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NEW CONCEPTS FOR CITIES CITIES THAT PRODUCE - FOOD FOR BILLIONS (TECHNOLOGICAL, ECONOMIC, SOCIAL, AND LEGAL ASPECTS OF VERTICAL FARMING)

Abstract: *Vertical Farming has been a primary topic of debate in the field of architecture, engineering, and agriculture. There has been a lot of skepticism and disbelief in the effectiveness and efficiency of vertical farms in cities. Many critics believe it is not affordable or realizable and the aim of this paper is to disprove these critics by presenting three examples that prove vertical farms are the future, and the dependence for billions of people; as great migration to cites are occurring all over the world. These examples will vary from the large scale farm buildings to small scale family farms: Singapore Sky Greens – Greens for Five Million; 1 Million Pounds/3 Acres ; Family Farm in the Big City. The paper will include technological, economic, social, and legal aspects of vertical farming.*
Keywords: *Cities, Vertical farms, Architecture, Technology, Engineering, Urban Agriculture*

1. INTRODUCTION

Ideas of vertical farming have been documented throughout history, but one of the earliest drawings of a tall building that cultivates food for the purposes of eating was published as early as Life Magazine 1909. The drawings are characteristic with vertically stacked homesteads set in a farming landscape. After that first publishing, the early 20th century had a few architectural proposals that inspire future Vertical Farm projects, including; Le Corbusier's Immeubles-Villas (1922) and SITE's High-rise of homes (1972). Following these theoretical projects researchers on the topic suggest that vertical farming was not a well pursued idea. [1]

One historically noted reason why vertical farms are still considered an un-pursuable ideal are the critics who argue that costs and consumption of additional energy needed for heating and lighting of vertical farms would outweigh the benefits of near-consumption localities of such farming ventures. Pro farm critics, on the other hand, argue that allowing traditional outdoor farms to revert to a natural state and reducing the energy costs needed to transport foods to consumers, vertical farms could significantly ease climate change produced by excess atmospheric carbon. [2]

Although architectural precedents remain valuable, the technological precedents that make vertical farming possible can be traced back to horticultural history through the development of greenhouse and hydroponic technology. Early building types or Hydroponicums where developed, integrating hydroponic technology into building systems.

These horticultural building systems evolved from greenhouse technology, and paved the way for the modern concept of the vertical farm.

One of latest version, of these very idea, is Dickson Despommier's "The Vertical Farm". Despommier, a environmental and microbiology professor at Columbia University, modernized the idea of vertical farming in 1999 with graduate students in a medical ecology class. Despommier had originally challenged his class to feed the population of Manhattan (about 2,000,000 people) using 13 acres of usable rooftop gardens. The class calculated that, by using rooftop gardening methods, only 2 percent would be fed. Unsatisfied with the results, Despommier made an off-the-cuff suggestion of growing plants indoors, vertically. The idea sparked the students' interests and gained major momentum. By 2001 the first outline of a vertical farm was introduced and today scientists, architects, and investors worldwide are working together to make the concept of vertical farming a reality. [3] In an interview with Miller-McCune.com, Despommier described how vertical farms would function:

"Each floor will have its own watering and nutrient monitoring systems. There will be sensors for every single plant that tracks how much and what kinds of nutrients the plant has absorbed. You'll even have systems to monitor plant diseases by employing DNA chip technologies that detect the presence of plant pathogens by simply sampling the air and using snippets from various viral and bacterial infections. It's very easy to do." [4]

Later in this paper will also be discussed about technology needed for vertical farming. Vertical Farming has been a primary topic of debate in the field of architecture and agriculture. There has been a lot of skepticism and disbelief in the effectiveness and efficiency of vertical farm architecture. Many critics believe it is not affordable or realizable and in this paper we want to start of this thesis by disproving these critics and presenting two examples that prove vertical farming is the future and will be the dependence for billions of people, as the great migration to cites is occurring all over the world as we speak. These examples will vary from the large scale to small scale family farms.

2. EXAMPLES

2.1 Singapore Sky Greens – Greens for Five Million (Large Scale)

With land prices at a premium in Singapore, the challenge of feeding a growing population is pushing the concept of urban farming to new heights. Very close to the city center exists a farm like no other. A five story glass boxes are line up in rows, with walkways in between. There are more buildings like this going up, as their construction is in progress. These glass box buildings contain the vertical farms. Though only five stories, they are super-efficient and are producing greens for 5 million residents.

