THE VERTICAL FARM THEORY

by Gordon James Graff

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"The power of population is so superior to the power of the earth to produce subsistence for man, that premature death must in some shape or other visit the human race."

Thomas Malthus, 1789

These words of warning were penned by the English demographer Thomas Malthus in his infamous dissertation *An Essay on the Principle of Population*, wherein he outlined his theory of the quantitative development of the human population. He rationalized that the geometric growth (eg. 2, 4, 8, 16, etc.) of the human population would eventually surpass the linear growth (eg. 1, 2, 3, 4, etc.) of agricultural production, leading to a disastrous famine and population crash.[24]

Nearly two hundred years later, M. King Hubbard devised the Peak Oil theory, in which he forecasted the point when global oil reserves would be outstripped by demand, leading to a potentially massive economic depression due to almost universal dependence on oil consumption. Additionally, because of the saturation of oil-dependent technology in modern agricultural practices, the Peak Oil scenario would expectedly lead to a widespread global famine due to the economic limitations of food production.

These dire predictions are the ominous voices of a population that is slowly becoming aware of its tenuous relationship to earth's natural bounty. And with the emergence of the theory of human induced global climate change at the dawn of the 21st century, there is a growing realization that we must severely restructure our interactions with the natural world in order to avoid destroying the source of our collective health and livelihood.

Among the many sectors of human activity effecting the natural environment, none have impacted the health of the earth's ecosystems as severely as agriculture. Agricultural activity has grown correspondingly to population growth, and advances in agricultural practices have accommodated the excessive population expansions experienced over the past 200 years.[11] Vast tracts of forests and other ecological processes vital to the preservation of human health have been destroyed to create more farmland for human consumption. In response to this, the initiative to severely densify agricultural production and reduce its fossil-fuel dependence has become a major point of discussion.

Among the few propositions offered to accomplish this lofty goal, the concept of the *vertical farm* is perhaps the most noteworthy to emerge at present date. It offers the promise of a severely

reduced ecological footprint for arguably the most damaging human activity to the planet, as well as presenting an active measure to counter the onslaught of global climate change.

2.0 - Concept Logic

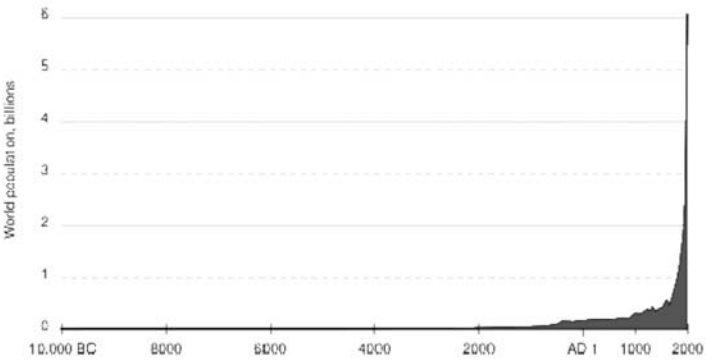
The concept of vertical farming consists of the practice of agricultural production inside high-rise buildings. The premise is derived from the desire to maximize agricultural production per area unit of land, effectively making agriculture 'denser' in order to reduce the land requirements necessary for food production. While the idea of growing food in tall buildings may seem like an improbable proposition, the concept has many compelling arguments.

Perhaps the most poignant argument supporting the concept of vertical farming is the unique solution it offers to combat the looming crisis of global climate change. Currently, the accepted strategies proposed by initiatives like The Kyoto Protocol and An Inconvenient Truth simply focus on the reduction of CO2 production and energy consumption – moves which only alter the speed at which climate change occurs. The vertical farming concept goes beyond this reductionist strategy by providing the opportunity to actually reverse global climate change simply by utilizing the processes of the natural world. Specifically, the concept allows massive increases in land efficiency through the densification of our agricultural production, and subsequently would allow significant portions of the world's farmland to be reforested. This reforestation would create carbon sinks that could sequester CO2 to help stabilize global weather patterns, while simultaneously cleaning air pollution, preventing desertification, soil erosion and flooding, and improving the biodiversity of the natural environment.

