675: Defining the architectural Typology of the Urban Farm

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Abstract

This paper focuses on the development of a large scale system of food production and distribution within the urban realm. This project seeks an alternative architectural approach, which combines the benefits of diverse natural based systems with the efficiency of production and scale of the industrial farm. Through architecture, the environment in which crops and livestock grow is manipulated thereby breaking the farmers' dependence on weather. A new architectural typology, the high rise urban farm, offers a platform for testing these theories.

The paper includes methods for developing a productive urban agricultural network and establishing an environmentally responsive farm that takes full advantage of solar access. Stacked farming provides more total crop area and more hours of exposure to direct solar radiation than ground level urban farming. Furthermore, direct solar radiation can be maximised with dynamic architectural systems that enable the building to respond to diurnal and seasonal changes. Adapting the growing calendar so that optimal growing temperatures are slightly above or below the outdoor air temperatures allows for passive heating and cooling throughout the year. The vertical farm couples and decouples with the exterior environment as necessary. On site processing facilities and the development of an alternative growing calendar encourages a symbiotic relationship between city and regional farmers, as urban food production volumes rise and fall conversely to rural production levels.

Keywords: urban farming and agriculture, solar access

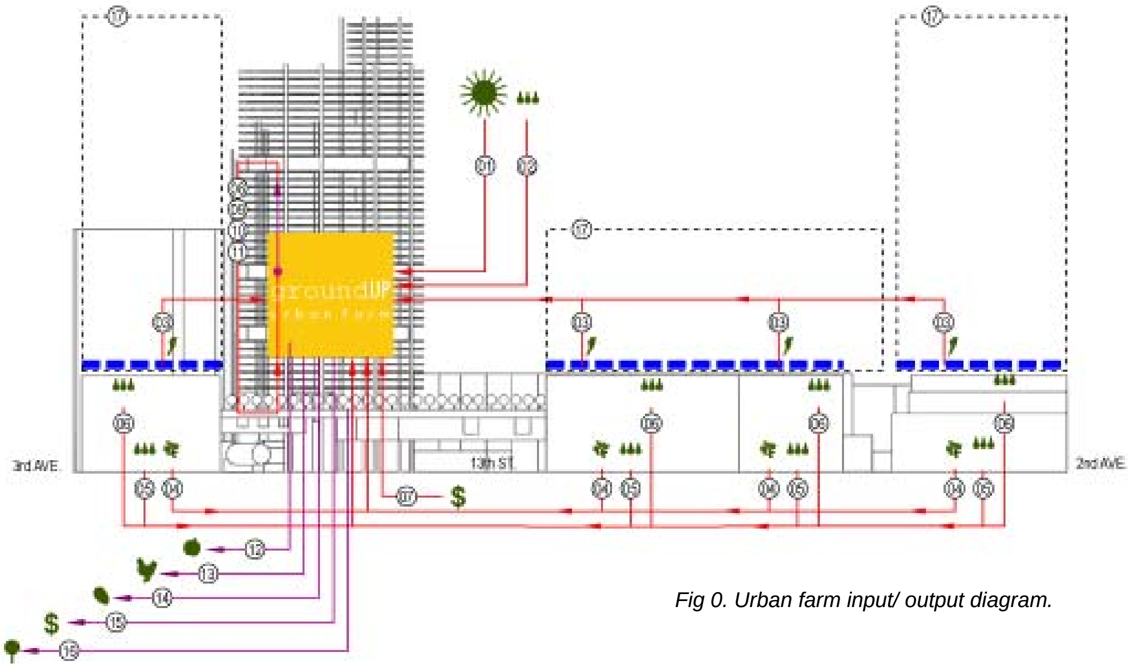

Fig 0. Urban farm input/ output diagram.

1. Introduction

With urban population increasing to an estimated 60% by 2030 [1], cities remain dependent on rural farms, which are far-flung, disparate, and increasingly threatened by urban expansion. Farming itself has shifted from rural, multi-crop and diversified livestock systems to specialized pseudo-urban mono-cultures dramatically changing the form of the American farm. These highly engineered farms produce an abundance of food at low cost to the consumer but arguably at a greater cost to its livestock and the environment. The distance food travels between harvest, production, and consumption, known as food miles [2], has a particularly damaging environmental effect due to CO2 emissions from transportation and increased efforts to maintain food freshness over longer periods. Food borne illnesses and environmental degradation associated with continually growing genetically similar crops or raising livestock in a single location have also increased [3, 4]. Although efficiency has increased, the tasks themselves remain essentially the same. Farmers may plant genetically modified but these seeds are still sewn, planted, and harvested by traditional agricultural cycles and farmers' livelihoods remain dependant on the weather. Instead of modifying the crops themselves, the high rise urban farm seeks to manipulate the environment in which they grow. Creating controlled, environmentally responsive environments is the greatest asset of the urban farm. Inclimate weather, natural disaster, and disease no longer dictate farm production and yield. Greenhouses are a simple means of protecting crops and extending the growing season but have not been implemented as part of an industrial food production system within the urban realm.

