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Study of Vertical Farming in Buildings

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ABSTRACT

Vertical farming is the urban farming of fruits, vegetables, and grains, inside a building in a city or urban centre, in which floors are designed to accommodate certain crops. These heights will act as the future farms land and as civil engineers we can shape these high-rises to sow the seeds for the future. The objective of this dissertation was to investigate the feasibility and plausibility of the vertical farming concept in three specific and interrelated research domains. The first research question was to investigate whether enough energy can be generated onsite to meet the needs of the building. The second research question was to investigate the carbon footprint of produce grown vertically and compare that to produce grown conventionally (greenhouse and outdoors). The final research question was to investigate how relevant stakeholders perceive the concept of vertical farming and what they believe are current barriers and opportunities toward uptake of the technology. The purpose of this investigation was to determine ways to supply food to cities in an energy efficient and sustainable manner from both a quantitative and qualitative approach.

INTRODUCTION

It is predicted that the world population will reach 9billion by 2050, of which 70% will live in urban centre. This change, alongside a changing climate, will strain Earth‘s resources ,specially the ability to supply food. A valuable investigation would be to determine other ways to supply food to cities alongside current agricultural practices in a sustainable manner. One idea is the concept of vertical farming. Vertical farming can be defined as farming fruits, vegetables, grains, etc. in the middle of a city inside of a building where different floors have different purposes (one floor for a certain crop, another floor for a vegetable, etc.) using hydroponics (1) (water with nutrients). The concept of supplying food in cities is not a new one as the history of urban agriculture goes back to many ancient civilizations, including the Mayans, the city of Tenochtitlan (Mexico City today), etc. There are many developments taking place today that apply the concept of urban agriculture, and the concept of vertical farming is a large-scale extension of urban agriculture.

It is becoming increasingly understood that both our forms of settlement and methods of sustenance are functionally incompatible with a planet of limited natural resources. Modern cities exhibit decisively ―linear‖ resource metabolisms where food, fresh water, energy, and other resource demands are imported from great distances, consumed, and then swiftly dispensed as sewage or rubbish that the natural world cannot easily process. Likewise, the high-yield farming methods that support our immense population are characterized by their insatiable consumption of our limited reserves of freshwater, fossil-fuel energy, and soil.

This dissertation presents an argument for the implementation of an emerging building typology, the vertical farm, as potential solution to the conflict between ecological stability and humanity ‘s persistent and economic growth.

OBJECTIVE

Vertical farming is the urban farming of fruits, vegetables, and grains, inside a building in a city or urban centre, in which floors are designed to accommodate certain crops. The objective of this dissertation was to investigate the feasibility and plausibility [6] of the vertical farming concept in three specific and interrelated research domains.

1) The first research question was to investigate whether enough energy can be generated onsite to meet the needs of the building.
2) The second research question was to investigate the carbon footprint of produce grown vertically and compare that to produce grown conventionally (greenhouse and outdoors).
3) The final research question was to investigate how relevant stakeholders perceive the concept of vertical farming and what they believe are current barriers and opportunities towards uptake of the technology.
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METHODOLOGY

Innovative Approach

1) Vertical farms build on the idea of rooftop farming by capitalizing on space vertically and utilizing natural light to produce energy.
2) Vertical farms create urban communities in which individuals can both live and work in a sustainable environment.
3) The vertical farm acts as a mini eco-system.
4) With the population increasing and the supplies decreasing, it is necessary that we think of innovative [5] and creative ways to feed and nourish everyone.

Sustainability

1) Saved space per 1 acre of vertical farm = 4 to 30 acres of flat land depending on crop.
2) Creation of sustainable spaces in urban environments.
3) Decrease in ―food miles‖ our produce travels, because we can grow a larger variety of produce year-round in a controlled environment, we will no longer have to import seasonal fruits and vegetables.
4) All VF [6] food is grown organically: no herbicides, pesticides, or fertilizers
5) Able to control and recycle any waste created
6) The eventual repair of ecosystems that have been sacrificed for horizontal farming
7) VF adds energy back to the grid via methane generation from composting non edible parts of plants and animals
8) VF dramatically reduces fossil fuel use (no tractors, plows, shipping.)

