fordhamopolis

a vision for an urban landscape in harmony with the natural world

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Inspired and Directed by Dr Dickson Despommier

To keep up with the project, please visit our website www.fordhamopolis.com

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INTRODUCTION

Fordhamopolis is a theoretical project undertaken by ten undergraduate students at Fordham University in an attempt to better understand the challenges of urbanization and the complexity of human ecology. The group included students pursuing Environmental Studies, Environmental Science, Visual Arts, and Urban Studies majors. The project culminated in this report and its corresponding website, which will remain as a resource to future groups. Our hope is that they may be inspired by the products of our labor, and compelled to improve upon them. This project occurred under the supervision and direction of Dr. Dickson Despommier. Without his support, optimism, and sense of humor, this project would not be possible.

CHARTER

I
the principle of human ecology
wherein we assert that human beings occupy an essential place in natural, social, and built environments. as members of the complex web and flow of energy in our world, we have a responsibility to be aware of the impact of our actions and to act consciously to retain the integrity and intricacy of mother nature and her environment

II
the principle of biomimicry
wherein we assert that the designs and innovations inherent in nature offer the most promising solutions for humans and the critical dilemmas they face. in this regard the imitation of natural laws and networks of of sustainability and equilibrium provide guiding principle for all forms of human organization and development

III
the principle of self-sustenance
wherein we assert the importance of sustainability in urban spaces and the need for cities of the future to accommodate to the needs of current populations and safeguard the environment for future generations. in this regard, standards and regulations will be instituted to ensure that human actions do not harm or introduce waste into the natural environment

IV
the principle of artificial intelligence

wherein we assert the necessity for the incorporation of advanced technological systems and artificial intelligence (ai) to monitor and act as a safeguard for the community. regulated and human controlled (ai) will function to provide data analysis and action to individual citizens, corporations, and public institutions for the purposes of sustainability

V
the principle of community
wherein we assert the rights and responsibilities of the people united by bonds of community and establish equality for all citizens. as the basis of social organization in the urban milieu the community takes care of all its members, the young, the weak, the old, and functions to provide a source of political strength.

LOCATION

Fordhamopolis is to be located near Paralimni, a town on the southeast coast of the Mediterranean Island of Cyprus. We chose this location because of its warm, sunny climate and coastal setting, which are both pleasant to live in and promising in terms of capturing solar energy. However, like many major cities around the world, Cyprus is relatively dry and suffers from water shortages that impacts its food supply, public health, and general quality of life. Droughts everywhere are expected to increase in frequency and scope due to climate change, and the shortage of freshwater will remain one of the largest threats to the sustained health of humans and the greater biotic community in years to come. Thus, situating Fordhamopolis by Paralimni was an exercise to help us formulate a solution to this global environmental threat that can be replicated in the world's fastest developing regions, many of which are located around the southeastern border of the Mediterranean and are ecologically very similar to Paralimni.

CITY PLAN

Fordhamopolis is designed to accommodate a population of 100,000 within 2 square miles. The city plan consists of neighborhood modules repeated to create boroughs. Each neighborhood can house 9,600 people and features 12 buildings arranged in clusters of 3 around a large public space comprised of a 2.6 acre, central public park with greenery, water features, and walking and biking trails, and four public plazas, each about 0.7 acres in size, located between each cluster of buildings. The buildings in question are 50 story mixed use constructions, the first 10 floors serving commercial, municipal, educational, and institutional functions. The remaining 40 floors are residential and can house an average of 20 people per floor in 5 apartments, putting the capacity of each building at 800 people. The plazas between each set of 3 buildings will serve as loci for outdoor markets from surrounding stores, outdoor restaurant and cafe terraces, and community activities and interactions.

A group of 4 neighborhoods comprises a borough, and the entire city consists of 3 boroughs aligned facing south. The layout of the boroughs is such that large areas remain in the center of and surrounding the complex of neighborhoods. The matrix between neighborhoods facing south will house all vertical farm complexes to maximize their exposure to sunlight. The 10.6 acre square area at the center of each borough will be allocated to industries, where the production of any materials and products will take place. Two kinds of circulation pathways will connect these factories to the surrounding neighborhoods: at grade, bike paths and pod rails for the movement of people, and flight paths for the transportation of goods to retail locations by A.I. controlled drones of various sizes. This airborne transportation will avoid cluttering human circulation routes with industrial transport, and the design of all buildings will feature a hollow central core within which drones can descend and stop at any floor for deliveries . The outer sides of mixed use buildings (facing away from the central plazas and parks) will feature ground floor retail, connected by circulation paths. The three central sections in blue represent zones for all municipal, educational, and institutional buildings, which will have low constructions scattered among greenery to maintain a positive aura. The outer sections represent the zones allocated to industrial production.