Vast tracts of forest cleared for farming

At the 'reduction' end of the climate change response, vertical farms offer an agricultural practice that virtually eliminates the use of fossil fuels in agricultural production. The fossil fuels used in the operation of conventional agricultural machinery would not be necessary for the vertical farm, and no petroleum-derived pesticides or fertilizers will be required with the hydroponic growing process. Furthermore, the vertical farm would virtually eliminate the need to

transport agricultural products from long distances into the heart of urban areas – as it enables an extremely wide variety of produce to be grown year-round right at the source of market consumption.



A graph showing the exponential growth of the human population

Another significant argument supporting the concept of vertical farming is its capability to accommodate the food requirements for the rapidly rising human population. To fully appreciate the magnitude of this developing problem, two issues must be addressed. First, the world's population is expected to grow to over 9 billion by 20504. Second, 80% of the world's arable farmland is already in use - meaning there isn't enough land available on earth to produce food, by way of conventional agricultural practices, to feed the expected three billion additional humans.[3, 4] Therefore, unless we can find a way to restrict population growth, we must develop a new agricultural practice that dramatically increases the land efficiency of food production in order to avoid a massive global famine and population crash.

Yet another important point to consider is the migratory shift of the human population from rural areas into urban centres. A United Nations report on human population patterns identified 2007 as the year when the percentage of the human population living in urban areas reached 50%, a quadrupling of the percentage of urban dwellers since 1950, with the number projected to rise to 60% by 2030.[13] This percentage rise, coupled with the mounting population numbers, means urban centres will become much larger and denser in the coming years. Vertical Farms built inside urban areas offer the ability for these growing cities to become dramatically more self-sufficient with their food requirements; a move that would alleviate the congestion of city streets and highways due to food imports.

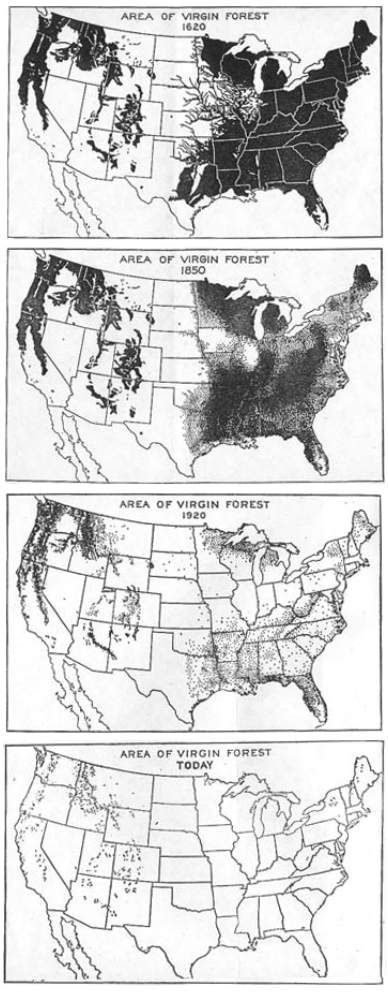
A final point to consider is the massive amount of chemical and biological pollution conventional farming practices impose on the natural environment, which would be completely eliminated with the introduction of vertical farms. No biologically harmful chemicals are necessary for the operation of the vertical farm, and all wastes can be easily and safely converted into usable

products inside the farm, either to be recycled back into the farm's production system or offered to consumers as saleable commodities (ie. compost).

3.0 - The Evolution of Agriculture

The emergence of agriculture is arguably the most important event in the evolution of human civilization, as it triggered the long line of economic, political, and technological developments that have led to our present condition. Therefore, in order to fully understand the factors which have generated the vertical farm concept, it is important to examine the historical progression of human agriculture.