This vertical farm in Singapore uses a system of rotating vertical planters and also relies on an aquaponic system (Which will be explained in the continuation of the paper). This method uses a moving system of racks that use a small amount of power. With the use of a water wheel, the system uses the same amount of energy it takes to power one light bulb. There is a reuse of water so that the whole system saves water compared to traditional techniques. This is not only a sustainable solution, but it drastically cuts down on pollution and energy consumption. Since the grown food is quite local, there are minimal transportation costs, which further benefit the environment.

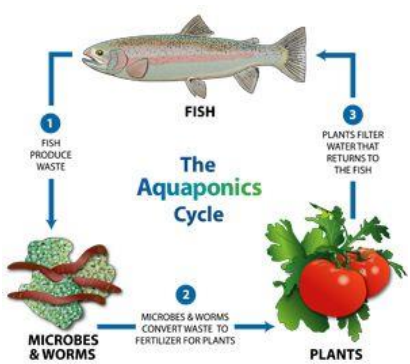
Slika 1

But the greatest benefit is that all the food is organic. Being grown in an aquaponic system means there is no dirt, just nutritious water, and the glass enclosure protects from the pesticides. All the plants also get the same amount of sun light as the system rotates rack like a conveyor belt. Therefore, the plants could also easily be monitored and harvested. [5][6]

2.2 Million Pounds on 3 Acres (Small Scale)

Will Allen is an urban farmer. He has taken vertical farming and aquaponic systems and perfected them. Allen little green house farm grows food all year round and he manages to produce one million pounds of food on three acres. This system does not just grow plants, but is a closed loop system of farming where he produces over 10,000 fish. (The diagram in the bottom shows the way the closed loop system works.)

Utilizing the vertical space and a single aquaponic pump, Allen has devised a system that takes water from the fish tanks bellow the crops and pumps it through the aquaponic tubes in which the plants grow. In this particular system, the plants don't rotate on racks, but the plant variety is different so that each plant is getting the appropriate amount of sun light. The water pumped is filled with microbes and worms that are eating the fish waste, which feeds and fertilizes the plants. The returning water in the tanks is filtered by the plants so that clean and aerated water returns to the fish. This system is similar to natural system, though what happens in nature is much more complex.



Slika 2

Allen's farm depends on and runs on the large amounts of compost they make from food waste, taken from the city. There are about 400 yards of worm infested compost that in turn heats the greenhouse and so no additional heat is needed for the plants to grow. The compost also becomes fertilizer for plants grown in the traditional way at the farm. "It's a great thing to divert this garbage from the landfill and provide cheap food for the community," says Allen, who is expanding his 3 acres, now that he has the system as efficient as possible. [7]

3. DEFINING VERTICAL FARMING

There are many reasons this new technique of farming is gaining exposure in the realm of sustainability. Its largest claim to being 'green' is its ability to be located and constructed in densely populated areas, far from traditional outdoor farms, where the cost and environmental damage of transporting produce is significantly decreased. So, as we explored the advantages and disadvantages of vertical farming, starting with historical precedents that lead to today's theories and practices and when we have established, at various scales, that urban and vertical farming are a solution, lets understand what it actually is. Vertical farming is a proposed agricultural technique involving large-scale agriculture in urban areas. This technique relies on greenhouse technology and greenhouse methods. Vertical farms focus on growing vegetables, herbs, fruits, fish and egg laying chickens. If successfully implemented, these 'farm scrapers' could offer urban renewal, sustainable production of food, and the eventual repair of ecosystems that have been sacrificed for horizontal farming.

4. TECHNOLOGY OF VERTICAL FARMING

Vertical farming relies on the use of various physical methods to become effective. Combining these technologies and devices in an integrated whole is necessary to make Vertical Farming a reality. Various methods are proposed and under research. The most common technologies suggested are: [8]

- The **greenhouse** - a structural building with different types of covering materials, such as a glass or plastic roof; it heats up because incoming visible solar radiation from the sun is absorbed by plants, soil, and other things inside the building. Air

warmed by the heat from hot interior surfaces is retained in the building by the roof and wall.