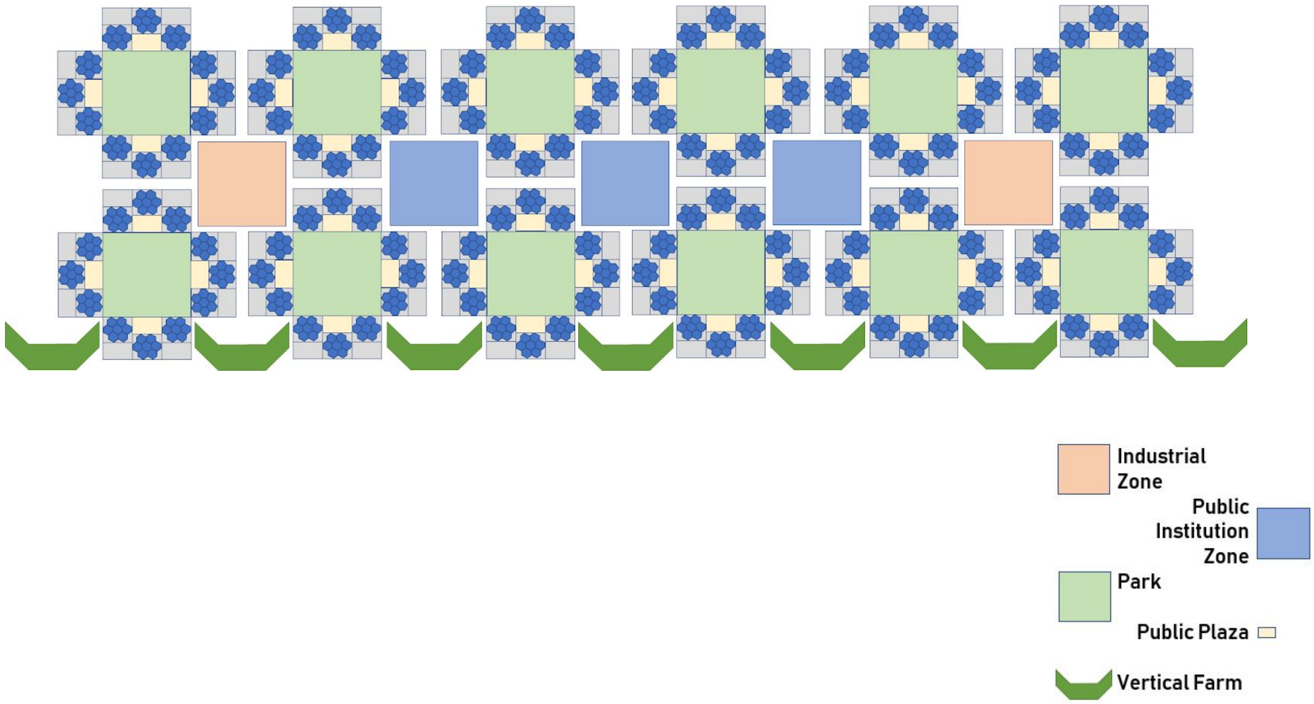


Figure 1: city plan with legend

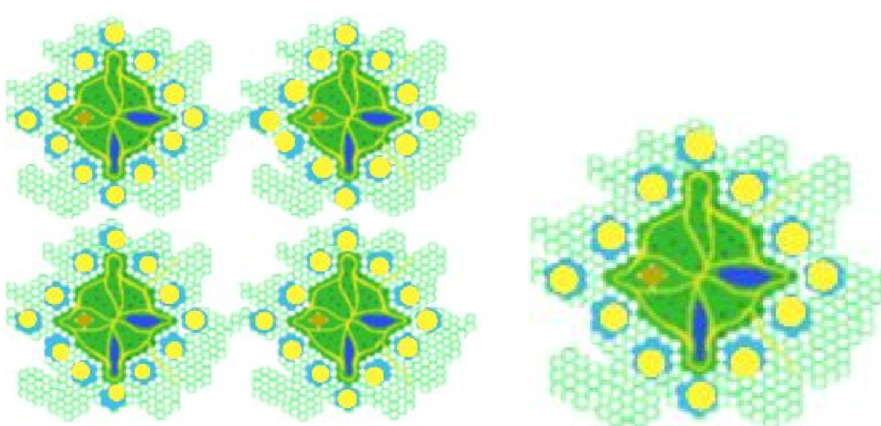
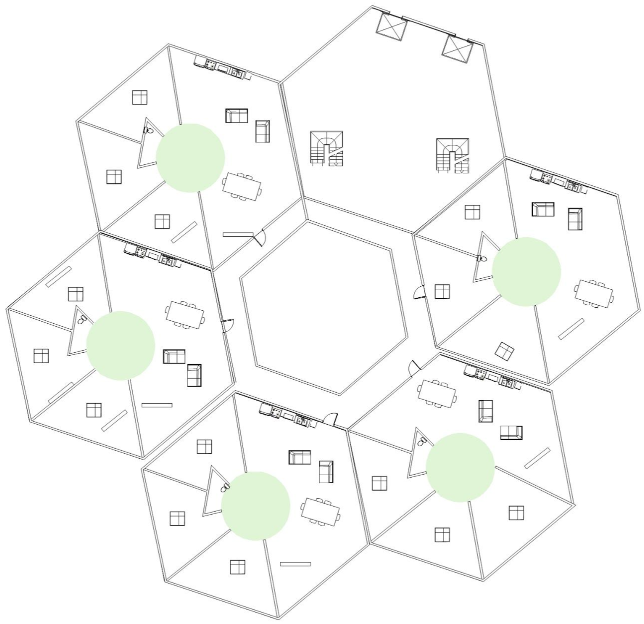
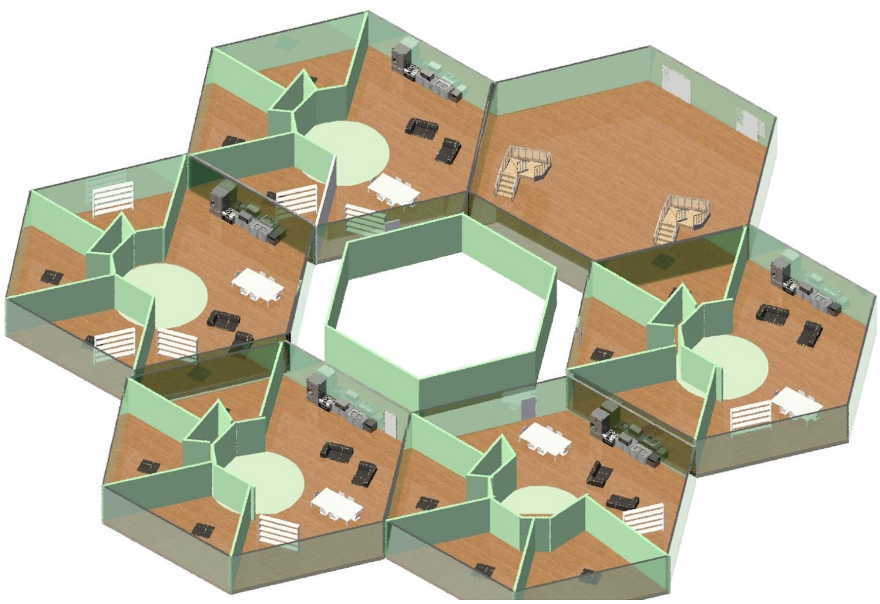
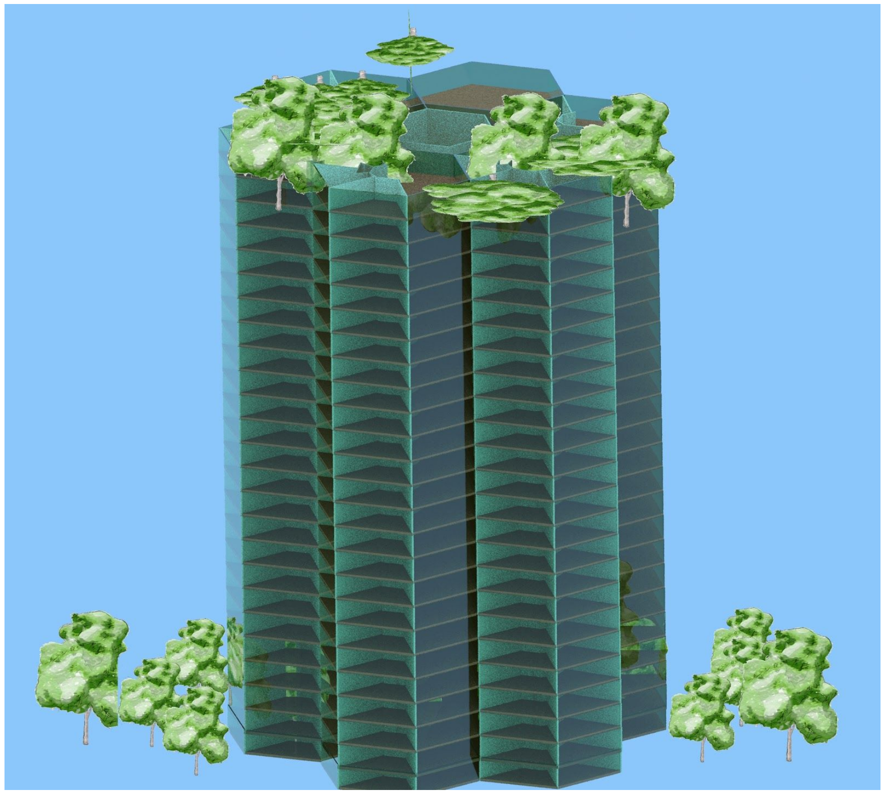