The story of agriculture begins with the end of the last major ice age, approximately 11,000 years ago. The earth's climate shifted toward the temperature and seasonal variations we experience today, including the formation of a sustained dry season that encouraged the flourishing of annual plants that leave dormant seeds or tubers to develop for the succeeding season. The first plants to be domesticated were edible seeds, such as wheat, barley, peas, lentils, chickpeas, and flax due to their ability to be stored, as well as their ease and speed of growth.[9,10] The emergence of annual plants gave humans the ability to manipulate the lifecycle of edible vegetation and would eventually sanction the shift away from the nomadic hunter-gather existence toward one fixed in settled villages supported by the newly domesticated agriculture produce. Remarkably, evidence from the 'Fertile Crescent' area of ancient Mesopotamia suggests that this change of lifestyle occurred in just a few short centuries.[10]

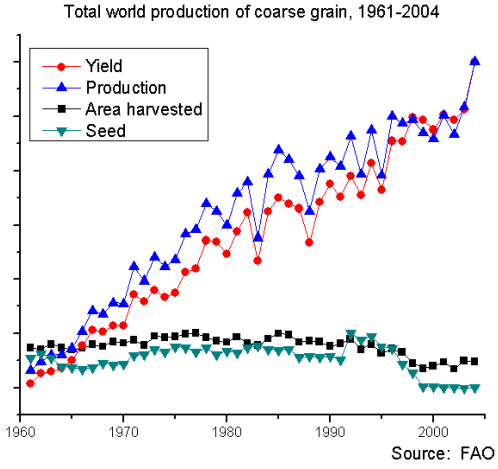


Evolution of the deforestation of North America, largely due to the increase in agricultural production

One of the most interesting aspects of the development of agriculture is that it occurred spontaneously in a number of geographically distant populations, independent from one another, over the few short millennia succeeding the last

major climate shift. When set against the 200,000 year age span of the human species, this extremely rapid emergence at the dawn of a global warming cycle suggests that climate change was in fact the primary cause of the development of human agriculture.[9]

As humans began to develop agricultural production, the resultant ecosystem alterations commonly associated with emergent farming started to surface. For example, the deforestation of land in Ancient Greece to accommodate agricultural production caused soil erosion that eventually resulted in the problematic silting of ports.[4,12] Similarly, civilizations started to experience other significant environmental effects of sustained agricultural practices, such as the depletion of minerals in the soil and soil salination.[9]



A graph showing the increased efficiency of agricultural production at the introduction of industrial farming

The Columbian Exchange (or Grand Exchange) at the end of the 15th century ushered in a new period of agricultural activity that saw widespread exchange of plants, animals, foods, goods, and ideas between the previously isolated Eastern and Western hemispheres.[9] While this emergence in global trade is also credited with allowing the transfer of diseases that depopulated many countries, the effects of the circulation of livestock and crops greatly improved the diversity of food production around the world, and in the long run accommodated large increases in world population.

In the succeeding centuries, the emergence of mechanization and other scientific innovations would enable much greater yields of agricultural production. The development of more efficient farming techniques, primarily in Europe, would enable higher yields of produce per land area unit, and subsequently human population levels started to rise. This led to technologically based initiatives like the Green Revolution of the 1960s that introduced advanced farming techniques, such as the development of fertilizers, pesticides, and new high-yield crops that significantly increased food production.

After the Green Revolution technology was introduced around the world, global food production doubled to meet the needs of an exponentially rising population.[11] However, the negative

environmental effects of some of these techniques, as well as the heavy dependence on fossil fuels for pesticides, fertilizers, and machinery, focused the debate concerning globalization and agricultural ideologies.

Presently, the two sides of the ideological argument are still butting heads. The development of national and international transportation networks, in conjunction with the aforementioned technological and scientific advancements (such as genetically modified produce), have enabled the developed nations of the world to maximize their available food production. Alternatively, the organic farming movement is quickly becoming the major trend in agriculture, with more producers each year switching from industrial to 'organic' cultivation methods.

However, as the world's population is expected to rise 40% by 2050, many agriculture experts claim that with our current farming techniques there simply isn't enough land available on earth to feed the expected population rise with our current farming techniques.[11]

Therefore, if human population levels continue to rise as predicted, maximizing agricultural output per land area will become the next major step in the evolution of agriculture.