A system must be developed that produces food at an industrial scale, incorporating dynamic architectural features that optimise passive heating and cooling. Opportunities abound for new distribution networks and infrastructure systems at a city and community level. The urban farm strives to create environmentally responsive architecture, in which climatic conditions and programme generate design. Establishing a larger network ensures the constant delivery of fresh fruits, vegetables, and meat throughout the year. It brings raw materials closer to consumers reducing food miles, concentrating resources, conserving land, decreasing loss due to spoilage, and lowering overall energy use.

The impetus for research is to evaluate the programme, form, and feasibility of urban agriculture. The project culminates in the design of a single urban farm as a typological example within a new metropolitan agriculture system; specifically, it proposes a dynamic semi-enclosed high rise. The research suggests that a high density vertical structure composed of growing fields and processing facilities, incorporating passive and on-site renewable energy can supply enough food to significantly reduce the city's reliance on external sources. The proposal seeks an alternative to existing greenfield agri-business that combines the benefits of diverse natural based systems with the efficiency of large-scale mono-cultures. Through a rigorously determined brief, optimal environmental conditions for plant and animal growth are proposed within the dynamic urban farm. A semi-enclosed structure creates a microclimate in which crops and livestock are produced year round. Solar access and indoor air temperature are the primary parameters investigated. This project seeks to demonstrate that urban industrial agriculture is a viable alternative; or that it may at least proffer alternative supplementary systems for food production on a smaller scale.

2. Context and Precedents

2.1 New York City Food System

Historically, New York City has enjoyed a bountiful supply of food from its hinterland and a few networks still link residents to local food today. Community gardens and small urban farms dot the cityscape, providing produce to local residents. Through Community Supported Agriculture (CSA) programmes, members invest financial capital in a regional farm and reap a share of the harvest. Urbanites share the risk and reward of farming and help supply much needed cash at the start of the planting season. The most popular and influential system is the farmer's market. "Greenmarket" emerged in 1976 with a dozen farmers in an empty parking lot. Today it hosts 200 local farmers, selling at 45 markets city wide, and serving over 250,000 customers weekly during peak seasons [5].

2.2 Precedents

Andre Viljoen expands on the ideas of urban autonomy and optimised space though his exploration of Continuous Productive Urban Landscapes. CPULs are continuous systems of vegetative landscapes woven into cities, incorporating urban and peri-urban farming, parks, community gardens, and pathways. Viljoen argues that redeveloping vegetative landscapes within the city allows urban dwellers to participate in and observe traditionally rural processes, "thereby re-establishing a relationship between life and the processes required to support it," [2].

CPULs are both environmentally and socio-economically productive. An increase in biodiversity or "ecological intensification" is one of the main strategies [2]. Vertically or horizontally integrated, intensification increases the amount of activities or uses of a space by layering, which occurs both physically, as in the stacking of landscapes, and over time, as space is appropriated based on diurnal conditions or a seasonal change of function. Transportation routes serve as park space. High rise agricultural fields clean the soil and air. Trees help cool the air in the summer and provide wind breaks during winter [2]. Activities within the CPUL change in response to climate and resident need.

MVDRV's Pig City, moves from the urban scale of CPULs to the building scale and providing a clear and convincing argument for vertical farming. For the Dutch, meeting demand for pork production within new ecological standards would fill 75% of the Netherlands' land. Pig City looks to redefine the pig farm in architectural and urban terms, as an alternative to horizontal sprawling farms. It reduces the environmental impact of pig farming while improving the pigs' quality of life and providing better meat. The project brief is defined around the daily schedules, life cycles, and spatial requirements of pigs with populations calculated to maintain an uninterrupted supply of pork. MVRDV argues that a concentration of farms creates an "economic critical mass" reducing unnecessary transportation that renders pigs susceptible to disease and injury [6]. Pig City addresses the realities of industrial food production and offers lessons for the design of urban farms, while advancing an exciting architectural vision.

Dickson Depommier, Director of The Vertical Farm Enterprise, offers another vision for high rise agriculture as part of an effort to address environmental and food safety issues. They argue that increased population and density in cities along with the loss of arable land intimates the need for vertical farms in urban areas, claiming that one 30 storey high rise covering a single New York City block (68m x 254m) could provide enough calories (2000 cal/ day/ person) for 50,000 people using current agriculture methods [7]. Advancements in technology could produce higher yields, although Depommier admits, “high-rise food-producing buildings will only succeed if they function by mimicking ecological process” and they “must be cheap to construct, durable and safe to operate, and independent of economic subsidies and outside support,” [7].