Figure 2: 4 neighborhoods comprise a borough (left), one neighborhood (right)

Figures 5&6 : Plan View and Model of Residential Floor Plan





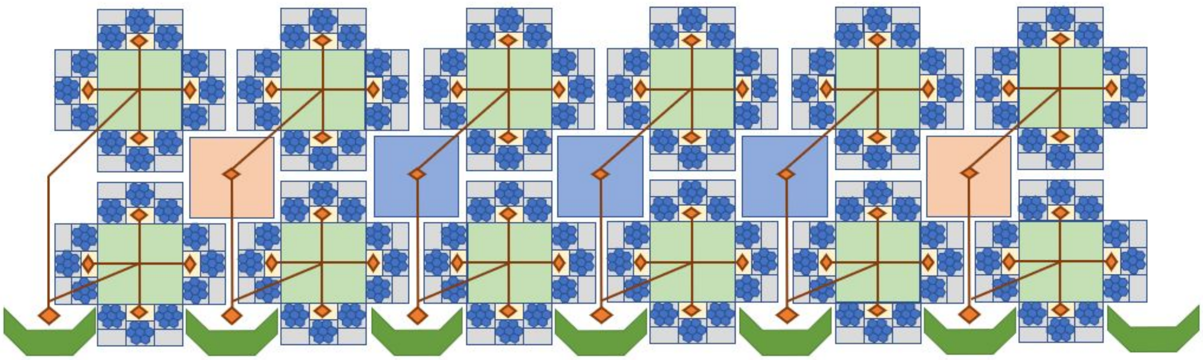


7: Rendering of Residential/Mixed Use building

WASTE

Abstract

This section covers the sorting, movement and treatment of organic and non-organic waste. It begins with the site of disposal in buildings and the artificial intelligence used to sort it, then moves to explain the process by which food waste is treated. It summarizes passive waste management to be implemented surrounding consumption and waste, and ends with an explanation of the plasma arc gasification system, which safely destroys virtually anything put into it and powers itself in the process.



Layout of the waste management systems (small diamond: underground collection and sorting plant, large diamond: waste processing plant)

Introduction

If Fordhamopolis is truly going to revolutionize life in the city and the relationship between the natural and built environments, the entire concept of "waste" must be interrogated. There can be no sedentary graveyards of items, perfectly reusable but replaced, perhaps time and time again, all arriving in a pit that accumulates toxic leachate. This is the status quo. So too is the harsh reality of starvation, and double bagged garbage in locked dumpsters. The concepts of "food" and "waste" are almost incompatible, although the industrialization of its production has certainly bound the two together inextricably. Our city begins with the aspiration of changing the way discarded materials, food or otherwise, are thought of altogether. Ridding oneself of something should be an unusual event, as re-appropriation, reuse, or conversion into energy will be automatic responses. As with all other things in Fordhamopolis, the burden of sustainability is not placed upon the individual. Waste disposal and re-appropriation will be a guilt-free, thoughtless experience, as the system will be designed to received and manage what is put into it. Construction the entire system from the ground up, beginning with principles of systemic efficiency, rather than awareness of the individual, will allow it to function more effectively and less to the frustration and confusion of the people it is meant to serve.

Disposal of Waste

In accordance with our vision of building in modular units situated around permanent, sedentary building cores, it naturally follows that waste should be directed through them. As it turns out, the trash-chute is a proven design that earned its place in this city of the future. With one central location on each floor, into which food waste is deposited down one chute and all other wastes down another, the concept is rather basic. Organic and inorganic matter will then follow paths to waste processing centers.

Subterranean Vacuum Network (SVN)

From here, all non-organic waste will enter an underground network of small, pressurized tubes that move the different types of material to one of the city's multiple waste processing centers. A number of these systems have been installed across the world, namely by a company called Envac, which was recently granted the contract for waste management in New York's multi-billion dollar Hudson Yards project.[1] Their existing operation in Roosevelt Island has successfully moved trash away from residences, parks, and restaurants for 40 years, operating at upwards of 65 miles per hour.[2] The biggest advantage of using vacuum tubes to transport waste is that it eliminates the need for a collection operation and the carbon emissions that come with operating many large trucks multiple times per day. Additionally, employing a system of this sort stores waste below ground for very short periods of time, limiting the odors and pests that come with dumpsters or curbside collection. All street trash receptacles will also connect to this system. In order to limit the energy used in moving the refuse, each receptacle will be equipped with a scale, sensor, and computer capabilities to communicate with other containers, beginning suction and releasing the garbage into the tube only when it is necessary to do so.

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[1] Clarke, Katherine. "Trash to Be Handled by Pneumatic Tube at Hudson Yards." *NY Daily News*, New York Daily News, 27 June 2014.

[2] Bodarky, George. "How New York's Roosevelt Island Sucks Away Summer Trash Stink."*NPR: Environment and Energy Collaborative*, NPR, 26 July 2017, www.npr.org/2017/07/26/539304811/how-new-york-s-roosevelt-island-sucks-away-summer-trash-stink.