4.0 - Vertical Farm Design Considerations

4.1 - Building Design

While there are many different strategies for creating densified urban agriculture, 'vertical' farms are, by definition, housed in buildings with multiple vertically stacked floors. However, within the requirement of a stacked physical structure there are few specific requirements for the vertical farm. As such, proposals of new construction or renovation of an existing building, with virtually any structural material or shape, are theoretically possible. However, the inherent initiatives of maximizing space efficiency and reducing building cost (for economic viability) do inform the designs of vertical farm proposals. Complex building designs run the risk of being regarded as fanciful propositions compared to the simple building requirements of the vertical farms. The simplicity of the rectilinear tower typology makes it ideal for a vertical farm design since it is the cheapest tower typology

A cylindrical vertical farm proposal

in terms of construction cost, and the most efficient in terms of usable floor area. Additionally, the rectilinear spaces work in agreement with the rectilinear standard of industrial equipment and components.

The cylindrical tower is another prevalent typology explored for the vertical farm. Among the many advantages it offers is the distinction of having the largest interior volume in relation to its exterior surface area for any extruded shape. This is beneficial to the cost-effectiveness of the design since high costs are associated with external wall systems, and control over the interior environment of the building area would increase due to less surface area of permeable exterior surfaces. Moreover, the circular floor plan of the cylindrical design accommodates the central placement (and delivery) of resources and monitoring stations. The illustrated example shows how a circular floorplate would enable the rotation of the growing area to maximize the sunlight absorption of the produce, and similarly a watering beam to irrigate the entire growing area. Nevertheless, there are drawbacks to the cylindrical typology. The higher costs associated with non-rectilinear floorplate construction, awkward orientation of the available growing area on a circular floorplate, and reduction in growing area as compared to on a rectilinear floorplate all render this a design of luxury, and as such it is less able to fulfill the requirements of the vertical farm.

Another essential element for a vertical farm is that it is housed in a structure that is effectively enclosed to protect the produce from harmful air-borne agents, and create an artificially optimal growing environment for produce under any external weather condition. Depending on the type of flora and fauna to be grown, it may also be required to make each floor of the building air-tight to enable control over the flow of particles emitted by some produce that could negatively affect the health of others1. In connection to this, it may be required to create a high amount of control over the internal environment within the building to accommodate optimal lighting and growing temperature differences between different produce.[1]

4.2 - Growing Medium

The usage of hydroponic crop production as the growing medium for the produce is a fundamental component of the vertical farm concept. Hydroponics is a massive technological advancement from geoponic (soil-based) agriculture, and one that solves the most pressing problems associated with existing agricultural production.

For instance, soil-based agriculture extracts most of the nutrients and minerals required for plant growth directly from the soil culture it inhabits. In traditional, high-yield farms this extraction of nutrients occurs largely without a reciprocal nutrient refurbishment of the soil, and thus requires artificial fertilizers to supplement the soil for the next growing cycle. This continual ‘stripping’ of the soil, and dependence on artificial fertilizers, often leads to soil erosion and contributes to the degradation of soil quality.[23] Hydroponics, in contrast, avoids this common predicament by

forgoing the use of soil entirely in favour of water as the growing medium. As soil is not required, soil-borne diseases are completely eliminated as a threat to produce. Additionally, the opportunity for weeds to flourish in soil-based agriculture is removed as a hindrance in hydroponic culture. Because of these two preceding points, the use of pesticides is completely unnecessary in the hydroponic growing process.

A simple 'stacked' hydroponic system

One of the most important characteristics of the hydroponic system to the vertical farm concept is its ability to be stacked vertically (see diagram) with minimal difficulty for most types of crops. This stacking massively reduces the space required for the agricultural production process, enabling the high land-use efficiency desired in the vertical farm concept. The simplicity and efficiency of hydroponic systems is another great improvement over traditional geoponic farming. Water usage in a typical hydroponic system is approximately 1/20th of that required for traditional outdoor irrigated soil-grown crops due to their closed-loop design, which enables water in the system to be recycled perpetually. This reduction in water usage significantly decreases the ecological footprint of hydroponic systems as compared to geoponics by lowering the amount of resources extracted and, after processing, expelled as waste.[23]

