building to hold [12].

3.2.3 LED

As mentioned previously, besides natural light, there is a need for artificial lighting too and one such source can be LEDs (Light Emitting Diodes). LEDs that have a longer life and lowering price are decent choices [7,15,26]. There are many alternatives that can help to provide for night interruption (NI) or Day Extension (DE) but LEDs are increasingly used as a source of light for plants. Among their advantages are a long life, efficiency in energy, the capability of targeting particular light wavelengths to better manage the photoperiod [22]. This can be realized by using LED lamps that consist of several dimmable diodes which have a divergent color spectrum. This type of lamp may be programmed so as to produce a light fit to the requirements of plants. LED technology helps to save energy by adjusting the strength of light as well as its spectrum via a method devised in Chalmers University [22]. Another advantage of LEDs is that they regulate the proportion of red color (R) and far-red (FR) to get the best answers from plants. If this proportion is low, the stem elongation is also increased. This is a shade avoidance technique in which plants are shaded by those surrounding them. The optimal mixture of R/FR as well as red/blue is under investigation right now. But, there is a need for further research about a wide range of ornamental plants. As an instance, just red light is used for lettuce [9]. There was a poor correspondence between high-pressure sodium lamps and the spectrum used by plants during photosynthesis. Not much of the red and blue light plants need is received. But, they receive a lot of infrared light that is detrimental to some products, and also the yellow light that cannot be used very much. Such organizations as NASA in a controlled environment for agriculture space investigated LEDs and found them as the best lamps requiring red and blue to make a good environment for plants to grow. Red light is required for photosynthesis while the blue is for creating an optimal environment for plant morphogenesis. This is all to enable food production in closed contexts [22,26].

Red and blue are the best colors for LEDs. However, the wavelength is the main determinant of efficiency. In other words, any color whose wavelength is longer than blue is more optimal. As pinpointed by Professor Albright, LEDs of these wavelengths were among those initially made and therefore lasted longer and led to more optimal units. Their photosynthesis is more efficient than green and white. Also, if 10-20% bluer is added to red, it creates a more normal shape of the crops. Those crops growing in red only get longer in shape [22,52].

3.3 Water Required

70 percent of the existing fresh water would go for modern farming. Much of this loss is because of the artificial watering of farms [13]. Also, most of the irrigation water gets lost due to evaporation. This evaporation is a natural procedure but there exists a bigger problem which is the water that goes out of farms as run-off which is useless for drinking since is polluted by fertilizers, salts, pesticides and etc [18]. When farms are transferred to indoors, less water is lost due to the above-mentioned reasons and can be used in plant growth instead [7,13,15]. The amount of water needed for hydroponic agriculture was estimated to be one liter for each square foot a day (or 10.71 per square meter) [12]. Contingent on the type of crop, 200-600 liters of water is needed to provide 1 kilogram of dry product. The amount of water supplied is a key productivity limitation so how to manage crops and soil to optimize the use of water and maintaining it inside soil is necessary to make sure of adequate products. There are a number of techniques used in VF to resist the lack of water, which is introduced below.

3.3.1 Water Retrieval by Means of Recycling

If the city water waste is recycled it provides a good source of farm-specific water supply and makes farms self-sustainable [15,31]. Not only can vertical farms use rainwater, but they can also use gray water supply which is a water used only once for example for showers or washing hands, or the water collected from the roof of the buildings. This water may be filtered and be used for watering indoor or outdoor plants [15,32]. The plan is first to funnel the water into a cistern under the earth gathered from a city somewhere located in the center. This water is then planned to be pumped to the top of a tower from which it will fall down and irrigate the crops through gravity force [23]. Water that is processed only once and does not need any further processing to suit drinkability, can be also used for watering plants in farms [33]. If water is recycled this way, there will be no water wasted and also less negative effects will threaten the water table.

3.3.2 Water Retrieval by Means of Dehumidification

Water that is evaporated and gone accordingly may be again gathered and used [13]. Water with all its nutrient content enters a plant through roots. Solutes get absorbed and the rest of water returns to the air through leaves. This water that evaporates is without any pollutants once it leaves the plant. In VF, this clean water that has been evaporated can be used again by dehumidification. There are certain devices to this aim that once installed on each floor can get back this water. This way, a natural way of purifying water has been used. This method helps to collect 220000 m3 of water every year [7, 9,15]. An instance of this is the company Aerofarms that takes advantage of a special irrigation technology. Water and its solutes are directly sprinkled to plant roots in the shape of a mist. This technology made the VF practiced in this company unique nationally and internationally (covering Saudi Arabia and Abu Dhabi). According to experience, this method of farming can use 1.2 timeless amount of water than usual farms to yield the same amount of crops. According to

statistics, even 70% less water can be used through hydroponics than the existing farming techniques while geoponics uses still 70% less than hydroponics [7,13,15].
The water produced this way is drinkable. It can as well be used for watering plants in farms that provide food or can merely be used for drinking [7]. if possible, this can imply a closed loop in using water which creates the possibility of self-dependent cities as far as water supply is concerned and saves a great deal of financial and environmental sources simultaneously [15].