Waste Service Facilities and Plasma Arc Gasification

Upon arriving the nearest of the cities two waste service facilities, large instruments like MAX-AI engineered by Bulk Handling Systems will properly filter and move different types of recyclables to their appropriate bins. These machines are capable of recognizing different types of materials and learning from their own mistakes.[3] After sorting, plastics, glass, paper, cardboard, and fabrics are all recycled. Remaining food waste is sorted into another anaerobic digester operated by the waste service facility. For all waste that is deemed unable to be reused, recycled, or re-appropriated, there must be a safe and sustainable mechanism for disposal. Fortunately, the answer already exists and is well within reach: plasma arc gasification. Essentially, this system incinerates trash – traditionally a very toxic and inefficient means of disposal – but does so at such high temperatures (7000-13000 °F), in conjunction with byproduct collection instruments, to ensure that no particulate matter, dioxins, or greenhouse gases escape into the atmosphere.[4] This means that it is safe to gasify even toxic or poisonous waste that would otherwise be, at best, treated then landfilled. The byproducts include synthetic gas, composed of carbon monoxide and H2, to be combusted on-site to power the plasma torch. As such, the system is self-sustaining. Also produced in the process of gasification is slag, composed primarily of heavy metals, which can be converted into construction and manufacturing materials.

The energy production of plasma arc gasification varies, depending primarily upon the size of the operation and the rate at which it is fed waste. Ideally, only a small fraction of what is disposed of in the city will arrive here, at least not until it has been recycled a number of times. As such, its energy production is not expected nor needed to be a significant source of the city's supply. Still, when using steam-turbine power generation, a plasma arc system could produce up to 816 kWh for each ton of municipal standard waste, nearly twice as efficient as incineration, without any of the ecological impacts. The best model at present for plasma arc waste disposal is found in Utashinai, Japan. It generates twice the amount of electricity necessary to

[3] O'Connor, Mary Catherine. "Using Artificial Intelligence For Smarter Recycling." *GE Reports*, General Electric, 10 July 2017, www.ge.com/reports/dumpster-diving-robots-using-ai-smart-recycling/.

[4] http://www.energy.ca.gov/proceedings/2008-ALT-1/documents/2009-02-17_workshop/presentations/Louis_Circeo-Georgia_Tech_Research_Institute.pdf

sustain its own operation, and gasifies 220 tons of MSW, or 160 tons of a shredded automobile and MSW mix everyday. Even if Fordhamopolis were to maintain the American average of 4.4 pounds of waste per person per day, one gasifier of this magnitude would be capable of handling all the refuse of the city.[5] Ultimately, if scaled to the adequate capacity, plasma-arc gasification holds the potential to "mine" Cyprus's multiple landfills, converting once-buried waste into clean energy, in what is a picturesque metaphor for the ways Fordhamopolis can right the wrongs of the past.

Food Waste

In the United States, food is the largest source of all municipal waste.[6] Typically food waste is thrown away and sent to landfills, where it is forgotten about by the general public. This excess is problematic because food waste is actually the third highest source of carbon emissions globally.[7] According to the Food and Agriculture Organization of the United Nations (FAO), "Without accounting for greenhouse gas emissions from land use change, the carbon footprint of food produced and not eaten is estimated at 3.3 Gigatons [billion tons] of CO2 equivalent: as such, food wastage ranks as the third top emitter after the USA and China".[8] When food is sent to landfills, the food decomposes through anaerobic digestion because of the lack of space and compact conditions of landfills.

Although ideally Fordhamopolis will have a low food waste footprint, there will still be food waste that will need to be taken care of sustainably. Anaerobic digestion will take care of disposing of the food waste in a way that is safe, environmentally friendly, and useful. An anaerobic digester (AD) acts as "a built system (lagoons or tanks) where anaerobic digestion takes place. Anaerobic digesters manage organic wastes, produce gas and digested materials, minimize odors, reduce pathogens, and reduce solid wastes"[9]. The digested materials that are produced as a product of the anaerobic digestion known as "digestate" is rich in

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[5] Willis, Ken P., et al. "Plasma Gasification: Lessons Learned at Eco-Valley WTE Facility." *18th Annual North American Waste-to-Energy Conference*, 11 May 2010, doi:10.1115/nawtec18-3515.

[6] Gerlock, Grant. "To End Food Waste, Change Needs To Begin At Home." NPR, NPR, 17 Nov. 2014, www.npr.org/sections/thesalt/2014/11/17/364172105/to-end-food-waste-change-needs-to-begin-at-home.

[7] http://www.fao.org/docrep/018/i3347e/i3347e.pdf

[8] Ibid.

9 "Anaerobic Digestion (AD)." *EPA*, Environmental Protection Agency, 2 Mar. 2017, www.epa.gov/anaerobic-digestion.

nutrients and can be used as fertilizer or compost for the local community gardens at Fordhamopolis. Biogas is also produced during anaerobic digestion, and it is considered a renewable energy source because “it is produced from natural resources that are replenished in short periods of time”[10]. Anaerobic digesters are meant to capture the methane and carbon dioxide that would have otherwise escaped into the atmosphere, perpetuating the negative effects of climate change. The biogas can be used to power the anaerobic digester, but it can also be used to remove carbon from the atmosphere. New technology by Cogent Heat Energy Storage Systems (CHESS) generates electricity while also removing carbon dioxide from the air. “It works by putting natural gas into a fuel cell, which generates electricity and heat. The generated heat is then used to break down limestone into lime and carbon dioxide. All of the carbon dioxide generated from the fuel cell and the broken down limestone is pure and can be sequestered cheaply and easily, and the lime that is left at the end of the process absorbs the carbon in the atmosphere”[11]. In this case, we have dealt with food waste in a sustainable way, that is in fact beneficial for the environment.

Passive Waste Management

In the vision for Fordhamopolis, the current scale of food waste will be an abstract concept and will nowhere near reach proportions of food waste of this era. Americans waste 150,000 tons of food each day, equal to about a pound per person every day.[12] By taking passive measures to change the culture of food waste, this will make an immense impact in reducing food waste. For starters, refrigerators will be much smaller than the behemoth appliances that exist today. Residents of Fordhamopolis will only be able to fit the food for the day, and maybe the following day. Additionally, refrigerators will also be outfitted with artificial intelligence to aid residents in food shopping. The technology for these smart fridges already exists, Imagine the following scenario: you are at the supermarket but you can’t remember how many bottles of milk you have left in the fridge. You take out your phone and ask your fridge whether the milk supply would last until next week or not. The answer is positive so you don’t buy

10 Ibid.

[11] Saint, Amanda. “Burning Natural Gas to Remove CO2 Emissions .” *Eniday*, www.eniday.com/en/technology_en/removing-carbon-from-the-air/.

[12]Milman, Oliver. “Americans Waste 150,000 Tons of Food Each Day – Equal to a Pound per Person.” *The Guardian*, Guardian News and Media, 18 Apr. 2018, www.theguardian.com/environment/2018/apr/18/americans-waste-food-fruit-vegetables-study.

any more milk. Mission accomplished for your AI powered smart fridge" [13]. We imagine AI refrigerators to be integral in learning residents shopping behavior, and making better and more informed shopping decisions, therefore reducing food waste. For the most part, Fordhamopolis residents will be eating fresh, and shopping on a daily basis so the reliance on refrigerators will be less than currently. Food that residents won't use before it begins to decompose could be offered up through food sharing programs, fostering a sense of community throughout the residents of Fordhamopolis.