Depommier and the VFE propose a fully enclosed high-tech growing machine. Viewed from a public health perspective, the vertical farm serves as a vehicle to fight hunger and reduce food borne disease. These high rise greenhouses offset energy use through renewables, focusing on methane digestion. High tech hydroponic and soilless growing systems and attempts at a closed biological loop through gray water recycling, generation of biofuels demonstrate the potential of technological advancement but offer little architectural expression. This may change though as the Vertical Farm Enterprise is working with Arup to develop a vertical farm in China providing an opportunity to test their ideas [7].

Both open air and fully enclosed systems offer benefits to production but may require greater energy inputs. A dynamic system working with seasonal variations could provide the greatest opportunity for maximising passive means of achieving optimal growing conditions for plants and livestock. Supplementary renewable energy systems are a vital part of a healthy urban farm. Standardization and modularity are keys to efficiency in building design and operation. In each precedent, consideration of both local effects and far reaching results are critical to the design proposal. The urban farm typology must operate in both contexts simultaneously.

2.3 Climate analysis

New York, New York is generally characterised as a humid continental climate, typical of the north-eastern United States. The city lies at a longitude of 73.58°N and latitude of 40.47°W indicating a moist climate with mild winters and hot humid summers. The seasonal variations and an annual rainfall of 1,072mm [8] support a wide range of vegetation. The consistency of rainfall suggests potential year round integration of water catchment and recycling. The psychrometric chart for New York shows a greater requirement for heating than cooling (64,225 heating degree hours versus 8,944 cooling degree hours) indicating a need for solar exposure to increase heat gain, thereby maintaining the desired growing temperatures [9]. An average temperature of -1.7°C in January suggests the need for heavy insulation of glazed facades at night to trap the heat gained from daily solar exposure. Average temperatures rise to 24.7°C in July demonstrating the potential for natural ventilation and indirect evaporative cooling should overheating become a problem. Direct solar radiation is available, varying slightly during the year from 320 Wh/m^2 to 490 Wh/m^2 per month, peaking in June.

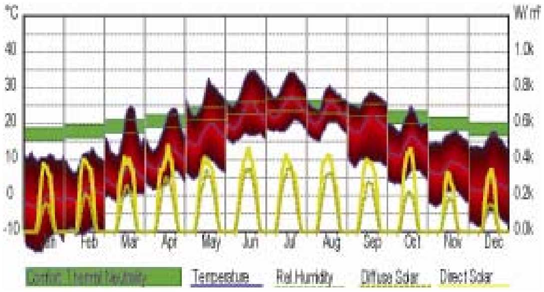

Fig 1. Monthly diurnal averages, New York, NY.

2.4 Livestock and Crop Environmental Needs

Defining and controlling the environmental conditions in which plants grow allows a continuous cycle of sowing, planting, and harvesting. Optimal temperature ranges for a selection of crops were considered (Fig. 2), indicating the temperatures at which the vegetation and livestock are most productive. Organizing the crops into several similar temperature zones gives more flexibility to control the environment passively. Overlaying the plant comfort zones onto a graph of monthly diurnal averages highlights periods during which the environment must be manipulated.

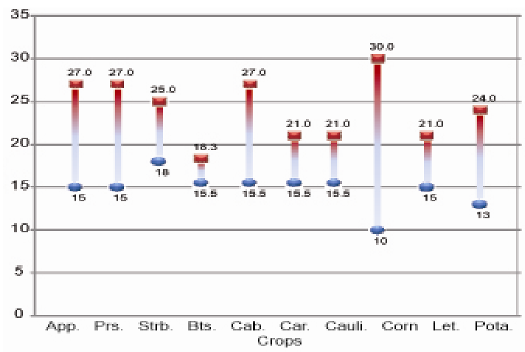

Fig 2. Optimal growing temperatures for crops.

Apple and pear trees have an adaptive comfort range and benefit little from modifications to their environment, as they require 800 to 1,200 cooling hours (33-50 days where $T_a < 6$°C) annually [10]. Strawberries however, require air temperatures remain between 18 and 25°C. From October through April, maintaining strawberry “comfort” requires heating beyond what is available passively, suggesting the need for renewable energy sources from within the metropolitan farming network.

Vegetables typically have consistent temperature requirements but would likely require active heating during January [11]. In conjunction with a highly insulated glass unit a supplementary system of insulated panels or curtains is necessary to prevent heat loss at the night. By stacking the plant beds vertically, a large open air zone is created which allows a greater south facing vertical surface area, contributing to increased indoor air temperatures. Summer air temperatures do not pose a problem for plants as natural ventilation and evaporative cooling should maintain optimal conditions.