3.4 Renewable Energy in Vertical Farming

Why the current energy needs to be quantified is to specify the amount of energy required to empower a target building (demand) and also whether reusable energy could satisfy the target demands of the building or not (generation) [12]. The vertical farms need the following: lighting and temperature for plants to grow, the energy needed for the technical equipment e.g. conveyors or movement of plants, fans, and ventilators, heat pump used to manipulate the climate, pumps used for diluting nutrients, agitators used to control plants [26].
As a scarce and still growing even, VF originates from an exciting background of renewable technology. In other words, VF was preceded by renewable technologies which emerged long ago as highly transforming. Therefore, these technologies are dominant and there is hardly a way to push them aside. There are many types of socio/economic organizations that follow these technologies. In the case of VF, this has to do with novelties in agriculture and conducting it indoors [37]. For example, one substitute for electricity is Switch-glass. As an instance, each ton of dry switchgrass can produce around two-third of energy a ton of coal produces [53]. A better source of renewable energy as compared to switchgrass is wind. Vertical farms usually use wind turbines. A turbine can produce twice as much electricity as the current energy of vertical farm models [15].

3.4.1 Replacing Electricity Energy with Solar Energy

The energy coming from the sun stands as a proper solution to energy problems [38]. According to the review of research, there are different methods to use solar energy, including the use of solar panels [39], solar walls [40] or trump walls [41]. The sun is the major source of energy over the globe, but its rays raise the temperature of the air and environment. As a result, this source of energy should be controlled if it is expected not to harm the surroundings. One way to cut down on the negative effects of the solar energy is to use vegetation cover as an ecological remedy. Since plants are clean sources, their use has many benefits [42].
Vertical farms usually have unclear roofs equipped with solar panels. There are solar dishes capable of changing 30% of the energy they take into electricity. There also exist pressure sodium lamps which are highly efficient lights in plant growth. They manage to turn 12-22 percent of that electrical energy to light. As a result, efficient solar systems in the past used electric lights which produce 7% less light than they absorb. This differs from a transparent glass-made roof which passes 90% of the light it receives to the plants inside. A solar receptor roof which stands above 10 floors which were formerly used to light up artificial lamps can also provide .7% lighter as provided by a transparent roof. A solar collector installed on roofs is not a decent substitute for transparent roofs, since it is more costly. There was a model devised to specify the number of solar panels required to satisfy energy needs (calculations to be done based on light and water provision estimations). The model then investigated if the building was spacious enough to house the number of PVs needed according to the area of the roof as well as the façade and the target dimensions [12,18].

3.5 Farming System

3.5.1 Crop Selection

Almost any crop can be produced in a vertical farm as far as all the required conditions are provided [1]. The first thing to think about when choosing the crops to grow is considering which plants can be better bred indoors. Because of limitations imposed by height, plants that grow on trees such as bananas, olives, avocados, and nuts are hard to grow inside. But, there is another chance to grow tree crops and that is to grow them in an outer area as much as there is space provided. This way, more than three dozen types of vegetables can be chosen to grow inside the building hydroponically. The most common products now produced in vertical farms are lettuce, leafy greens, herbs, strawberries, and cucumbers. Theoretically speaking, corn and wheat can also be produced along with biofuel crops and plants to be used as herbal medicine [23].

3.5.2 Hydroponic and Aeroponic

Hydroponics is a strategy used in farming which makes no use of soil. Rather, an aquatic solution is given to the roots of the plants. It provides every vital nutrient needed by the plant. These systems development that is now used widely in advanced greenhouses worldwide [6, 10, 18]. As compared to outdoor agriculture, they save a lot of water. Such systems take advantage of gray water, as previously defined [20]. Additionally, Voss in 2013 envisions that the nutrient solution used in these methods do not have any metabolic byproduct of human so there would be no fecal pollution caused by the foods produced [15].

In this system, no soil is used in cultivation and instead, they take advantage of a nutrient solution. The first point about hydroponics is that it supplies physical support and the second issue is that here soil plays the role of a mineral nutrient storage. Once the nutrients of soil are solved in water they are better prepared for absorption by the plant roots. What hydroponics does is either to keep the plant root directly in nutrient solution or within a supportive medium for example sand, gravel, perlite, etc. Therefore, the soil is now redundant for plant growth [6, 15, 18]. It usually uses a cylinder-shape growth system (typically made up of PVC pipes) to hold the plants. It transports a thin layer of solved nutrients to the plant roots which are touching the liquid part of the operation. This technology makes the growth of all types of plants possible using enriched water [6]. Six key forms of the indoor hydroponic system exist for growing crops. These include Nutrient Film Technique (NFT), Wick System, Water Culture, Ebb and Flow (Flood and Drain), Drip Feed System and Aeroponic Systems [19].