4.3 - Energy System

The most discussed and variable component of vertical farms is the method of providing a suitable source of energy for the growth of produce. There are two basic options – utilizing passive solar energy or energy from artificial lighting. Both of these options have their advantages and drawbacks. For direct solar energy, the obvious benefits of having a free and unlimited power source would make it the obvious choice to grow produce. However, when agricultural production is stacked vertically, all floors below the top level receive virtually no direct light. Furthermore, while the quantity of land area can be artificially replicated though the process of stacking floors, the amount of solar radiation that contacts the footprint of the building cannot, and as such is insufficient for the extreme density of agricultural production proposed in the vertical farm.

The other option, using artificial lighting for radiant energy, has its own inherent complications. The benefit of being able to easily satisfy the energy requirements for plant growth, with the ability to extend and modify its delivery to maximize efficiency, is countered by the high energy requirements associated with that system. Considering the rising cost of energy, the energy required to power the multitude of artificial lights would render the concept an economic improbability. However, with the increasing ability to generate renewable energy on-site through photovoltaic panels and wind turbines, the prospect of using artificial lighting to grow produce becomes the most plausible option available for the vertical farm concept. In addition, the biological wastes produced from the farm operations would enable a continuous supply of bio-fuel to power the farm's various processes. Nevertheless, the method of delivering radiation energy for plant growth will be subject to much debate, and undoubtedly improved through the technological advancements of renewable energy generation, as well as passive options, such as the development of fibre optics for sunlight redistribution.[1]

A prototype for a vertical-axis wind turbine that will greatly improve building integrated wind power generation © 2007 TMA

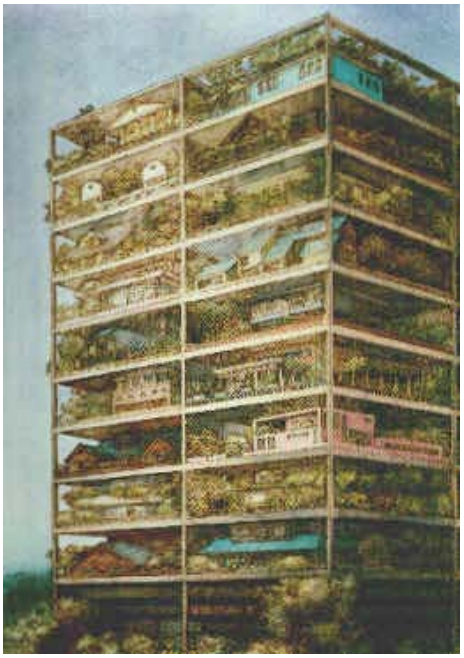
5.0 - Precedents and Formation

Even though the vertical farm concept itself is a new proposition, it is composed of two familiar typologies that can be examined as precedents; namely, the process of densification through vertical 'high-rise' construction and the practice of indoor agricultural production. Both of these ideas have developed in conceptual seclusion over the preceding centuries, and are currently two consistently endorsed typologies cited to accommodate the global demographic changes expected in the succeeding century.

The practice of increasing land efficiency by building vertically has always been a basic principle of urban construction. The eventual emergence of the skyscraper represents the pinnacle of this tendency for density and land use efficiency, as buildings reached astonishing footprint-to-floor area ratios. For instance, the Sears Tower rests on a 1.2 acre footprint, yet offers over 87 acres of useable floorspace within the building. An even greater land use densification could be seen in each of the former World Trade Center Towers, which constituted an area one hundred times greater area then their footprints.

This basic stacking principle, as it relates to the vertical farm, is perhaps best illustrated in conceptual projects such as James Wines' 'Highrise of Homes'. Conceived in 1981, Wines describes the project as one that can,

> *"…accommodate people's conflicting desires to enjoy the cultural advantages of an urban center, without sacrificing the private home identity and garden space associated with suburbia."*[16]



Highrise of Homes
© 1981 S.I.T.E. Architects

Physically, the concept is a simple steel and concrete frame of eight to ten stories, erected in a U-shape for use in a densely populated area. Homes would be designed and built to the owner's specification on purchased 'plots' within the tower's levels, and would be serviced by communal utilities fixed into the structure. Ultimately the radical nature of the project rendered it an economic impossibility. However, it is the theoretical nature of the project that has generated its lasting appeal. It gracefully illustrates one perspective of the human relationship to the natural landscape in the modern age, wherein the ability exists to simply construct artificial land area when the natural variety is in short supply. The precarious relationship exhibited between this concept and the natural landscape perfectly echoes that of the vertical farm.