Design

1) Multi-storied buildings growing different crops at each floor.
2) Integrated assembly line including: seed sorting facilities, distribution.
3) Continuous planting system including monitoring growth and harvesting
4) All creating a 'miniature eco-system' that acts to enable the urban population to manufacture and produce food locally.
5) The architecture itself:

Requires innovative design concept & architectural knowledge. Integrating greenery alongside traditional architectural forms.

Impact of Vertical Farming

1) Reduction of energy costs in transportation.
2) Year-round crop [8] production preparation protection from weather.
3) Crops are then sold within the same infrastructure (reduction of crop waste).
4) Elimination of crop machinery fossil fuel emissions.
5) Growth of enough food to replace lost productivity as farmland is urbanized.
6) 5 acres of land in traditional farming would produce the same amount of crops to that of a 30-story building (2,400 acres of land).

Scope of Vertical Farming

1) 2050- 80% of world population will be around Urban Centers + 3 Billion [9] more People.
2) 70% of all Fresh water is used in irrigation for traditional agriculture.
3) Unsustainable factory farming techniques.
4) Approximately 800 million hectares of land being used for farming = area of Brazil.
5) Reduction in vehicular transport is also foreseen; there will be less demand for delivery trucks, garbage trucks and other utilities.
6) Overall wellness because city wastes will be channeled directly into the farm building's recycling system, hence, less bacteria can find its way in the environment and the atmosphere.
7) Abandoned or unused properties will be used productively.
8) Water can be used more efficiently in a vertical farm.
9) The grey water [8] from office *etc.* can be used efficiently.
10) The layers of atmosphere can be used effectively in vertical build ups.
11) Less CO2 emissions and pollution by decreasing reliance on coal-burning power plants and transportation, and implementing renewable-sources of energy.
12) Crops will be protected from harsh weather conditions and disturbances like typhoons, hurricanes, floods, droughts, snow and the likes. Food production as well as food transport will not be affected.
13) Crops will be consumed immediately upon harvest since there is no need to transport them to far-off places. Spoilage will also be lessened.
14) The use of chemicals as pesticides will be eliminated; hence, even vector borne diseases can be prevented.
15) Less deforestation and land use, this means less erosion and less flooding.

LIMITATIONS

1) The initial phase will be cost intensive, and certain flaws integrated in the system that may appear during its initial run can still dampen efforts for its full maximization.
2) There will be fewer varieties of foods to choose from because not all plants and vegetables are suitable in a controlled and limited environment
3) The public will find it hard to reconcile with the idea of using black water for food production.
4) Black water or the wastewater and sludge from soils, from the vertical farms need an additional costly filtration system in order to be recycled and conservative of the water resources.
5) Displacement of agricultural societies, potential loss or displacement of traditional farming jobs.

ADVANTAGES OF VERTICAL FARMING

Reliable Harvests

Vertical Farm Systems growing cycles are consistent and reliable, allowing commercial growers to confidently commit to delivery schedules and supply contracts. In a well-managed Vertical Farm System there are no such things as 'seasonal crops' and there are no crop losses. Vertical Farm Systems are fully enclosed and climate controlled, completely removing external environment factors such as disease, pest or predator attacks. It also means our farms are not dependent on fertile arable land and can be established in any climatic region globally irrespective of seasonal daylight hours and extremes in temperature.

Minimum Overheads

Production overheads in Vertical Farm Systems installations are commercially competitive and predictable. In some cases, profitability of over 30% has been demonstrated even after deducting full amortization of capital equipment over a 10-year period. Minimum overheads and grow costs are maintained through.

Low Energy Usage

The use of high efficiency LED lighting technology ensures minimum power usage for maximum plant growth. Computer management of photosynthetic wavelengths in harmony with phase of crop growth further minimizes energy use while ensuring optimized crop yields.