Hydroponic greenhouses have become so popular today since they enjoy certain benefits over traditional methods of farming. According to experience, plants that have grown with the help of hydroponics proved to grow faster. They get ripe in a shorter time and yield ten times more crops than a soil-based cultivation. Moreover, they contain more nutrients that crops produced in soil [13,15].

3.6 Aquacultural Sub-system

There is a fish farm inside the VF building which helps to get rid of waste and acts as a source of plant nutrients as well as food production (esp. fish filet). There are certain tanks in which the vegetables are planted. These tanks move slowly with a conveyor system. The old nutrient solution is spread by mixers [9]. This procedure is named aquaponics used in indoor farms. In other words, it uses fish excretions to feed plants as nutrients in a closed water cycle [45, 54]. Similarly, it may use the rain gathered from the building roof and save it under the earth in order to fill flush toilets or fish tanks [33]. A body of research indicated that aquaponics provided very eligible fish farming operations [16]. For example, as Banerjee and Adenauer's design, they use 5 various tank size fitted to the optimal production amount of about 700 fish a day on each floor. It results in totally 341 tons of fish every year as well as 137 tons of food fish fillet. The type of fish bred is tilapia which can be fed many kinds of food. The required water temperature of this kind of fish is appropriate for vertical farms which use LEDs as a source of light. Food is easily changed by tilapia to animal protein and the proportion of food to fish mass is between 1.5 and 2 contingent on the conditions of water and the quality of food. The popularity of tilapia is mostly because of its moderate taste. Bacteria are converted to nitrogen. So, water gets clean and accordingly fish waste is used as fertilizers for plants (Figure 5) [8, 9].

3.7 Livestock Production

Producing livestock on the basis of pasture if incorporated in VF similar to a fish farm has certain social and environmental advantages. It has the benefit of a significant cultural variety. In recent times, the focus of livestock industry of developed countries has been on animal health, environmental matters, food security, and human well-being more than the quality of the manufacturer. There is a need for further investigations to make sure of the responsiveness of the livestock section to the increasing need for animal-based products. They should take care of the negative environmental effects of livestock production to remove global worries about the environment, the quality of food and ethical standards of animal health [3]. Moreover, mention can be made of poultry farming that needs the least space but produces the most amount of meat in kilos based on farming standards (Figure 6) [9].

Fig. 5: Aqualculture in Vertical Farming [9].

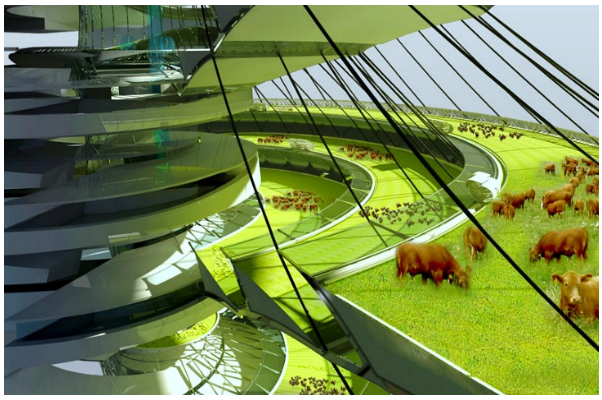

Fig. 6: Livestook production in Vertical Farming [9].

3.8 Control Environment System

3.8.1 HVAC Sub-system

Temperature, air conditioning, and ventilation system are all important in designing of VF. The following privileges of HVAC (Heating, ventilation and air conditioning) system make it suitable for VF: indoor quality of air, saving energy, consistency of moisture [19] and heat in vertical farms provided by the shades of plants. The building which uses the least energy possible is highly efficient in saving energy [42].

Another point considered is heating/cooling of the building which depends on the geographical coordinates of the vertical farm. Using regenerative energy needs to be supported by sensible and sufficient distribution and transfer systems. The following are suggested to be within this procedure: use of geothermal equipment, heat pumps, and solar energy plants for heating or cooling along with the opportunity of using ground water or surface water. Water supported systems translocate thermal loads. To realize regenerative energy, earth canals are used along with air collectors to adjust the required healthy quality of the air outside. There is a constant monitoring of the heating conditions of the inner area in individual sections of a vertical farm. The monitoring is done by control systems that manage the supervision by proper automated intervening tasks. Evaporation of water that happens to the leaves is called transpiration. Still, the plants' stomata are kept open to provide for photosynthesis and moving minerals from roots throughout the leaves and making them cool. Once transpiration water is collected in a closed area it can impede photosynthesis of rice and can result in condensation on plants along with other sorts of surfaces. Condensation of transpired water contributes to viral infections and fungi and therefore adds to the danger of disease occurrence. Moreover, humidity that is not controlled helps to establish algae as well as other unrequired organisms. As a result, dehumanization is crucial in VF. Contrary to many other crops, rice can maintain highly efficient photosynthesis even when humidity is high. Therefore, there is a less need for dehumidification and demand for the related energy. There are three techniques for dehumidification:

1. Natural ventilation (either wind-based or stack-based) along with forced ventilation (using fans) are the most prevalent ways of dehumidifying in business-based greenhouses. Ventilation helps to substitute the warm or very humid air in a greenhouse with cooler and drier one. In case there is no

need for cooling, energy will be required for reheating the new air. In addition, ventilation is not capable of transferring the moisture from indoors when the air existing outside is more humid. However, in moderate areas, it remains to be the most economically optimal method of dehumidification in traditional greenhouses [46].