Chickens experience adaptive comfort similar to humans, tolerating warmer weather in the summer and cooler temperatures in the winter [12]. With over a 12°C temperature gap in comfort level and average temperature, a combination of passive solar heating, thermal mass and heavily insulated coop walls is necessary. Captured heat generated by composting facilities or methane digesters can be used to warm the chicken coops. In the summer shading and natural ventilation strategies suffice.

In addition to growing temperature, each food stuff has particular spatial needs for successful growth. A series of sections (Fig. 3) showing bed depths, plant/ animal height, and spacing began the initial investigation of the spatial dimensions of urban farming. These diagrams provide an easy visual comparison of different plants and animals. "Floor" and "ceiling" levels are shown to consider the vertical dimension required to raise the food stuffs. Water and sunlight requirements factor heavily in the selection of crops and livestock, and are therefore included in the diagrams.

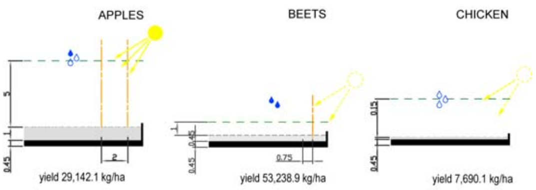

Fig 3. Sample of diagrammatic sections showing environmental and spatial characteristics of food stuffs.

2.4 Site Introduction

New York City serves as the site due to its density, verticality, and seasonal variations. The site consists of four parcels, three located on 13th Street and one opening onto 14th Street between 2nd and 1st Avenues in the East Village neighbourhood of Manhattan. The neighbourhood typically consists of four to eight story buildings with commercial business on the ground floor and residential above, demonstrating the potential for solar access through taller anomalies in the urban plan.

Reviewing the sun path diagram reveals a fair amount of overshadowing around the edges of the site at grade, most prevalent in the early morning and late evening when the sun is lower in the sky. In a stacked condition however, this low sun angle provides deeper penetration between bed levels.

3. Design Brief and Strategies

3.1 Urban Network

Throughout the city, different site conditions and scales allow a variety of highly specific farms engineered to maximise site potential for raising and producing complementary foodstuffs. Unique site characteristics, such as proximity to water, wind conditions, solar access, and size, are coordinated with the spatial and environmental requirements of individual plants, livestock, and processes. Fields needing direct exposure to the sun may be overshadowed at the lower levels. Processing operations that need daylight rather than sunlight provide a podium on which the fields stack. This ensures the optimization of each site to best benefit the growth and production of the urban food network. Sites with less potential for fields may focus more on processing, meeting the needs of their own raw materials and farms nearby. Processing on site or within the network reduces travel time and distance, and allows opportunities for programming complimentary activities on-site (i.e. programme with less stringent daylighting requirements can occur on lower floors beneath growing fields that need sunlight). Thereby, the inputs and outputs of the individual farm are met through the agricultural network, maintaining a closed system.

Each individual farm mimics the mono-culture practice instituted on industrial farms as needed. One farm may grow tomatoes and peppers which have similar environmental needs but different spatial needs. Performing as part of a larger network enables this level of homogeneity in ways current industrial farms cannot match, as they operate outside of a closed biological system. The cattle farm has a waste problem and the corn field has a fertilizer deficiency [2]. Within the urban network individual farms establish mutually beneficial relationships to close the biological loop. The close proximity of these metro-farms encourages productive adjacencies and simplifies logistical constraints. Distributing the farms throughout the city also provides enough separation to counter the spread of food borne illnesses which can easily destroy an entire season's worth of crops.

3.2 Annual Adaptations

As floor-to-floor heights increase so too does the depth that sunlight penetrates space. To maximize floor density, crops with small demands for vertical space are grown. Initial studies pursued a stepped system, but even with such a parti, the depth of solar penetration is a function of floor-to-floor height. Sun angle calculations prove that greater solar exposure is not achieved by merely stepping bed levels. Straight stacks, by contrast, provide increased density and greater efficiency of plumbing, lighting, and circulation. To provide access to crops and general flexibility, levels are divided into modular soil beds and troughs (1m x 4m and 15mm x 4m respectively) that support recommended crop spacing, provide a manageable dimension, and maximize the penetration of direct solar radiation throughout the year. Crop trays are spaced a minimum of 1.5m apart, as determined by bed depth, plant height, access clearances, and a low winter altitude of 26°. At this angle, sunlight falls 2.75m into the space. In the summer, bed-to-bed heights are adjusted to accept a higher solar altitude.