- **Aeroponics** - the process of growing plants in an air or mist environment without the use of soil or aggregate medium
- **Hydroponics** - uses water as a growing medium and all the essential minerals to sustain plant growth are transferred trough the water.
- The **Folkewall** - a construct-ion with the dual functions of growing plants and purifying waste water. It was designed by Folke Günther in Sweden. The basic design is a wall of hollow concrete slabs with compartments opening on one or both sides of the wall.
- **Compost** - is organic matter that has been decomposed and recycled as a fertilizer and soil amendment. Compost is a key ingredient in organic farming. At the simplest level, the process of composting simply requires making a heap of wetted organic matter (leaves, "green" food waste) and waiting for the materials to break down into humus after a period of weeks or months. Modern, methodical composting is a multi-step, closely monitored process with measured inputs of water, air, and carbon- and nitrogen-rich materials. Worms and fungi further break up the material.
- A **grow light** - an artificial light source, generally an electric light, designed to stimulate plant growth by emitting an electromagnetic spectrum appropriate for photosynthesis. Grow lights are used in applications where there is either no naturally occurring light, or where supplemental light is required.
- **Phytoremediation** - describes the treatment of environmental problems through the use of plants that mitigate the environmental problem without the need to excavate the contaminant material and dispose of it elsewhere. Phytoremediation consists of mitigating pollutant concentrations in contaminated soils, water, or air, with plants able to contain, degrade, or eliminate metals, pesticides, solvents, explosives, crude oil and its derivatives, and various other contaminants from the media that contain them. [2]
- Controlled-environment agriculture (CEA) - any agricultural technology that enables the grower to manipulate a crop's environment to the desired conditions. CEA technologies include greenhouse, hydroponics, aquaculture, and aquaponics. Controlled variables include temperature, humidity, pH, and nutrient analysis. [8]

5. THE ADVANTAGES OF VERTICAL FARMING

"By the year 2050, nearly 80% of the earth's population will reside in urban centers... An estimated 109 hectares of new land will be needed to grow enough food to feed them, if traditional farming practices continue as they are practiced today. At present, throughout the world, over 80% of the land that is suitable for raising crops is in use. Historically, some 15% of that has been laid waste by poor management practices. What can be done to avoid this impending disaster?" [4]

Improved crop production | Growing produce indoors means that these crops can be utilized year-round. *"All-season farming multiplies the productivity of the farmed surface by a factor of 4 to 6 depending on the crop."* Having crops in the immediate area of consumption means that the transport of the goods is reduced dramatically. This means less fuel used in planes and trucks to move produce and also less energy to refrigerate produce prior to consumption. It also means that fruits and vegetables are fresher and less likely to spoil between production and sale. "Research has shown that 30% of harvested crops are wasted due to spoilage and infestations, though this number is much lower in developed nations." [8]

Effect on human health | Unfortunately, tradition agriculture brings a range of dangers to both the famers producing the produce and unknowingly to those who are consuming it. Those who are out on the fields are exposed to hazardous sprays and chemicals that take a toll on human health. *"Such risks include: exposure to infectious diseases such as malaria, exposure to toxic chemicals commonly used as pesticides and fungicides, confrontations with dangerous wildlife such as poisonous snakes, and the severe injuries that can occur when using large industrial farming equipment."* Vertical farming is done in a much more controlled

environment where those dangers are not present. A secondary side effect of traditional farming is that transport into cities makes products expensive and encourage consumption of cheap fast food. This leads to consumers having poor eating habits and suffering from health problems like obesity, heart disease, diabetes. *"Vertical Farm would encourage healthier eating habits of the surrounding population, decreasing the occurrences of major health issues related to poor dieting."*[8]

Shield | Indoor farming also allows crops to be protected from natural events that are hazardous to production. Large rainstorms, tornados, and droughts are just a few of the extreme weather events that outdoor crops encounter. Global warming also proposes extreme weather conditions that can harm crops. *"Three recent floods (in 1993, 2007 and 2008) cost the United States billions of dollars in lost crops, with even more devastating losses in topsoil. Changes in rain patterns and temperature could diminish India's agricultural output by 30 percent by the end of the century."* [3]

Organic crops | The controlled growing environment reduces the need for pesticides, herbicides and fungicides. Advocates claim that producing organic crops in vertical farms is practical, and a good marketing strategy. [8]

Preservation of resources | Each unit of area in a vertical farm could allow up to 20 units of area of outdoor farmland to return to its natural state, and recover farmlands due to development from original flat farmlands. Vertical farming would reduce the need for new farmland due to overpopulation, thus saving many natural resources, currently threatened by deforestation or pollution. Deforestation and desertification caused by agricultural encroachment would be avoided. Because vertical farming lets crops be grown closer to consumers, it would substantially reduce the amount of fossil fuels currently used to transport and refrigerate farm produce. Producing food indoors reduces or eliminates conventional plowing, planting, and harvesting by farm machinery, also powered by fossil fuels. Burning less fossil fuel would reduce air pollution and the carbon dioxide emissions that cause climate change, as well as create healthier environments for humans and animals alike.[9]