2. The desiccant is used in the hygroscopic method, for example, aqueous chloride solutions of calcium and lithium for removing water from the air. This method can be truly efficient particularly if it is mixed with air temperature conditioning [47]. With regard to the main energy, there are many privileges as compared to the systems based on cold vapor refrigeration compressor. Rather than exegetic quality electricity, use can be made of low temperature in conditioning outside air. So, this method causes a lowering of costs involved in operations.

3. One of the three methods of dehumidification is condensation which is regarded as the most applicable to indoor crop production. In traditional greenhouses, transparent glass is used as a natural dehumidifier. Once insulation was developed to cover cold surfaces, it was used for condensation. It is costly to use mechanisms that apply to cold surfaces depending on standard climate conditioning systems [46]. Particularly in hot weather, incorporation of different cold sources can be beneficial and include geothermal, lakes, wells, basement aquifers as well as water tanks [26].

3.8.2 Waste Management Sub-system

The yearly bio-waste from the plant cultivation rooms is calculated to be approximately 2443 metric tons. In aquacultural systems, the same figure is estimated to be approximately 517 tons. Assume that each ton of the plant-produced waste is fed to tilapia every day, then the rest is about 7.11 tons a day as an average. In growing eatable biomass, vertical farms produce bio-waste in their by-product (for example leaves, stems, fibrous roots, fruits or vegetables that are damaged) as well as those from an aquaculture system. As a vertical farm is expected to work in a closed loop, the waste is supposed to turn into beneficial sources for instance liquid fertilizer or biofuel. During a nutrient extraction procedure, wastewater is recycled and is pumped in pipes full of volcanic rock parts. In designing vertical farms, there must be two floors for handling the waste [8].

The instance of 'SlurryCarb' machine can be given as an alternative power system. The temperature in this instrument compresses the waste which is in the shape of the slurry. Accordingly, carbon and water-based constituents get disintegrated. Water and solid segments are taken out by the machine and dispatched to a power generator. Inside the steam turbines, the carbon-like slurry is burned so as to provide electricity. The turbine works with the high pressure of the steam coming from hot water. Some chemicals which kill bacteria are used to process black water which is also known as stabilized water emitting from the system. It is then converted to humus once it passes the drying machine. Bioremediation is used to filter the water which is released. Such bioremediations include cockle shell, bamboo and water plants. The process goes on until it becomes appropriate for farming [9].

Moreover, what obsessed Gordon Graff who worked for an architecture in Toronto was the energy needed for the artificial lightening of vertical farms. Graff devised what was known as Skyfarm. He predicted that his 59-floor project was capable of providing enough food for 50000 families. However, providing the light for such a building needed 82 million kilowatt hours of energy annually. This amount of electricity is used by 8000 North American families. According to Graff, half of this energy can be reused if the methane product of the farm's waste is burnt. According to the conversion rate of a kilogram per kilowatt hour, 45000 tons of wet waste need to be produced every year in Skyfarm to meet half of the energy needs via recycling. The rest originates from the methane produced in other municipal wastes [53].

3.8.3 Smart Devices

As a totally automated operation, VF makes a great use of sensors and actuators (known as smart equipment) that also interact with other systems with no human interference. In order to realize VF as a technology, there needs to be a comprehensive calculating system which is constantly aware of the environment and helps to generate proper information and services [9, 11]. There is a database which covers every information about the crops and the probable diseases. Even in conditions where the crops grow inside buildings, there is a need for outdoor weather when the ventilation system is taken into account. Information about the weather is gained from weather forecast in real time and based on this information appropriate decisions can be made. Information about the context is required to make the right decisions about selecting the controller [50]. Knowing about the amounts of crops to be produced as well as probable diseases significantly affect the creation of a healthy environment for growing food preventing diseases. An integration of control agent with the required knowledge about the system helps to make the best supportive decisions possible [19, 49]. The main ideas are categorized as context, devices, service, environment, network, location and user [49].

4. Discussion

Throughout this review, VF has been identified as having excessive potential, but also many constraints and weaknesses. In order to better implement VF, it is important to consider all the limitations and potentials. The following three points have been identified which is more discussed in the literature and which therefore need further thinking.