Taking advantage of the lower sun angle, a higher density of production occurs during the winter by allocating more levels for fields. A result of this adaptation is lower output in summer months, which is in direct contrast to hinterland conditions (Fig. 4). A symbiotic relationship is formed between urban farms and their rural counterparts, as the city supplements the country in the winter, and vice versa during the summer. The relationship between rural and urban farms within a given region becomes complementary rather than competitive. During summer, urban farms can process more than they grow, potentially serving regional suppliers, further reducing food miles and developing connections with outlying farms. By transforming the dynamics of seasonal crop rotation into an architectural language, the building itself changes with the seasons.

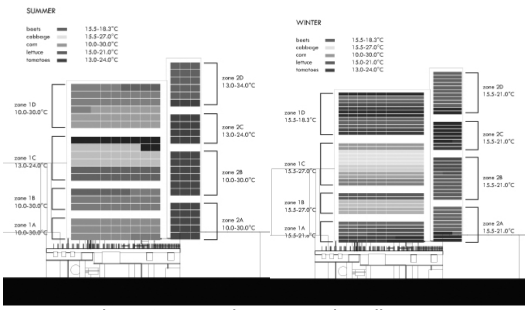

Fig 4. Seasonal crop rotation diagram.

3.3 Brief

Each urban farm consists minimally of growing fields and the necessary operational facilities. Public access to a portion of the site is also required as part of the urban and community network. The 13th Street Farm includes training and education rooms in addition to livestock and processing facilities. A farmer's market and public "sky parks" complete the programme. The brief differs seasonally, spiking in production inversely to the natural cycle. Greater area dedicated to fields exists in the winter months when less food grows locally and more food is imported into the city. The amount of each crop grown is based on dietary guidelines established by the United States Department of Agriculture [14]. The farm provides 25% of the recommended fruit and vegetable intake and 100% of the protein serving for 25,000 people. Smaller farms best operate integrated with other programmes, such as mixed use combinations of agriculture and housing or offices.

Sunlight requirements initially were a critical factor. Combining plants which have lower daylight requirements with livestock resulted in more optimal building layouts. Additionally, combinations of sun loving and shade tolerant plants proved valuable in filling deeper floor areas. Crops were chosen for their high yields and minimal spatial requirements shade tolerance, processing capabilities, potential for continual harvesting, and synergies with other crops. Corn and vine tomatoes capitalize on the void of space created by the greater level to level height in summer. A fruit tree orchard offers a large area for water catchment and chicken pasture thereby serving multiple functions. For meat production, chickens were an obvious choice due to the spatial requirements of beef and pork. Including egg production was an added incentive. Finally, chickens help maintain the orchard by eating worms and fertilising the ground.

Growing seasons of the chosen crops are based on environmental and socio-economic conditions. The environmental factors are access to direct solar radiation and seasonal variations of temperature. Socio-economic conditions include food production levels within the existing agricultural region and potential profits through processing. This is reflected in the urban farm growing schedule where one can see the manipulated crop seasons compliment the natural seasons.

4. Proposal

4.1 Community and Network

The urban farm engages the surrounding buildings, tapping into resources available only in an urban context. In return the farm provides goods, services, and the amenity of public parks and improved microclimates (Fig.0).

01: Solar radiation- allows plant growth, providing food and mitigating urban heat island effect.
02: Harvested Rainwater- allows plant growth, prevents stormwater runoff.
03: Electric power- generated from renewable systems on roofs of neighbouring properties, which can produce approximately 110 kW of power per month using photovoltaic panels [14].
04: Organic waste-from neighbouring commercial and residential properties. New York City produces over 10 million kilograms of waste daily, 39% of which is organic material [5].
05: Gray water recycled from neighbouring properties can be used and cleaned on site.
06: Harvested rainwater from roofs of neighbouring properties, providing 7,784m^2 for water catchment.
07: Revenue generated from street-level food markets and related retail.
08: On site heat recovery.
09: Organic waste/ biofuel generation.
10: Animal waste/ biofuel generation.
11: Recycled Gray water.
12: Fruit and vegetables: apples, pears, strawberries, beets, cabbage, corn, lettuce, tomatoes.
13: Meat: free-range chicken.
14: Eggs.
15: Profit generated from farm network, a potential source of public funds.
16: Public open space.
17: "Air rights" from neighbouring properties can be bought to ensure solar exposure and access to adjacent rooftops.

4.2 Design

The environmental requirements employ different architectural methods for growing crops. Vegetation typically has a growing cycle that aligns the climate wherein, microclimates would not greatly extend the season or produce higher yields or whose natural cycles can be quickened and repeated due to minor, passive climatic interventions. Two architectural types emerge from these crop categories: roof gardens and modular vegetation trays.