WATER

Abstract

Fordhamopolis will use innovative technologies for its water systems in every area possible. Our primary goal is to be an example in efficiency and conservation while catering to all of the needs of residents. By tackling every aspect of water use in Fordhamopolis, from private to agricultural, we have devised a multifaceted plan to obtain, distribute, and reuse water. By comprehensively approaching all of the major areas of water use, including pumping, desalination, personal use, wastewater treatment, agriculture, and indoor climate control, the city aims to reclaim all used water and eliminate water waste. The aforementioned sections will rely on one another to create a virtually closed circuit for water throughout the Fordhamopolis system. Some levels of evaporation loss will take place through personal and agricultural uses; however, even in these cases we have striven for the minimum amount of external losses. To summarize, the pumping system will mimic the xylem and phloem system in plants, the desalination plant will combine technology from the Sorek plant in Israel and Massachusetts Institute of Technology, personal water use will incorporate efficient appliances and reuse grey water, the waste water treatment system will

13 "AI Refrigerators: Here's Where We Are Right Now – The AI Center." *The AI Center*, 21 Nov. 2017, theaicenter.com/ai-fridge/.

reclaim water for maximal reuse, and the agriculture system will use a loop system of irrigation while rainwater collection and purification will provide drinking water to the city's residents. The entirety of Fordhamopolis will be engineered so as to require minimal additional inputs of water for functional and irrigation purposes once all water systems are initially filled using desalination. All used water will be reclaimed and reused in a manner that mimics the hydrologic cycle in nature, in which water resources are sustainably reused circularly to sustain life. For further questions, please contact Madeleine Griffith or Chloe Jaquenoud.

Introduction

Water is the foundation of all life on Earth. Water sustains living beings and is a huge factor in the regulation of Earth's climate over time. Our approach to water as a limitless resource has led our current water systems to develop in an unsustainable manner. According to the US Geological survey, approximately 71% of Earth's surface is covered in water with 96.5% of that in the oceans as salt water.[14] The total amount of water on Earth is estimated to be roughly 326 million trillion gallons, but the US alone withdraws 355 billion gallons of water everyday.This water is used residentially and in many industries such as agriculture, manufacturing.[15] One of the primary goals of Fordhamopolis is to create a city that is completely sustainable. In order to achieve this goal, we will implement a major upheaval in Western societies perception of water by creating new urban pathways for water while spurring a paradigm shift in the way people think about water use. Everything from toilets to farming will be adapted to meet the needs of the residents of Fordhamopolis, while simultaneously establishing water recycling systems adapted to Fordhamopolis' specific environment.

Fordhamopolis is located in present-day Paralimni in Cyprus. The annual average rainfall for Paralimni is 351mm, which over the area of the present city's 18.5 square miles equates to 0.351m, or about 4,442,889,165 gallons. The city limits of

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[14] Howard Perlman, "How much water is there on, in, and above the Earth?", US Geological Survey, District of Columbia, 2016. https://water.usgs.gov/edu/earthhowmuch.html
[15] Water-Use Web Team, "Industrial Water Use", US Geological Survey, District of Columbia, 2016. https://water.usgs.gov/watuse/wuin.html

Fordhamopolis however is only 2 square miles, so in that case there is only about 480,312,342 gallons. Although from a glance this number may seem large, the US utilizes 740 times that amount every single day.[16]

Water is a necessary part of sustaining human life and functions because it acts as the building material for every cell. Water regulates our internal body temperature through sweating and respiration and flushes out waste through urination. Adult males require 3 Liters and females require 2.2 Liters for direct consumption but for overall use men and women are about equal.[17] Fordhamopolis will use new innovations that combine the newest technologies available with artificial intelligence and biomimicry to implement a sustainable pumping, desalination, geothermal climate control, wastewater treatment, rainwater collection and agricultural irrigation systems.

Pumping System

One of the primary changes Fordhamopolis is striving to make is incorporating natural systems that have evolved over millennium. An important element of biomimicry in terms of water use is the way in which we will deliver water from the source/desalination plant, and into people's homes. In nature, specifically the *Sequoia sempervirens*, or California Redwood Tree has adapted to transport water from deep underground all the way into the leaves and branches 350 feet up into the air.[18] To accomplish this incredible engineering, trees use a system of cells called xylem and phloem. Xylem is composed of elongated cells "once the cells are formed, they die. But the cell walls remain intact and serve as an excellent pipeline to transport water" while phloem is tissue "responsible for translocating nutrients and sugars... to areas that are metabolically active", so these systems have interesting applications to residential buildings.[19] Each room in a building can be considered a metabolically active site, so it is to each of these locations that the xylem and phloem need to transport water. Xylem and phloem adapt throughout the year with each season and

[16] Water-Use Web Team, "Total Water Use", US Geological SUrvey, DIstrict of COlumbia, 2016. https://water.usgs.gov/watuse/wuto.html
[17] Howard Perlman, "The water in you", US Geological Survey. District of Columbia, 2016. https://water.usgs.gov/edu/propertyyou.html
[18] Donald J. Merhaut, "How do large trees, such as redwoods, get water from their roots to the leaves?", Scientific American. Asuza, CA, 1999. https://www.scientificamerican.com/article/how-do-large-trees-such-a/
[19] I.b i.d.

supply the tree with as much water and nutrients as it needs. In the winter trees become semi-dormant, and this can be applied to night time when residents would be sleeping and not needing as much water in their pipes. In the summer, assuming there is no drought, trees are constantly pumping water to every area, so this can be applied to the day time when water demand is higher. “The suction that exists within the water-conducting cells arises from the evaporation of water molecules from the leaves” so when a tap is opened in a home, or farms need to water the plants, then water will automatically be available where it is needed.[20] There are already examples of this technology being used on small scale so before Fordhamopolis comes to fruition more experimentation and expansion will need to take place, but researchers have already created “hydrostatic pressure developed [by a] synthetic passive loader” to transport water and sugar water.[21] In addition, by using a combination of artificial intelligence monitoring to look for demand trends we will create an efficient network of pipes that mimics the method in which xylem, freshwater, and phloem, wastewater, function in nature to get water where it is needed the most. The dicot system will be the primary example for building the piping system through the Fordhamopolis residential buildings.