Greenhouse Agriculture

The other typology fundamental to the concept of the vertical farm is the practice of indoor agricultural production. The simple notion of growing plants indoors has, not surprisingly, existed since antiquity, with the first reported incidence being the indoor cultivation of cucumbers for the Roman emperor Tiberius.[18] With the emergence of industrial glass production in the 19th century, and the development of hydroponics in the 20th century, indoor farming has become a viable method of high-yield agricultural production. Currently this practice only accounts for a small fraction of the agricultural production in the world; however it is an extremely fast growing sector of agriculture. In Canada, which is the largest greenhouse crop producer in the Americas, total sales from greenhouse products went from $1,072,542 in 2003 to $2,151,614 in 2005 – over a doubling in production in just 3 years.[19] In Europe, the land scarcity of the Netherlands has encouraged the Dutch to invest heavily in

greenhouse farming, which in 2002 saw 4,300 hectares of greenhouse vegetable production, compared to less than a thousand in Canada and the United States combined.[20]

The Netherlands, with its relative land scarcity and high agricultural production, is one of the primary sites for the vertical farm concept's fusion between indoor farming and high-rise construction. In 2001, the Dutch architecture firm MVRDV developed the conceptual project Pig City, which is a theoretical design for a series of skyscrapers completely dedicated to the production of pork. The designers explain their proposal by stating,

> *"In 2000, pork was the most consumed form of meat at 80 billion kg per year. Recent animal diseases such as Swine Fever and Foot and Mouth disease are raising serious questions about pork production and consumption. Two opposing reactions can be imagined. Either we change our consumption pattern and become instant vegetarians or we change the production methods and demand biological farming."*[21]

Their design studies the combination of organic farming practices with the concentration of land area required for meat production. This project has particular traction in the Netherlands, as it is the European Union's chief exporter of pork and, due to land restrictions, currently under pressure to reform their agricultural practices to reduce agricultural pollutions and increase food safety.[7]

The Netherlands is also the site of the most advanced attempt to realize a dense agricultural production facility. Proposed for the docklands of Rotterdam in 2001, the massive Deltapark project is the world's first politically endorsed initiative to construct a large-scale indoor densified farm. Its intended proportions are astonishing; roughly 1 kilometre in length and 400 metres in width, which, multiplied by its 6 floors accounts for a total of 200 hectares (500 acres) of indoor 'farmland'. Deltapark's creator, Jan Broeze of the University of Wegeningen, describes the concept's logic: *"If you cluster various activities, like greenhouses, fish farming, and manure processing, then you create a sufficient scale for more sustainable food production…The idea is to use wastes from one industry to sustain another."*[7]

Pig City – Skyscrapers for pork production
© 2000 MVRDV

Termed an "agro-production park", the Deltapark project was conceived not only to densify agricultural production, but also as a hyper-efficient agricultural process that artificially mimics the waste transfer

processes of the natural world. It uses a 'clustering' of production facilities to maximize the energy distribution and biological metabolism of the system. Similar to the vertical farm proposal, Deltapark is designed to be run by 'managers' and technicians rather than farmers.[7]

Amidst this activity of densified agricultural concepts emanating from Holland, the majority of recent research into densified/vertical farming has been lead by Dr. Dickson Despommier, professor of Microbiology and Health Sciences at the University of Columbia. His work, ranging from the agricultural processes of vertical farming to the cost-effectiveness of such a design, is the primary force behind its emergence in North America. Dr. Despommier's interest in the concept of vertical farming emerged almost by accident through an ad-lib project he proposed for his medical biology class in 2000.[22] Since then he and his students have generated the lion's share of available material promoting the concept, primarily though its climate change and rising population accommodating virtues.