Roof Gardens provide single layered open air vegetative spaces, which is a well established type used throughout New York City. At the 13th Street Site, a roof garden spans the entire site, hosting the orchard whose fruit trees have optimal temperature ranges that match the outdoors. Other crops are housed in the vegetation towers in a series of modular trays and troughs. An adaptive semi-permeable envelope consisting of self sealing glazed louvers and insulated interior panels encloses the trays. The envelop moderates the degree to which the interior space couples with the exterior conditions. In New York, strict decoupling occurs in the winter. Conversely, temperatures from late summer to autumn allow an open air mode.

By manipulating the field conditions, planting and harvest seasons are no longer dependent on annual cycles. This is evident in the farm growing schedule. The vegetation tower gives architectural form to the agricultural logic of the city's food production. Delineating separate zones accommodates several temperature ranges (Fig. 4). Colour gradation represents the change in crop over time; the darkest fields were planted first. The density of production, development of crops, and variation in response to climate is all evident in the elevation.

Initial massing for the design began by establishing which parts of the programme needed direct solar radiation (Fig. 5). Programme requiring daylighting only, offices, processing, recycling systems, provide a podium upon which the vegetation fields can sit. Raising the building in this way draws the public into the site and frees the ground level for a market and distribution services. Using the familiar “roof garden” typology, the large orchard clearly identifies the structure as part of the urban agriculture network. This particular roof garden serves as a massive truss, literally and metaphorically supporting the processing, composting, and management spaces which hang from it. Publicly accessible when the chickens are not at pasture, visitors can glimpse down into the processing facilities through openings in the orchard floor.

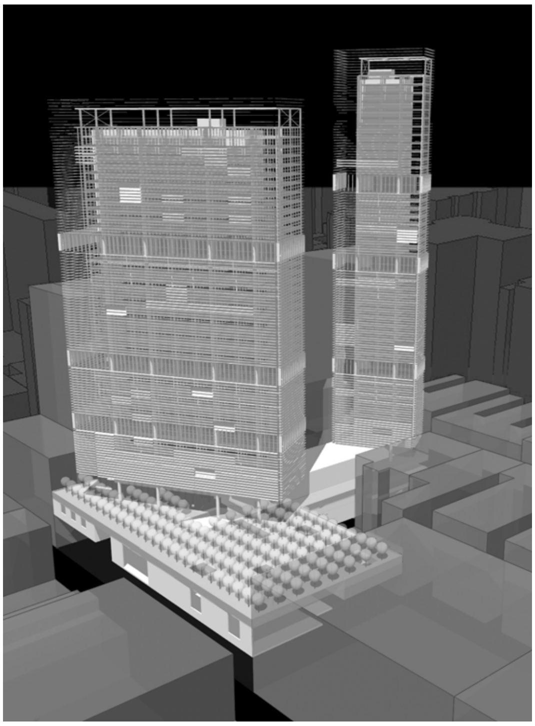

Fig 5 High rise urban farm proposal.

The elevated orchard serves as a podium for the compact, densely stacked vegetation towers. Rotating the towers to face south ensures the maximum penetration of direct solar radiation between levels. The mass of vegetation trays promotes an efficient use of inputs due to its density. Water, fertilizer, and supplemental light reach many plants in a small area. The potential for annual adaptations as previously described strengthens this massing strategy despite the consistent lack of direct solar radiation reaching the north-western area of each level. Primary circulation occurs in the rear core wrapping the north-western corner of the vegetation tower, including cargo and passenger elevators, and stairs. Secondary circulation through the vegetation tower is minimal, primarily to monitor the crops. This circulation is a series of perforated modular platforms, fitting into the same grid as the trays and allowing air flow through the platform and creating less shadow.

An integrated LED light system supplements the sunlight. To ensure optimal growing conditions throughout the year, a supplemental light system is imperative. The key is to design the fields so that this system is used as little as possible. Radiation sensors can consistently control the lighting levels providing the right amount of light (in time) in the right area (over space). Lighting and all other functions, including, water, fertilizer, small harvesters, and environmental monitoring are integrated in the underside of the tray. Each tray plugs into the other trays and connects to the mains on the north side of the tower. Computerized monitors and tray moving machines run up and down the structural frame on vectors to access the plants, provide nutrients, and help harvest.

5. Conclusion

To determine the area receiving more than 6 hours of direct solar radiation simulations were performed using ECOTECT v. 5. To account for the seasonal adaptation of the building, the winter state was tested from 21 October to 21 April, while the summer condition was tested from 21 April to 21 October. In winter the floor to floor height is 1.5 meters while summer enjoys 3 meter heights. Simulations were performed on tray levels that remain throughout the year (whole number heights above grade). Data for the second set of trays (starting at +17.5m) was interpolated from the trays directly above and below. Winter trays directly below a public space receive more direct solar radiation than a typical tray since the public space steps back into the tower. For these six special cases, the simulation was performed since interpolating the results would have been imprecise.