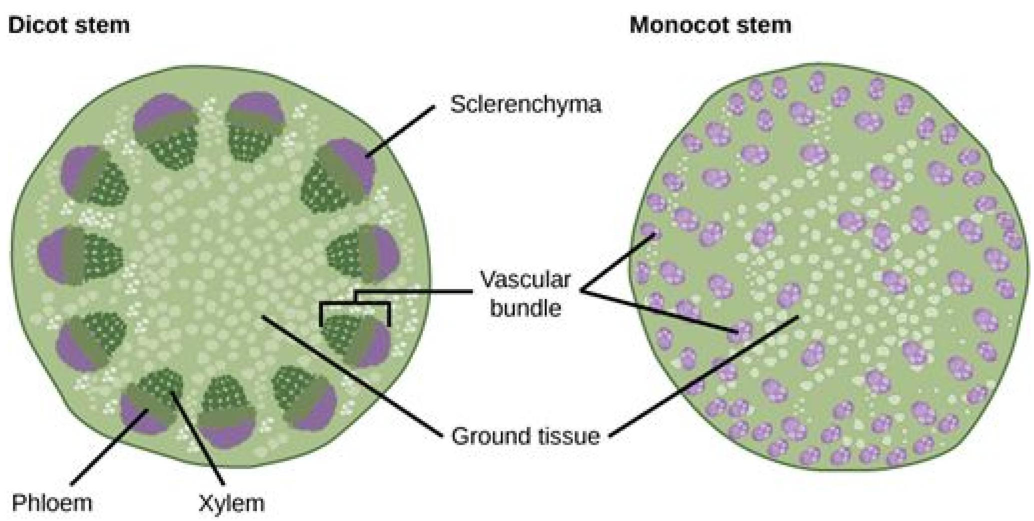

Figure 1. Cross sections of dicot and monocot stems showing the vascular structures[22]

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[20] Donald J. Merhaut, “FOLLOW-UP: How do trees carry water from the soil around their roots to the leaves at the top? Clearly, they are fighting gravity--so how do they do it?”, Scientific American. Azusa, CA, 1999. https://www.scientificamerican.com/article/follow-up-how-do-trees-ca/

[21] Jean Comtet, “Passive phloem loading and long-distance transport in a synthetic tree-on-a-chip”, Nature Plants, 2017. https://www.nature.com/articles/nplants201732

[22] Shana Kerr, “Biology 1520”, Georgia, 2016. http://bio1520.biology.gatech.edu/growth-and-reproduction/plant-development-i-tissue-differentiation-and-function/

Although this system may work well for residential buildings that need smaller amounts of water everywhere throughout the building a different type of pumping system will be used in the agriculture buildings. The plants constant need for water makes the requirements for those buildings and so a traditional piping system will make more sense for those buildings.

Desalination System

We will model our desalination plant off the Sorek plant near Israel (Figure 2). Sorek utilizes reverse osmosis to convert saltwater into freshwater. Traditionally this has been a very expensive process because it requires pushing pure water through a very small pore so that the salt ions do not get through. In our system atom-thick sheets of carbon called graphene followed by "tentacle like brushes made of polyamide that are hydrophilic" will increase the efficiency even further than the traditional polymer membranes.[23] These graphene membranes could cut the energy required by 15 to 46 percent which means more energy can go to other sectors of Fordhamopolis. Other aspects of the Sorek plant is the size and types of pumps, by increasing the diameter from 8 inches to 16 or potentially 20 inches we can save on piping and other hardware.[24] An important element in order to maintain the high output and efficiency we will strive for is constant maintenance. Although artificial intelligence monitoring will be in place, some damage due to constant use may occur and it is crucial to have people available with the knowledge and replacement components available to keep it running. The approximately 627,000 cubic meters, or 165,635,877 gallons, that will be created each day can then be recycled and used in more conservation friendly ways.[25] The wastewater treatment plants will create enough clean water per day that the added 165.5 million gallons per day will be more than adequate. Desalination is the best option for Fordhamopolis because of the low rainfall it receives each year and the limited groundwater availability. By implementing innovative technology into the Sorek 2.0 plant located in Paralimni, Fordhamopolis can serve as an example for places that will inevitably have to turn to desalination due to growing populations and the necessity for clean water. The plant will be used to

[23] David Talbot, "Desalination out of Desperation", MIT Technology Review. Boston, 2014. https://www.technologyreview.com/s/533446/desalination-out-of-desperation/
[24] David Talbot, "Megascale Desalination" MIT Technology Review. Boston, 2015. https://www.technologyreview.com/s/534996/megascale-desalination/
[25] Ibid.

supply the city's water systems upon their activation, but most systems will feature mechanisms for the reuse of water. Thus, the plant will not need to be kept running at a high rate once all of the systems are initially saturated with water. The Sorek 2.0 desalination plant is going to be one of the most important facilities in Fordhamopolis because of the irreplaceable service it provides, and as result will also supply the city with a lot of stable jobs from engineering, to maintenance, to data configuration. The A.I. system in Fordhamopolis will play a large role in the monitoring and control of the all water systems. A.I. will track the amount of losses throughout the city, and be responsible for the activation of the desalination plant to replenish the water systems. Over time, A.I. will help the city's water systems become increasingly efficient through data monitoring and corresponding adjustments.

Figure 2. Sorek desalination plant near Palmachim, Israel.[26]

Personal Use

Daily human activities in the home involve the use of large quantities of water. Global population increases combined with increased frequency and intensity of drought periods as a result of climate change will impose intense water stress on cities, particularly in arid environments. Current household water use in most developed countries is approximately 80 to 100 gallons per

[26] Ben Sales, "Water surplus in Israel? With desalination, once unthinkable is possible", Jewish Telegraph Agency. Palachim, 2013. https://www.jta.org/2013/05/28/news-opinion/israel-middle-east/water-surplus-in-israel-with -desalination-once-unthinkable-is-possible

person per day, and personal decisions regarding water usage are rarely made based on ecological consequences.[27] In order to maintain sustainable amounts of domestic water consumption, Fordhamopolis will feature innovative engineering methods to minimize water use per capita, accompanied by the encouragement of important behavioral changes.