Wildlife | Outdoor farming on many acres of land does more harm to the native wildlife than we think. Outdoor agriculture is disruptive to animal populations that inhabit farm land. Animal enthusiasts are excited about the concept of vertical farming as an alternative to traditional farming methods. *"One study showed that wood mouse populations dropped from 25 per hectare to 5 per hectare after harvest, estimating 10 animals killed per hectare each year with conventional farming. In comparison, vertical farming would cause very little harm to wildlife."*[10]

Urban growth |The addition of vertical farming to urban environment has the ability to enhance urban growth. The introduction of farming into densely populated areas means that the city can become self-sufficient in terms of produce. Production becomes localized and can have economic benefits to the residents by providing a new industry with new jobs. Shift from traditional farming to vertical farming will allow for a displacement in employment- from rural areas into more densely populated urban areas. [8]

Energy production | Major energy consumption will be coming from the electrical needs from light for the indoor crops. A methane digester is a convertor that transforms organic waste into a biogas that could be burned to generate electricity for the vertical farm. The farm use grow lamps, electric lamps designed to emit light appropriate for photosynthesis. [10]

Advantages:

- Will encourage healthy eating at relatively low prices.
- Reduce transportation costs, fresher foods, less transportation pollution.
- Produces approximately 20 times the normal production volume for field crops.
- Requires 5% of the normal water requirements for field crops.
- Does not use herbicides or pesticides.
- Will have very significant operating and capital cost savings over field agriculture.
- Can work in a variety of environments: urban, suburban, countryside, desert etc.

6. THE DISADVANTAGES OF VERTICAL FARMING

Land Use | A common misconception about vertical farms is that they would be able to replace the existing farms we already use. It is impossible for vertical farms to replace traditional ones because important crops like

corn, rice, and wheat would not thrive as well as fruits and vegetables. This means that traditional crops will never become obsolete. Some crops are just not conducive to greenhouse growth. [9]

Economics | The concept of vertical farming is a fairly new idea in which the detailed cost analysis has not been determined or generalized. Things like operation, transportation, and fertilization all relate to the economic feasibility of a vertical farm. The economic success of vertical farming rests on the fact that 'food miles', or the distance food travels from farm to consumer, is significantly reduced. If the energy and cost used to power and operate a vertical farm is not less than the energy spent on food transport, the vertical farm is not performing as successfully as it is intended to. The main economic and environmental loss in a project like this will come from the energy costs associated with watering, lighting, and ventilating a project of this size.

CO2 Use | *"As plants acquire nearly all their carbon from the atmosphere, greenhouse growers commonly supplement CO2 levels to 3-4times the rate normally found in the atmosphere. This increase in CO2, which has been shown to increase photosynthesis rates by 50%, contributes to the higher yields expected in vertical farming."* Vertical farming will need a steady CO2 source which is commonly produced from burning fossil fuels. The CO2 is necessary for the farm to work but can propose a hazard to the city when the gases escape the farm and are exposed to the people and environment in high concentrations. [9]

Energy Use | *"The normal amount of light, which is over 90% utilized by field crops, is being split between 30 or so floors, ten to forty watts per square foot of supplemental light will be required."*A criticism is that the power usage for such a large project would be too expensive and not logical when traditional crops only have to use natural daylight. Lights would have to stay on well past sunset and periodically though the night. A 30-story building with such high lighting needs would result in light pollution in urban areas and unhappy immediate residents. Energy would also need to be used for the heating of the vertical farm in the winter months in cooler climates. One of the many advantages is having year-round crops, but the disadvantage to this is the heating costs associated with keeping it running. [3]

Disadvantages:

- Operating 24 hours a day means high energy needs and light pollution.
- Construction and initial phase will be cost intensive.
- Smaller variety of foods.

7. INTERNATIONAL FRAMEWORK FOR VERTICAL FARMING AND URBAN AGRICULTURE

In the last two decades, vertical farming, as a part of urban agriculture, came into focus of international public as one of the ways to solve the rising issue of food deficiency in today's world, which resulted in the adoption of a number of international declarations dealing with urban agriculture as a solution for the mentioned problem.