1. Globally speaking, 40% of the whole energy is used up in building construction. To this aim, architects and designers should be presented with a set of sustainability criteria for the whole cycle of creating sustainable buildings. These are combined with designs characterized by optimal energy consumption that takes advantage of advanced technologies so as to lessen the needs for energy and use in terms of heating/cooling services, electricity and so on [55]. Considering the influence of buildings on the reduction of energy consumption which negatively affects the environment, a number of strategies exist such as: 'reduced energy needs', 'increased energy efficiency' as well as 'passive design techniques applied'. These main strategies further imply: cutting down on the use of energy sources, using the sources again, using recycled materials, protecting natural reservoir, ridding of toxic materials, heading to economic matters and enhancing quality. These all are suggested for conceiving sustainable construction. At the same time, we can infer variables are involved in sustainable construction such as enhancing the usability and taking into account financial matters [33, 55]. In order to work optimally, other systems can be also used in vertical farms. They include aerodynamic ventilation, thermal mass storage and rain collection [2, 33].

2. In the matter of agricultural technology view of VF, these attempts need to cause secure and good-quality food or other products of farms.It can act as the criterion to select acceptable tasks in each production phase which are sustainable both environmentally and socially. However, it is demanding to incorporate them in a framework which aims to strengthen farming and fulfill nutrition and energy requirements. Growing crops with such instruments as marker-assisted selecting tools as well as genetic engineering can be influential indeed as they pave the way for providing new biofuel products. The way to reduce this pressure is to make optimally sustainable farming attempts which benefit from harmony and homogeneity all along the way. Therefore, reusable sources of energy can be used safely and with no damage to the environment. There is a need for investigations to delve into the interrelations of these constituents and to be convinced of gaining the most and the best outcomes, the best-quality technologies are to be used in order to take care of the environment and cut down on waste and at the same time guarantee the quality and safety of foods. Many links should, therefore, be created among multiple phases of food production and processing. The existing gap among agronomic attempts and between various fields of research need to be filled so that industrial, collective thinking is created and the effect of diverse technologies, attempts and materials are strengthened on productivity. It also better characterizes sustainability at local and global levels. Sustainable farming is not a brand new concept since there currently are quite a lot of attempts that try sustainability. Producing food can be added to for 4 to 30 times as much as horizontal agriculture by employing advanced technology in aeroponic and

aquaponic systems. The volume of crops is also increased since each acre of hydroponics equals about nine acres of farm land [2].

3. As a reassuring idea, VF integrates contextual matters and the economical. It emphasizes the downsides of present farming and tries to solve problems according to prospective social status. Nevertheless, there is a chance for development in any new concept. One such development is technological. This can be realized in vertical farms. As concerns VF, these sustainable agricultural methods with sustainable building method can be applied to VF model to pave the way for urban sustainable farming. Fig 7 indicates how VF can play a role in forming sustainability of city areas.

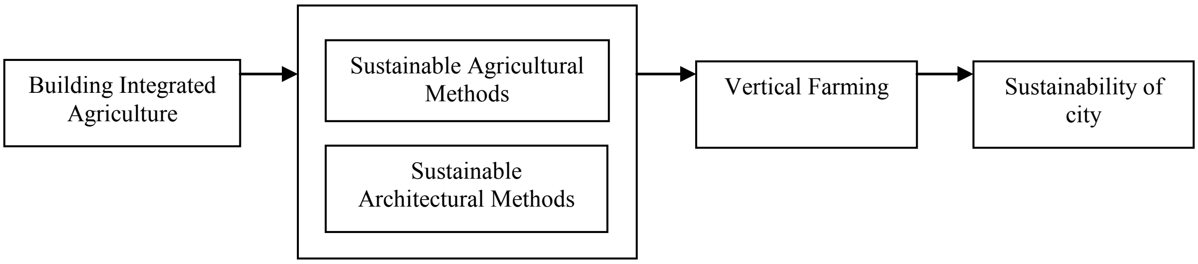

Fig. 7: The role of VF technology to the sustainability of an urban area.

5. Conclusion

Agriculture is one of the activities that play the main role in supporting a human in the world. However, drinking water is already in shortage stage, but, most of the available freshwater, is already using for agriculture. More than 20 percent of the fossil fuels annually is using for agriculture in industrialized countries. Farming has become more fund centralized during the last years. Developing the high-tech farming systems are the results of the energy sources and new methods of farming [56]. Moreover, overpopulation of cities needs new agricultural methods so as to bring conventional farming inside cities. A single technological strategy cannot be a panacea to the ever-growing food production system. Instead, there is a need for a mixture of multiple techniques to guide us towards the 21-century green revolution.

Vertical farming is one of the greatest interesting examples of somewhat new that may contribute to these answers. Others have mentioned to this occurrence as controlled environment agriculture or agriculture integrated building. Also have basically involved it as technical elements within the superior phenomenon of urban or local agriculture with different food production. Vertical Farming has the potential way for sustainable progress to produce food or related services in urban areas. The goals and future vision have been planned with the purpose of generating sustainable cities around the world. To sum it up, to create a city context where most of human food needs are met by self-production and recycling and reusing drinkable water would not be far-fetched since the required technologies are already availed. Where there is strong enough motivation and adequate social pressure, prospective eco-city can be actualized soon enough.