In the US, the national average of indoor residential water use per person per day in the US is 60 to 70 gallons, 50-75% of which occurs in the bathroom. Modern water efficient toilets can use as little as 0.8 gallons per flush, in comparison to standard toilets which range from 3.5 to 7 gallons per flush. Another large source of water usage is faucets, which can use between 0.5 and 5 gallons of water per minute. The use of faucet aerators, however, can reduce this rate by up to 1 gallon per minute, and low-flow shower heads can reduce the flow of 4 to 7 gallons per minute by 2 gallons per minute. Finally, washing machines use massive amounts of water, with standard washing machines ranging from 45 to 55 gallons per load, but water efficient washing machines are available that use only 20 to 25 gallons per load.[28]

Ultimately, the use of water for washing purposes cannot be entirely avoided, but new and continually improving technologies increasingly provide more efficient alternatives. For example, the new development of almost-waterless washers by Xeros has brought the world one step closer to waterless washing.[29] In Fordhamopolis homes, the most efficient toilets, faucets, washing machines, and dishwashers will be used, but additional means of water reuse and recycling within homes and buildings will be implemented to create a cyclical system emitting as little water waste as possible. Existing technologies already allow for the reuse of grey water, or the relatively clean wastewater from sinks, showers, washing machines and other appliances. Relatively simple systems exist to collect faucet grey water (Figure 2), and transfer it to toilets for flushing, allowing for the reuse of sink grey water before it is discarded. Such systems will be implemented in all bathrooms in Fordhamopolis, but flushed brown water will be processed and continually recycled, in an effort to mimic natural cycles that make use of all available resources. For other

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[27] Elizondo, Gloria M., and V. A. Lofthouse. "Towards a sustainable use of water at home: understanding how much, where and why?." (2010).
[28] http://www.nyc.gov/html/dep/html/residents/wateruse.shtml
[29]Cuthbertson, Anthony. “How Almost Water-Less Washers Are Using Beads to Save the Environment.” *Newsweek*. Feb. 9, 2017. http://www.newsweek.com/2017/02/17/almost-waterless-washers-use-beads-help-save-environment-554511.html

household fixtures and appliances that use larger volumes of water, purification of the released grey water will take place using innovative filtration systems detailed in the “Wastewater Treatment” section. These water purification and reuse systems will apply to the recycling of water for multiple household uses, but potable water will be sourced directly from the rainwater collection and purification system. To encourage behavioral changes in personal water use in the home, bathroom sinks will come equipped with infrared sensors to detect the presence of hands and turn on accordingly, in order to avoid water waste from sink faucets left running when not in use. Furthermore, the A.I. system will track water use per residence, display usage data to residents, and provide incentives for reduced household usage.

Figure 3: Gray water from sinks can be used for toilets in systems like this Aqus toilet.[30]

Heating & Cooling

[30] Elizondo, Gloria M., and V. A. Lofthouse. "Towards a sustainable use of water at home: understanding how much, where and why?." (2010).

Water systems will also be used for cooling and heating purposes. All buildings in Fordhamopolis will feature sections of ventilated trombe wall along their facades for passive heating and cooling methods in order to reduce the amount of energy required for climate control. Researchers from Lund University and the German University in Cairo have taken advantage of the 19th century concept of Trombe walls to develop a highly efficient new design that has been extensively tested in a residential setting and shown to reduce the energy required to heat a building by 94%, and for cooling by 73%.[31] This climate control system is highly customizable to conditions and ideal for semi-arid climates such as Cyprus' (more information can be found in the Lund University article published in *Solar Energy*). In addition, buildings will be equipped with an active system for heating and cooling through geothermal units, high efficiency alternatives to traditional furnaces, boilers, and air conditioning that use the (almost) endlessly renewable heat energy from the Earth's core. The cooling system will take advantage of the earth's temperature to cool water running through a closed loop piping system, which will run through buildings to cool the warmer, ambient air through natural heat exchanges (Figure 4). The heat extracted from the ambient air will then be stored in water heating tanks and used to heat water being used for household purposes. During colder months, the soil temperatures are higher than those of ambient air, and the heating aspect of the geothermal system will draw this heat from within the soil and conduct it to indoor spaces as a supplement to the heat captured by the ventilated trombe wall. A preliminary map of geothermal temperatures in cyprus shows the average soil temperature in the area of Paralimni, Cyprus to be about 22 to 24.6 degrees Celsius (Figure 3).[32] With an average room temperature of 23 degrees Celsius, this soil temperature is ideal for geothermal cooling and heating systems. This system will be constantly monitored by our A.I. system in all building types in order to maximize efficiency by using collected space use data to determine peak use hours in every room and activate the circulation in each room accordingly in residential buildings, and tailor room temperatures to specific uses in industrial and agricultural buildings.

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[31] Dabaieh, Marwa, and Ahmed Elbably. "Ventilated Trombe wall as a passive solar heating and cooling retrofitting approach; a low-tech design for off-grid settlements in semi-arid climates." *Solar Energy* 122 (2015): 820-833.

[32] Kalogirou, Soteris A., Georgios A. Florides, Panayiotis D. Pouloupatis, Paul Christodoulides, and Josephina Joseph-Stylianou. "Artificial neural networks for the generation of a conductivity map of the ground." *Renewable Energy* 77 (2015): 400-407.

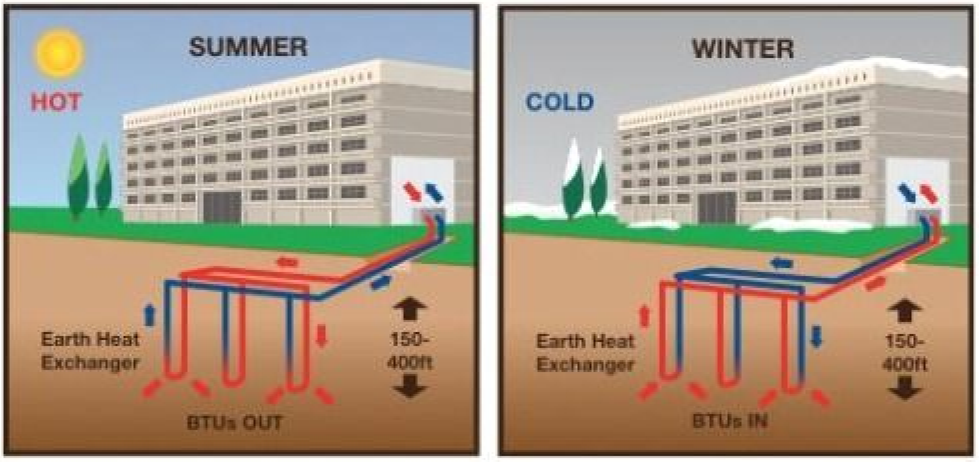

Figure 4: Geothermal heating and cooling systems[33]