1) Greatly reduced energy usage for climate control is the direct result of not requiring sunlight inside the growing area which enables the use of high thermal efficiency buildings rather than poly greenhouses, and the vertical design of our systems means that for the same growing area the total air volume of a Vertical Farm Systems building is around 88% less than the air volume of single level growing systems.
2) The potential for use of green energy and the elimination of fossil fuel powered tractors, irrigation pumps and other horticultural equipment, Vertical Farm Systems can be structured as carbon emissions competitive.

Low Labour Cost

Vertical Farm Systems are fully automated growing systems with automatic SMS text messaging for any faults. Manual labour is only required on-site for planting, harvesting and packaging of crops - and the required skill levels are very low

Low Water Usage

Being a totally closed growing system with controlled transpiration losses, Vertical Farm Systems use only around 10% of the water required for traditional open field farming and around 20% less than conventional hydroponics. Water from transpiration is harvested and re-used and spent nutrient water is also processed for re-use.

Reduced Washing and Processing

Vertical Farm Systems growing environments are fitted with strong bio-security procedures to eliminate pest and disease attacks. Total elimination of the need for foliar sprays, pesticides and herbicides in cropping systems results in produce that does not require holding times or expensive and product damaging washing or post-harvest processing.

Increased Growing Area and Space Saving

For the same floor area, Vertical Farm Systems multi-level design provides nearly 8 times more growing area than single level hydroponic or greenhouse systems. This compact design enables cost-effective farming installations in industrial estates, urban warehouses and other low cost and typically under-utilized environments not previously associated with high-quality high-margin agricultural activities. It is estimated that every acre used for vertical farming is equivalent to 4 acres of horizontal farming.

1) Year-round crop production
2) Eliminates agricultural runoff
3) Significantly reduces use of fossil fuels (farm machines and transport of crops)
4) Makes use of abandoned or unused properties
5) No weather-related crop failures
6) Offers the possibility of sustainability for urban centers
7) Converts black and gray water to drinking water
8) Adds energy back to the grid via methane generation
9) Creates new urban employment opportunities
10) Reduces the risk of infection from agents transmitted at the agricultural interface
11) Returns farmland to nature, helping to restore ecosystem functions and services
12) Controls vermin by using restaurant waste for methane generation

ANALYSIS

Analysis of the research question, regarding the case studies with focus on the impacts of environment, society, and cost:

Case Study 1: —The Living Tower by: SOA Architects

1) Healthier products (no insects or need for pesticides)
2) Regulation of climate (more reliable production of products)
3) Use of renewable energies as power (Wind and Sun)
4) No reliance on coal

Case Study 2: —The Eco-Laboratory by: Weber Thompson

1) **Energy**: While conserving energy through infrastructure design and decreasing energy costs, the vertical farm will also implement renewable sources of energy, decreasing reliance on coal-burning industries.
2) **Water**: Collection and recycling of water will be done in a sustainable and mindful practice.
3) **Aesthetics**: As a societal impact, Weber Thompson supports the infrastructure design as jointly visually pleasing and functional in energy conservation.
4) The possibilities of Vertical Farms with respect to waste management practices, the ecology of a city, and other societal impacts (a summary of ideas of research)

Advantages	Disadvantages
Water can be used more efficiently in a vertical farm.	Black water or the wastewater and sludge from soils, from the vertical farms need an additional costly filtration system in order to be recycled and conservative of the water resources.
Less CO2 emissions and pollution by	Initial costs of designs and renewable

decreasing reliance on coal-burning industries and transportation, and implementing renewable sources of energy.	energy is often unattractive to developers.
Less deforestation and land use, which means less erosion and less flooding (Natural ecosystem)	NA
Healthier products and urban farming jobs	Displacement of agricultural societies, potential loss or displacement of traditional farming jobs.