The recent traditional farming approaches due to a great imbalance in the environment. In the other hand, the recent environmental approach caused by concentrated traditional farming approaches that contribute to the ecological problem has been overviewed. Agriculture it still plays a very significant role in many cities. It causes thousands of acres of forest land to be plowed up sacrificing thousands of acres of land. Endmost, it appears that the concept of the vertical farm in the city center of urban areas could solve a lot of real issues related to food production and environmental degradation. Then no harvests would fail by severe weather phenomenon like droughts, floods, and hurricanes, etc. Hence, the vertical farming making of a sustainable city environment that encourages the people to live there for the safe and healthy environment, cleaner air, safe drinking water, safe usage of public liquid waste, new employment chances, and less abandoned lots and constructions. Vertical farming has the benefit of a seasonally wet and warm weather. They can easily minimise cooling and heating water, use of indoor temperature and artificial light and also have a plentiful amount of natural resources such as long hours of sunlight and enough water from daily rain to cultivate.

As a conclusion, the number of technologies provided for decreasing the agricultural effect on the earth as well as oceans is restricted although it helps to sustain the increasing human population. From our perspective, VF is among the few novel paths to fully delve into the following 10 to 20 years particularly if we really aim to live in a balance with other living organisms and not to threaten their life nor ours.

Optimally, VF is required to be: a. cheap and affordable b. resistant and securely operable c. not requiring financial subsidies or external support. In case these conditions are met in a dynamic, all-inclusive research programs, farming in cities can supply many foods for 60% of the population who reside in cities up until 2030. VF has the potential for success in proper conditions. It simultaneously helps to reduce poverty, adds to food safety, and increases contextual sustainability and human well-being.

References

[1] P. Platt, "Vertical Farming: An Interview with Dickson Despommier," *Gastronomica*, vol. 7, no. 2, pp. 80–87, 2007.

[2] L. Ahlström and M. Zahra, "Integrating a Greenhouse in an Urban Area," (Unpublished Master's Thesis).Chalmers University of Technology,Göteborg, Sweden., 2011.

[3] R. Albajes, C. Cantero-Martínez, T. Capell, P. Christou, A. Farre, J. Galceran, F. López-Gatius, S. Marin, O. Martín-Belloso, M.-J. Motilva, C. Nogareda, J. Peman, J. Puy, J. Recasens, I. Romagosa, M.-P. Romero, V. Sanchis, R. Savin, G. A. Slafer, R. Soliva-Fortuny, I. Viñas, and J. Voltas, "Building bridges: an integrated strategy for sustainable food production throughout the value chain," *Mol. Breed.*, vol. 32, no. 4, pp. 743–770, Dec. 2013.

[4] S. C. M. Hui, "Green roof urban farming for buildings in high-density urban cities," in *World Green Roof Conference*, 2011, no. 18–21 March, pp. 1–9.

[5] T. Caplow, "Building integrated agriculture: Philosophy and practice," *Urban Futur.*, vol. 2030, pp. 54–58, 2009.

[6] D. Despommier, *Encyclopedia of Food and Agricultural Ethics (Vertical Farms in Horticulture)*. Dordrecht: Springer Netherlands, 2014.

[7] D. Despommier, *The vertical farm: feeding the world in the 21st century*. Macmillan, 2010.

[8] C. Banerjee and L. Adenaeuer, "Up, Up and Away! The Economics of Vertical Farming," *J. Agric. Stud.*, vol. 2, no. 1, p. 40, Jan. 2014.

[9] M. Cicekli and N. T. Barlas, "Transformation of today greenhouses into high technology vertical farming systems for metropolitan regions," *J. Environ. Prot. Ecol.*, vol. 15, no. 4, pp. 1779–1785, 2014.

[10] D. Despommier, "Farming up the city: The rise of urban vertical farms," *Trends Biotechnol.*, vol. 31, no. 7, pp. 388–389, 2013.

[11] S. Sivamani, N. Bae, and Y. Cho, "A Smart Service Model Based on Ubiquitous Sensor Networks Using Vertical Farm Ontology," *Int. J. Distrib. Sens. Networks*, vol. 9, no. 12, p. 161495, Dec. 2013.

[12] M. Al-Chalabi, "Vertical farming: Skyscraper sustainability?," *Sustain. Cities Soc.*, vol. 18, pp. 74–77, Nov. 2015.

[13] J. Ellis, "Agricultural Transparency: Reconnecting Urban Centres With Food Production," (Unpublished Master's Thesis).Dalhousie University,Halifax, Nova Scotia, 2012.

[14] S. S. Grewal and P. S. Grewal, "Can cities become self-reliant in food?," *Cities*, vol. 29, no. 1, pp. 1–11, 2012.

[15] P. M. Voss, "Vertical Farming: An agricultural revolution on the rise," *Halmstad*, pp. 1–21, 2013.