Although ran together, results for each tower were tallied separately. Contour lines displayed in the analysis grid permitted area calculations in autoCAD. Summer and winter data was totalled to produce results for the entire year. Both summer and winter calculations show the total sunlight hours between 06.00 and 20.00, using average daily values and a detailed shading mask. The analysis grid is set from 0 to 8 hours as the crops need a daily average of six hours of direct solar radiation for optimal growth. The values for each layout were totalled and then figured as percentages of their total area. A total of 4,829m^2 receives 6 or more hours of direct solar radiation.

Mean indoor air temperatures were calculated in winter to determine if indoor temperatures can reach optimal growing ranges. Total solar radiation for January, a value of 3,490 Wh/m^2 was used since this month has the lowest average temperature. Using the following formula, T_{in} (mean) = T_o (mean) + G / HLC, calculations show that for single glazing the indoor temperature rises 12K [15]. Double glazing provides 13K but would not justify the difference in cost. Instead, night insulation could be applied to prevent heat loss. Combining these two strategies should provide constant temperatures of at least 15.5°C. Crop rotation must account for a difference in temperature less than 12K.

Stacked farming provides more area receiving the necessary amounts of solar radiation than ground level urban farming. The urban farm contains 5,485m^2 of vegetative area receiving more than six hours of direct solar radiation (including 656m^2 at orchard). At grade, the site does not receive more than 6 hours of direct solar radiation in any area. At roof level the entire site receives more than 6 hours of direct solar radiation amounting to 2,476m^2, less than half that of the vegetation towers.

Furthermore, adaptive conditions lead to a greater gain of direct solar radiation over the year. Adapting the growing season to be marginally (+/-12K) outside of the outdoor air temperatures allows for passive energy growing year round. Creating a dynamic structure that can couple and decouple with the exterior environment is essential to passive farming. The success of this research lies in developing this method of scheduling crop rotation. Such a system will prove valuable in the development of urban farms. Defining field types spatially, roof garden and vegetation trays, is also a valuable step in developing the architectural typology of the urban farm. From here further design research for an environmentally responsive architecture can be undertaken including more rigorous performance based simulations. These are the most essential steps in providing validity to the urban farms claims. The development of more site specific proposals and their quantitative results continues.

Table 1: Sun hour results for tower plans.

	TOWER 1- SUMMER					TOWER 1- WINTER				
HEIGHT	plate area m^2	h≥6	6>h≥4	4>h≥2	2>h	plate area m^2	h≥6	6>h≥4	4>h≥2	2>h
+16m	342	9.0	30.0	28.0	275.0	342	79.0	35.0	45.0	183.0
+17.5m	0					342	81.5	34.5	50.5	175.5
+19m	342	14.0	29.0	28.0	271.0	342	84.0	34.0	56.0	168.0
+20.5m	0					342	82.5	34.5	56.5	168.5
+22m	342	13.0	30.0	33.0	266.0	342	81.0	35.0	57.0	169.0
+23.5m	342					342	135.0	39.0	50.0	118.0
+25m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+26.5m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+28m	342	11.0	30.0	33.0	268.0	342	82.0	36.0	53.0	171.0
+29.5m	0					342	82.0	36.5	54.0	169.5
+31m	342	9.0	31.0	26.0	276.0	342	82.0	37.0	55.0	168.0
+32.5m	0					342	83.5	36.0	53.5	169.0
+34m	342	14.0	27.0	34.0	267.0	342	85.0	35.0	52.0	170.0
+35.5m						342	135.0	36.0	51.0	120.0
+37m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+38.5m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+40m	342	13.0	30.0	28.0	271.0	342	83.0	34.0	55.0	170.0
+41.5m	0					342	82.5	35.0	55.0	169.5
+43m	342	13.0	34.0	26.0	269.0	342	82.0	36.0	55.0	169.0
+44.5m	0					342	82.5	34.0	56.0	169.5
+46m	342	22.0	20.0	29.0	271.0	342	83.0	32.0	57.0	170.0
+47.5m	0					342	83.5	32.0	58.5	168.0
+49m	342	20.0	22.0	30.0	270.0	342	84.0	32.0	60.0	166.0
+51.5m	0					342	85.5	31.5	59.5	165.5
+52m	342	21.0	18.0	34.0	269.0	342	87.0	31.0	59.0	165.0
+53.5m	0					342	87.5	31.5	57.0	166.0
+55m	342	23.0	22.0	29.0	268.0	342	88.0	32.0	55.0	167.0
+56.5m	0					342	141.0	39.0	47.0	115.0
+58m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+59.5m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+61m	342	21.0	22.0	30.0	269.0	342	86.0	34.0	57.0	165.0
+62.5m	0					342	85.5	33.5	57.0	166.0
+64m	342	20.0	21.0	31.0	270.0	342	85.0	33.0	57.0	167.0
+65.5m	0					342	85.0	33.0	57.5	166.5
+67m	342	20.0	21.0	34.0	267.0	342	85.0	33.0	58.0	166.0
+68.5m	0					342	86.0	32.5	56.5	167.0
+70m	342	20.0	23.0	30.0	269.0	342	87.0	32.0	55.0	168.0
+71.5m	0					342	85.5	33.0	55.5	168.0
+73m	342	21.0	22.0	28.0	271.0	342	84.0	34.0	56.0	168.0
+74.5m	0					342	84.0	34.0	56.0	168.0
+76m	342	342.0	0.0	0.0	0.0	342	342.0	0.0	0.0	0.0
+77.5m										
+79m										
+80.5m										
+82m										
+83.5 m										
+85m										
Totals	6,498	626	432	511	4,587	11,970	3,357	1,161	1,873	5,580