LITERATURE REVIEW

1) Literature reviews to examine the current agricultural practices were exhausting our natural resources, and whether it was sensible to explore other farming options.
2) Knowing the history and overview of urban agriculture. The history of urban agriculture was provided because it offered a sense of the history and development of the concept, its applications in the past and today, and the advantages and disadvantages associated.
3) To quantify the energy flows in the building. Also, to study how much energy can be generated on site and how much energy will be used on site. The energy generation source was from photovoltaic [6], and the energy was used to pump the water, light the building (for indoor cultivation), and ventilate the building.
4) Conduct the carbon foot print [7] analysis for horizontal conventional and vertical farming methods.
5) Conduct life cycle analysis of leafy veggies grown vertically.
6) An exploration of social perceptions of relevant stakeholders, and this includes architects, engineers, and the general public.
7) Conduct semi structured interviews to explore the concept.
8) Conduct the experiments and study to find out the crop growing condition at different levels of atmosphere.
9) Detailed case study on vertical framing and bio climatic sky scrapers to know the design process and approach.
10) Comparative studies of crop cultivation and yielding in a conventional method and vertical farming.
11) Finding out solutions for the correct implementation of techniques and materials for the same.

CONCLUSION

The Implications of Vertical Farming in an Urban Ecology

This dissertation will conclude by examining how vertical farming can encourage a more resilient, cyclical resource metabolism to emerge in the microcosm of human society, the city. Large scale urban farming, in the shape of vertical farms, can thoroughly affect the way we provide for our daily necessities. Its potential is enormous, positively affecting transportation, food quality, the economy of cities, skyline and the sociological landscape of urban areas. However, it depends on its level of implementation how influential it can be.

Also, as a long vision future is urban totally. And here the vertical farming concepts can really act as an emerging trend for resource (oil, land, water etc.) management. The impact of urban agriculture, vertical or not, could range from large to small. The range spans from a nice and functional addition to the agricultural services providing some places with a percentage of their food contribution in highly developed countries, to revolutionary

development in food production that shifts the balance from rural to urban and empowers developing countries in economical, political and social ways as not seen before.

To effectively explain vertical farming‘s impact on urban resource metabolism it is important to address the underlying systematic behavior of cities in relation to that of their sustaining natural ecosystems. Like ecosystems, cities are classified a―complex adaptive systems‖; complex in that they are diverse and composed of multiple interconnected agents, and adaptive in their capacity to evolve in response to stimulus. Both can be described as emergent phenomena wherein their overall form and behavior are determined not by the sum of their constituent parts, but rather the patterns that emerge from the interactions of their constituent parts. Both are also strongly influenced by their contextual forces: the hydrological and thermodynamic signature of a region for ecosystems and the regional economic, demographic, and environmental forces for cities. Urban systems will expand or contract, evolve or become stagnant over time, just like ecological communities.

The evident behavioral distinctions between cities and ecosystems can be explained primarily by the differing levels of diversity among their respective constituent agents. It is widely understood that ecosystems exhibit a complex cyclical metabolism. This is enabled by the heterogeneous array of organisms that compose ecosystems, where the waste material discharged by one organism can become the nourishment for another. This metabolic structure is astonishingly self-reliant, requiring few inputs beyond sunlight and externalizing no material output waste.

On the other hand, modern cities have overwhelmingly linear metabolisms distinguished by their insatiable appetite for natural resource inputs and substantial production of waste outputs. This simplistic resource usage pattern is a product of the homogeneity of a city‘s composition. In contrast to the internal diversity of ecosystems, cities are largely composed of entities fulfilling the role of heterotrophic consumption.

Urban citizens consume food, water, and other commodities, their buildings and appliances consume electricity, and their vehicles consume fuel – the latter two also involving the consumption of raw materials in their manufacture.

Without the complimentary metabolic functions of producers or decomposers urban agents must obtain these resources from sources found outside the community, while also creating wastes of little use to the community, forming the traditional input and output externalities of urban life.

Stated simply, vertical farming is the urban replacement of imported rural agriculture. It introduces the possibility for large-scale agriculture to exist within the confines of dense urban environments, enabling cities to achieve greater self sufficiency in their nutritional demands.

The impact of this transition on the resilience of urban economies is hard to overstate. For example, a network of vertical farms would protect cities from the temporary instances of volatility that can disturb the importation of vital commodities, such as extreme weather and social unrest. Increased commodity security is particularly important for food, since most food products have a limited shelf life and must travel thousands of miles to reach urban markets.

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