The first of such international declarations was the Habitat Agenda, adopted at the second United Nations Conference on Human Settlements held in Turkey in 1996. The *Habitat Agenda* was adopted by 171 countries, and it contains over 100 commitments and 600 recommendations on human settlements issues. [11] Namely, it provides some guidelines for the improvement of food security and urban agriculture practices as fundamental components of its objective to improve the quality of urban settlements in response to unprecedented urban population growth. [12]
In that sense, the Agenda states that land dedicated to agriculture and the protection of green areas within the city are just as important as the provision of land for housing, industry, commerce, infrastructure and transport, and that this needs to be included in the planning of urban and peri-urban areas. [12]

The second, and most important international declaration was the *Quito Declaration*, adopted in Ecuador in 2000. The Quito Declaration was the first international declaration to refer directly to the Urban Agriculture, and it involved a broad spectrum of participants from international, national and local level spheres, thus giving it legitimacy. [12] This declaration is remarkable as it clearly points out the essential role of urban agriculture in improving life conditions of poor people in cities through: (1) increasing their food intake; (2) improving their urban environment; and (3) generating income and jobs for vulnerable urban populations. [12]

Since the Quito Declaration in 2000, there have been a number of declarations which have contributed to consolidating urban agriculture as part of the urban development agenda of various cities. [12] The mentioned declarations are: the *Hyderabad Declaration*, adopted in India in 2000, which, inter alia, deals with the issue of using of wastewater in urban agriculture; the *Nyanga Declaration*, adopted in Zimbabwe in 2002, which deals with several issues in urban agriculture; *Villa Maria de Triunfo Declaration*, adopted in Peru in 2002, which deals with question of gender equality, as one of the issues that need to be resolved for the success of the concept of urban agriculture, *Harare Declaration*, adopted in Zimbabwe in 2003, which calls for an appropriate regulation of urban agriculture; and *La Paz Declaration*, adopted in Bolivia in 2007, which covers benefits, challenges and specific recommendations for urban agriculture implementation for the whole supply chain: production, agro-processing, distribution, marketing and consumption. [12]

As we can see from the mentioned, the legal regulation of urban agriculture is still at the level of recommendations, guidelines and indications of the importance of urban agriculture, but unfortunately still not at the level of legally binding rules. However, considering the fact that about 55% of world's population lives in urban areas, [13] and that that number is only increasing, and bearing in mind the fact of food deficiency, there is no doubt that in very close future, this issue will be regulated by legally binding rules, both in the international, and nation level.

8. CONCLUSION

Projects from Singapore to Allen's Farm are of contemporary pioneers. The conclusion seems to be that the advantages of vertical farming outweigh the disadvantages. Such projects are revolutionary and could make our cities self-sustaining places. Though designers need to perform more life-cycle tests on the proposed building to guarantee their future savings will be greater than their initial construction costs, the vertical farms seem an inevitable part of our future. What these three case studies have shown is that the only way to get efficiency you must improve the system over time; finding the right balance. This self-improvement will allow developers and farmers to understand the implications of such a project and be supported by the community. These vertical farms are not meant to be the death of traditional farming, just a new way to look at urban farming as a solution to over population in urban areas.

REFERENCES:

[1] Dickson, D. (2008). Vertical Farm Essay I, Vertical Farm.

[2] Pollan, M. (2009). Big Food vs. Big Insurance, Retrieved from: http://www.nytimes.com/2009/09/10/opin ion/10pollan.html

[3] Dickson, D. The Vertical Farm, The Vertical Farm Project - Agriculture for the 21st Century and Beyond, Retrieved from: www.verticalfarm.com.

[4] TEDx Talks, Dickson (2013). The Vertical Farm: A Keystone Concept for the the Ecocity: Dickson Despommier at TEDxWarwick 2013., YouTube.

[5] CNN Money. Vertical Farms Solve Land Problem. YouTube

[6] Journeyman Pictures. Feeding 9 Billion: Vertical Farming - Singapore., YouTube.

[7] Green Learning. 1 MILLION Pounds of Food on 3 Acres. 10,000 Fish 500 Yards Compost.,YouTube

[8] Fears, N. The Advantages and Disadvantages of Vertical Farming, Find Health, Education, Science & Technology Articles. Retrieved from: www.brighthub.com/environment/science environmental/articles/39036.aspx?p=2.

[9] Blom, T.J., Straver, W.A., Ingratta, F.J., Khosla, S., & Brown, W. (2002). Carbon Dioxide In Greenhouses

[10] Dickson, D. (2009). *The Rise of Vertical Farms Scientific American*. Scientific American Inc, New York.

[11] Retrieved from: http://ww2.unhabitat.org/declarations/habitat_agenda.asp

[12] Cabannes, Y. (2012). *Pro-poor legal and institutional frameworks for urban and peri-urban agriculture*. Food and Agriculture Organization of the United Nations, Rome.
[13] Retrieved from: http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/