[16] S. Thomaier, K. Specht, D. Henckel, A. Dierich, R. Siebert, U. B. Freisinger, and M. Sawicka, "Farming in and on urban buildings: Present practice and specific novelties of Zero-Acreage Farming (ZFarming)," *Renew. Agric. Food Syst.*, vol. 30, no. 1, pp. 43–54, Feb. 2015.

[17] C. Abel, "The vertical garden city: towards a new urban topology," *CTBUH J.*, no. 2, pp. 20–30, 2010.

[18] D. Despommier, "The rise of vertical farms," *Sci. Am.*, vol. 301, no. 5, pp. 80–87, 2009.

[19] X. Liu, "Design of a Modified Shipping Container as Modular Unit for the Minimally Structured & Modular Vertical Farm (MSM-VF)," (Master's Thesis).Available from ProQuest Dissertations and Theses database. (UMI No.1573000)., 2014.

[20] D. Despommier, "The vertical farm: controlled environment agriculture carried out in tall buildings would create greater food safety and security for large urban populations," *J. für Verbraucherschutz und Leb.*, vol. 6, no. 2, pp. 233–236, Jun. 2011.

[21] J. A. Glaser, "Green chemistry with nanocatalysts," *Clean Technol. Environ. Policy*, vol. 14, no. 4, pp. 513–520, Aug. 2012.

[22] V. M. Perez, "Study of The Sustainability Issue of Food Production Using Vertical Farm Methods in An Urban Environment Within The State of Indiana," (Master's Thesis).Available from ProQuest Dissertations and Theses database. (UMI No.1565090)., 2014.

[23] D. S. Ankri, "Urban Kibbutz: Integrating Vertical Farming and Collective Living in Jerusalem, Israel.," (Master's Thesis).Available from ProQuest Dissertations and Theses database. (UMI No.1482437), 2010.

[24] K. Specht, R. Siebert, I. Hartmann, U. B. Freisinger, M. Sawicka, A. Werner, S. Thomaier, D. Henckel, H. Walk, and A. Dierich, "Urban agriculture of the future: an overview of sustainability aspects of food production in and on buildings," *Agric. Human Values*, vol. 31, no. 1, pp. 33–51, Mar. 2014.

[25] G. Vogel, "Upending the traditional farm," *Science (80-.).*, vol. 319, no. 5864, pp. 752–753, Feb. 2008.

[26] J. Germer, J. Sauerborn, F. Asch, J. de Boer, J. Schreiber, G. Weber, and J. Müller, "Skyfarming an ecological innovation to enhance global food security," *J. für Verbraucherschutz und Leb.*, vol. 6, no. 2, pp. 237–251, Jun. 2011.

[27] G. Overton, "Harnessing sunlight moves beyond conventional photovoltaics," *Laser Focus world*, vol. 46, no. 6, pp. 59–63, 2010.

[28] D. Zhang, S. M. Lanier, J. A. Downing, J. L. Avent, J. Lum, and J. L. McHale, "Betalain pigments for dye-sensitized solar cells," *J. Photochem. Photobiol. A Chem.*, vol. 195, no. 1, pp. 72–80, 2008.

[29] C. Eigenbrod and N. Gruda, "Urban vegetable for food security in cities. A review," *Agron. Sustain. Dev.*, vol. 35, no. 2, pp. 483–498, Apr. 2015.

[30] R. C. Morrow, "LED lighting in horticulture," in *HortScience*, 2008, vol. 43, no. 7, pp. 1947–1950.

[31] F. Kalantari, O. Mohd Tahir, N. Golkar, and S. Kalantari, "Restoration of Tajan River through ecological design approach," *ALAM CIPTA, Int. J. Sustain. Trop. Des. Res. Pract.*, vol. 8, no. spec. 1, pp. 52–59, 2015.

[32] F. Kalantari, O. Mohd Tahir, N. Golkar, and N. A. Ismail, "Socio-Cultural Development of Tajan Riverfront, Sari, Iran," *Adv. Environ. Biol.*, vol. 9, no. 27, pp. 386–392, 2015.

[33] S. Afrin, "Green Skyscraper : Integration of Plants into Skyscrapers," (Master's Thesis).Kungliga Tekniska högskolan (KTH), Stockholm, 2009.

[34] F. H. Besthorn, "Vertical Farming: Social Work and Sustainable Urban Agriculture in an Age of Global Food Crises," *Aust. Soc. Work*, vol. 66, no. 2, pp. 187–203, Jun. 2013.

[35] E. Ellingsen and D. Despommier, "The Vertical Farm - The origin of a 21st century Architectural Typology," *CTBUH J.*, no. 3, pp. 26–34, 2008.

[36] J. Sauerborn, "Skyfarming: an alternative to horizontal croplands.," *Resour. Eng. Technol. a Sustain. World*, vol. 18, no. 1, p. 19, 2011.

[37] A. Miller, "Scaling Up or Selling Out? A Critical Appraisal of Current Development in Vertical Farming," (Unpublished Master's Thesis).Carleton University,ottawa, ontario,Canada., 2011.