	TOWER 2- SUMMER					TOWER 2- WINTER				
HEIGHT	plate area m^2	h≥6	6>h≥4	4>h≥2	2>h	plate area m^2	h≥6	6>h≥4	4>h≥2	2>h
+16m	60	0.0	2.0	4.4	53.6	60	0.0	0.0	9.0	51.0
+17.5m	0					60	0.0	3.5	12.5	44.0
+19m	60	0.0	3.0	6.0	51.0	60	0.0	7.0	16.0	37.0
+20.5m	0					60	3.0	14.0	15.0	28.0
+22m	60	1.0	8.0	11.0	40.0	60	6.0	21.0	14.0	19.0
+23.5m	0					60	6.0	21.0	14.5	18.5
+25m	60	1.0	8.0	10.0	41.0	60	6.0	21.0	15.0	18.0
+26.5m	0					60	6.0	21.0	14.5	18.5
+28m	60	2.0	9.0	10.0	39.0	60	6.0	21.0	14.0	19.0
+29.5m	0					60	15.0	24.0	12.0	19.0
+31m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+32.5m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+34m	60	2.0	10.0	9.0	39.0	60	6.0	21.0	13.0	20.0
+35.5m	0					60	6.5	17.5	16.0	20.0
+37m	60	2.0	5.0	14.0	39.0	60	7.0	14.0	19.0	20.0
+38.5m	0					60	7.0	16.5	17.0	19.5
+40m	60	3.0	9.0	9.0	39.0	60	7.0	19.0	15.0	19.0
+41.5m	0					60	8.0	18.5	14.0	19.5
+43m	60	3.0	8.0	10.0	39.0	60	9.0	18.0	13.0	20.0
+44.5m	0					60	10.5	17.5	13.0	19.0
+46m	60	5.0	9.0	9.0	37.0	60	12.0	17.0	13.0	18.0
+47.5m	0					60	13.0	17.0	13.5	16.5
+49m	60	7.0	8.0	8.0	37.0	60	14.0	17.0	14.0	15.0
+51.5m	0					60	26.0	16.0	10.0	8.0
+52m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+53.5m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+55m	60	8.0	8.0	9.0	35.0	60	16.0	15.0	13.0	16.0
+56.5m	0					60	17.0	14.0	13.0	16.0
+58m	60	9.0	6.0	11.0	34.0	60	18.0	13.0	13.0	16.0
+59.5m	0					60	18.0	13.0	13.0	16.0
+61m	60	9.0	7.0	10.0	34.0	60	18.0	13.0	13.0	16.0
+62.5m	0					60	20.0	12.0	12.0	16.0
+64m	60	9.0	7.0	10.0	34.0	60	22.0	11.0	11.0	16.0
+65.5m	0					60	33.0	11.0	9.0	5.0
+67m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+68.5m	Public	NA	NA	NA	NA	Public	NA	NA	NA	NA
+70m	60	9.0	6.0	10.0	35.0	60	29.0	9.0	12.0	10.0
+71.5m	0					60	28.0	9.5	12.5	10.0
+73m	60	8.0	7.0	10.0	35.0	60	27.0	10.0	13.0	10.0
+74.5m	0					60	27.0	10.0	13.5	9.5
+76m	60	8.0	7.0	10.0	35.0	60	27.0	10.0	14.0	9.0
+77.5m	0					60	28.5	10.0	13.0	8.5
+79m	60	8.0	6.0	12.0	34.0	60	30.0	10.0	12.0	8.0
+80.5m	0					60	30.0	10.0	12.0	8.0
+82m	60	7.0	8.0	10.0	35.0	60	30.0	10.0	12.0	8.0
+83.5 m	0					60	30.0	10.0	12.0	8.0
+85m	60	60.0	0.0	0.0	0.0	60	60.0	0.0	0.0	0.0
Totals	1,260	161	141	192	766	2,460	685	563	530	693

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