6.0 - Points of Detraction

Despite the concept's many advantages, there is significant momentum acting in opposition to vertical farming. For instance, many people are initially sceptical about the concept's energy consumption, and therein its sustainability, due to the massive amount of artificial lighting needed for growing the crops.[14,15] While this is a valid point of uncertainty, it is currently possible to solve this issue by way of renewable power generation, such as the incorporation of photovoltaic panels or wind turbines. The ease of solving this issue will rise correspondingly with the evolution of on-site renewable energy generation for buildings. An example of such a leap in technology that has dramatically eased the initiative to generate on-site renewable energy can be found with the new designs for vertical-axis wind turbines suitable for building integration5.

Another point of contention lies in the costing viability of the construction and operation of the vertical farm proposal.[14.15] This point is obviously dependant on current market trends, and one that must be taken into account in the design process. By selecting a very economical form of construction, perhaps even a renovation of an existing building, and offering the produce at local market values, studies have shown the concept can be economically viable and profitable2. The hypothesized scenario when on-site energy generation capacity would exceed energy consumption, making way for a profit in selling unused energy to the grid, would add further financial incentive.

However, the most critical voices of vertical farming come from those who view traditional husbandry as a fundamental component of human culture, and subsequently regard the concept of growing food in a centralized, artificial ecosystem, outside of the natural environment, as an immoral proposition. Additionally, some view the inevitable marriage this concept could sanction between industrial enterprises and food production as a logistical nightmare.[6]

This position is the latest incarnation of the ideological argument against the intervention of technology on traditional ways of life that has existed since the dawn of the industrial revolution. Just as the Luddites and Pre-Raphaelites were campaigning against the emergence of industrial involvement in the manufacturing crafts during the 19th century, many today stalwartly resist the prospect of industrial and technological involvement with agricultural production. For example, the attempt to enhance crop yields and plant resilience via genetic modification has been met with passionate resistance, despite the absence of empirical substantiation to validate such scepticism. Of course, this opposition is based largely on ethical grounds rather than scientific evidence.[8]

A vertical beef farm located in Japan serves as an indicator of the ethical dilemma inherent in agricultural activity disconnected from the natural environment

A more specific example relating to the concept of vertical farming can be found in the reaction to the proposed Deltapark superstructure farm in the Netherlands. The proposal has generated criticism from a few of the world's top agricultural voices. Thomas Cierpka, executive director of the International Federation of Organic Agriculture Movement, said,

> *"Organic farmers want to control their production, but never nature as a whole. Food production of this kind, unattached to nature, can in my mind never be called ecological."*[7]

Angela Caudle, also with the IFOAM, said,

> *"The technological solution distracts from our human connection to agriculture and food production…I can appreciate an attempt to find sustainable ways to deal with producing more food for more people, but for me this is kind of like laboratory food".*[7]

Many Dutch politicians and agricultural specialists have stood out against the idea. Socialist MP Ruude Poppe commented on the proposal by saying, *"Animals can't be produced in the same way as a toothbrush of a car. Food production has always been a basic part of human culture. It's about culture, not industry."*[7]

Additionally, Henk Udo, associate professor of animal production systems at the University of Wegeningen, says,

> *"My personal feeling is that this is turning agriculture into bio-industry. I doubt if farmers will wish to become managers; that's not what farming is about. I certainly wouldn't be keen on buying the products from Deltapark and I don't believe this is what consumers want."*[7]

These concerns can be viewed as valid in the context of the current race toward the industrialisation of every aspect of human production, and subsequently are acting out of fear of contributing to the detachment of the human population from the natural world via the adoption of a synthetic agricultural system.

7.0 Conclusion

Despite the aforementioned validity to the objections of vertical farming, it must be understood that these voices are largely acting out of cultural sentimentality rather than rational objectivity. When weighed against the vertical farm's ability to dramatically minimize the ecological footprint of agricultural production, counter global warming through the active reforestation of existing farmland, and accommodate the rising food requirements of an exponentially rising population, a rational mind must deduct that the shortcomings of vertical farming are largely overshadowed by its virtues. Subsequently, unless humans are able to dramatically alter their relationship with the earth's ecosystem, and sufficiently reduce the pace of global population rise, the vertical farm's solution to the colossal problems of feeding a growing population and suspending global climate change make it a very promising option.