[38] M. Z. A. A. Kadir and Y. Rafeeu, "A review on factors for maximizing solar fraction under wet climate environment in Malaysia," *Renew. Sustain. Energy Rev.*, vol. 14, no. 8, pp. 2243–2248, 2010.

[39] B. Parida, S. Iniyan, and R. Goic, "A review of solar photovoltaic technologies," *Renew. Sustain. Energy Rev.*, vol. 15, no. 3, pp. 1625–1636, 2011.

[40] O. Saadatian, C. H. Lim, K. Sopian, and E. Salleh, "A state of the art review of solar walls: Concepts and applications," *J. Build. Phys.*, vol. 37, pp. 55–79, 2013.

[41] O. Saadatian, K. Sopian, C. H. Lim, N. Asim, and M. Y. Sulaiman, "Trombe walls: A review of opportunities and challenges in research and development," *Renew. Sustain. Energy Rev.*, vol. 16, no. 8, pp. 6340–6351, 2012.

[42] T. Safikhani, A. M. Abdullah, D. R. Ossen, and M. Baharvand, "A review of energy characteristic of vertical greenery systems," *Renew. Sustain. Energy Rev.*, vol. 40, pp. 450–462, Dec. 2014.

[43] D. La Rosa, L. Barbarossa, R. Privitera, and F. Martinico, "Agriculture and the city: A method for sustainable planning of new forms of agriculture in urban contexts," *Land use policy*, vol. 41, pp. 290–303, Nov. 2014.

[44] C. G. Wagner, "Vertical Farming: An Idea Whose Time Has Come Back," *Futurist*, vol. 44, no. 2, pp. 68–69, 2010.

[45] A. Graber, A. Schoenborn, and R. Junge, "Closing water, nutrient and energy cycles within cities by urban farms for fish and vegetable Production," *Int. Water Assoc. Newsl.*, vol. 37, pp. 37–41, 2011.

[46] J. B. Campen, G. P. A. Bot, and H. F. De Zwart, "Dehumidification of Greenhouses at Northern Latitudes," *Biosyst. Eng.*, vol. 86, no. 4, pp. 487–493, 2003.

[47] S. Jain and P. K. Bansal, "Performance analysis of liquid desiccant dehumidification systems," *Int. J. Refrig.*, vol. 30, no. 5, pp. 861–872, 2007.

[48] M. Dubbeling, "Integrating urban agriculture in the urban landscape," *Urban Agric. Mag.*, no. 25, pp. 43–46, 2011.

[49] S. Sivamani, N.-J. Bae, C.-S. Shin, J.-W. Park, and Y.-Y. Cho, "An OWL-Based Ontology Model for Intelligent Service in Vertical Farm," in *Lecture Notes in Electrical Engineering*, vol. 279, 2014, pp. 327–332.

[50] S. Sivamani, K. Kwak, and Y. Cho, "A Rule Based Event-Driven Control Service for Vertical Farm System," in *In Future Information Technology*, vol. 276, J. J. Park, I. Stojmenovic, M. Choi, and F. Xhafa, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2014, pp. 915–920.

[51] H.-G. Kim, D.-H. Park, O. R. Chowdhury, C.-S. Shin, Y.-Y. Cho, and J.-W. Park, "Location-Based Intelligent Robot Management Service Model Using RGPSi with AoA for Vertical Farm," in *Lecture Notes in Electrical Engineering*, vol. 279, 2014, pp. 309–314.

[52] S. W. Hogewoning, G. Trouwborst, H. Maljaars, H. Poorter, W. van Ieperen, and J. Harbinson, "Blue light dose–responses of leaf photosynthesis, morphology, and chemical composition of Cucumis sativus grown under different combinations of red and blue light," *J. Exp. Bot.*, vol. 61, no. 11, pp. 3107–3117, 2010.

[53] B. Michael, "Energy and Vertical Farms," 2010. [Online]. Available: https://energyfarms.wordpress.com/2010/12/02/energy-and-vertical-farms/. [Accessed: 17-Sep-2016].

[54] K. Specht, R. Siebert, S. Thomaier, U. Freisinger, M. Sawicka, A. Dierich, D. Henckel, and M. Busse, "Zero-Acreage Farming in the City of Berlin: An Aggregated Stakeholder Perspective on Potential Benefits and Challenges," *Sustainability*, vol. 7, no. 4, pp. 4511–4523, Apr. 2015.

[55] A. Ghaffarianhoseini, N. D. Dahlan, U. Berardi, A. Ghaffarianhoseini, N. Makaremi, and M. Ghaffarianhoseini, "Sustainable energy performances of green buildings: A review of current theories, implementations and challenges," *Renewable and Sustainable Energy Reviews*, vol. 25. Elsevier, pp. 1–17, 2013.

[56] F. Kalantari, O. Mohd Tahir, R. Akbari Joni, and E. Fatemi, "Opportunities and Challenges in Sustainability of Vertical Farming: A Review," *J. Landsc. Ecol.*, vol. 2, no. 2, Jan. 2017.