BIBLIOGRAPHY

1. Despommier, Dickson. Professor of Health Sciences, University of Columbia, Multiple Dates [interview]
2. Vertical Farms. (2007), Wikipedia.org, April 20th, 2007 <http://en.wikipedia.org/wiki/Vertical_farm>
3. Chamberlain, Lisa. “Skyfarming”. New York Magazine. April 9 th, 2007.
4. Despommier, Dickson. “The Vertical Farm: Reducing the impact of agriculture on ecosystem functions and services”. <http://www.verticalfarm.com/essay2_print.htm>
5. TMA Global Wind Energy Systems. <http://www.tmawind.com/>
6. Opar, Alisa. “The Farmer in the High-Rise”. Plenty Magazine (New York) January 30 th, 2007.
7. Vidal, John. “Farm of the Future?” Guardian Magazine (London) August 22 nd, 2001.
8. Genetically Modified Foods. (2007), Wikipedia.org, May 18th, 2007 <http://en.wikipedia.org/wiki/Genetically_modified_food>
9. History of Agriculture. (2007), Wikipedia.org, May 5th, 2007 <http://en.wikipedia.org/wiki/History_of_agriculture>
10. Diamond, Jared. “Location, Location, Location: The First Farmers” <http://www.unl.edu/rhames/courses/orig_agri_tur.html>
11. ACF Newsource. “Population Boom”. February 16th, 2006 <http://www.acfnewsource.org/science/population_boom.html>
12. Tjeerd H. van Andel, Eberhard Zangger, Anne Demitrack. "Land Use and Soil Erosion in Prehistoric and Historical Greece” Journal of Field Archaeology. Winter 1990
13. Population Division, Department of Economic and Social Affairs, United Nations. “World Urbanization Prospects: The 2005 Revision.” <http://www.un.org/esa/population/publications/WUP2005/2005wup.htm>
14. Bellows, Alan. “Z-Axis Urban Agriculture: The Vertical Farm Project.” December 25th, 2005. <http://www.damninteresting.com/?p=296>
15. Metafilter Community Weblog. “VerticalFarm: Highrise Urban Farm (concept)” May 12th, 2004. <http://www.metafilter.com/33060/Vertical-Farm>
16. Matilda McQuaid, ed., *Envisioning Architecture: Drawings from The Museum of Modern Art*, New York: The Museum of Modern Art, 2002, p. 220
17. Hydroponics. (2007), Wikipedia.org, May 20th, 2007 <http://en.wikipedia.org/wiki/Hydroponics>
18. Greenhouses. (2007), Wikipedia.org, May 21st, 2007 <http://en.wikipedia.org/wiki/Greenhouse>
19. Mailvaganam, Siva. “Greenhouse Industry Statistics”, Ontario Ministry of Agriculture, Food and Rural Affairs Division May 25th, 2006 <http://www.omafra.gov.on.ca/english/stats/hort/greenhouse1.html>
20. Greenhouse Vegetable Industry Factsheet, British Columbia Ministry of Agriculture, Food, and Fisheries. 2002 <http://www.agf.gov.bc.ca/ghvegetable/publications/documents/industry_profile.pdf>

21. MVRDV. (2001) “Pig City” <http://www.mvrdv.nl/_v2/projects/181_pigcity/textcredits/index.html>
22. Chamberlain, Lisa. “Vertical Farm” Polis Magazine (New York) April 9 th, 2001. <http://polisnyc.wordpress.com/2007/04/02/vertical-farm/>
23. Buck, Anisa; Dine, Danial;et al. (2004) “Feeding 50,000 People”. <http://www.verticalfarm.com/plans-2k4.htm >
24. Heilbroner, Robert L. (1953) “The Worldly Philosophers: The Lives, Times, and Ideas of the Great Economic Thinkers”, Simon & Shuster