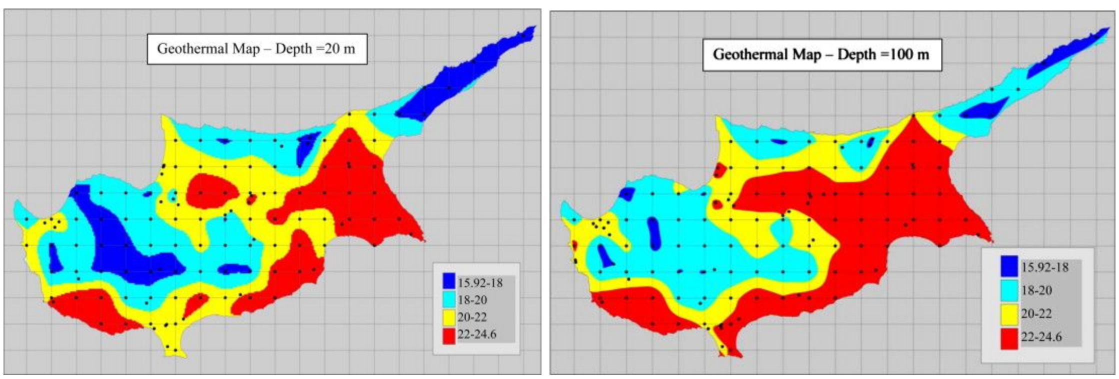

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Figure 3: Cyprus geothermal map of ground temperatures at 20 and 100 meter depth.[34]

Wastewater Treatment

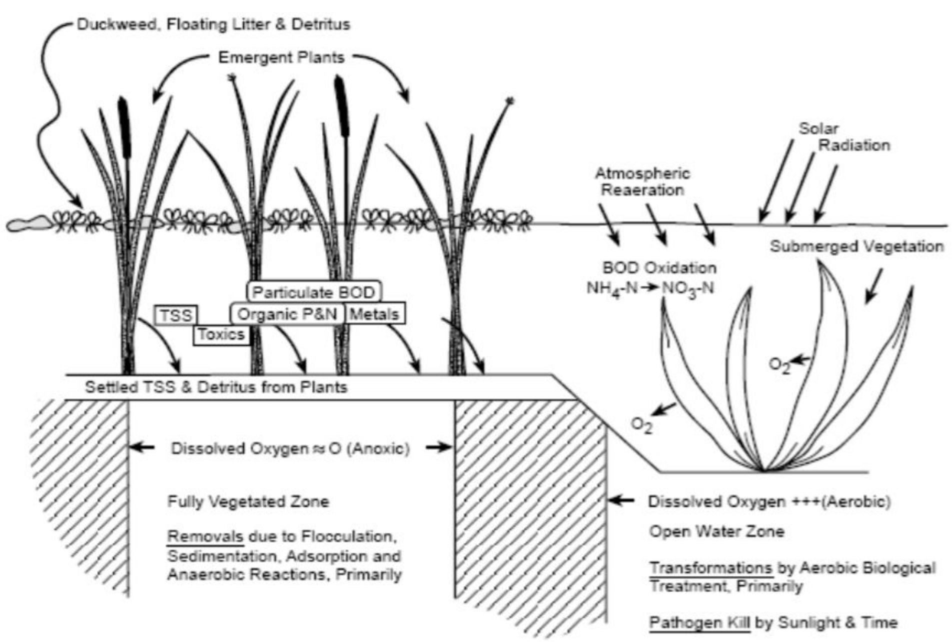
The treatment of wastewater in Fordhamopolis will integrate the most innovative and efficient water treatment methods available in order to repurpose used water in a cyclical pattern to minimize the input of new desalinated water needed, while tapping into the energy resource potential of wastewater. With the combination of resource collection and photovoltaic windows,

[33] https://cleantechnica.com/2010/12/03/the-large-potential-of-geothermal-heat-pump-systems/
[34] Kalogirou, Soteris A., Georgios A. Florides, Panayiotis D. Pouloupatis, Paul Christodoulides, and Josephina Joseph-Stylianou. "Artificial neural networks for the generation of a conductivity map of the ground." *Renewable Energy* 77 (2015): 400-407.

the treatment plant will likely generate more energy than it needs to operate and will be able to contribute power to the transportation systems.

The initial removal of waste particles from wastewater in sedimentation tanks will generate slug, which will be turned into biogas, which will then be used as an energy source to power the treatment plant. This system will be a hybridization of methods used by a net-zero wastewater treatment plant in Gresham, Oregon, and new research on wastewater treatment using osmotic and aerated membrane bioreactors.[35] This method involves hydrolysis, which is a [36]biological process that can be witnessed in wetlands (Figure 4), or nature's water purification systems, in which organic matter in water is naturally filtered by the activities of macro and micro fauna and flora.[34]

Figure 4 - Natural water purification mechanisms in wetlands[37]



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[35] Nguyen, Nguyen Cong, Shiao-Shing Chen, Hau Thi Nguyen, Saikat Sinha Ray, Huu Hao Ngo, Wenshan Guo, and Po-Hsun Lin. "Innovative sponge-based moving bed–osmotic membrane bioreactor hybrid system using a new class of draw solution for municipal wastewater treatment." *Water research* 91 (2016): 305-313.

[36] Norton, Stephen. "Removal Mechanisms in Constructed Wastewater Wetlands." *ONLINE: http://home. eng. iastate. edu/~ tge/ce421-521/stephen. pdf* (2014).

[37] Norton, Stephen. "Removal Mechanisms in Constructed Wastewater Wetlands."

The biological hydrolysis method of sludge treatment involves a series of filtrations and anaerobic digestions of organic solids and nutrients, which yields biogas used to generate energy [38]. The remaining, processed sludge will be sent to waste treatment via the SVN (see Waste section). This method will be enhanced by new, innovative filtration systems that are being explored and have been shown to be more efficient than simpler methods like reverse osmosis.[39] Reverse osmosis filtration is already being widely used and relies on ion exchange properties to remove minerals and other compounds such as detergent residues from water, however, the method has some downfalls that include rapid membrane fouling.[40] A newly tested hybrid of a sponge-based moving bed and an osmotic membrane bioreactor system was found to have close to 100% nutrient removal efficiency by combining processes of nitrification and denitrification, and results in much less membrane fouling. In Fordhamopolis water treatment plants, will integrate hydrolysis and the aforementioned hybrid purification method, followed by a UV sterilization, which will disinfect water by disrupting the cellular functions of any microorganisms that remain, as an alternative to modern chemical disinfectants like chlorine. UV sterilization of microorganisms, most importantly pathogens, is a process that also occurs naturally over time due to solar radiation[41]. Grey water will be processed in a system separate from sewage water, so as to prevent contamination, but its treatment will rely on a similar system, although biological hydrolysis for the removal of sludge will not play as large of a role. Reclaimed grey water will be redirected to non-potable household uses, and any excess will be directed to industrial uses, although all industries will be run with minimal water use using innovative technologies. The final component of the reclaimed water systems will irrigate community greenhouses situated throughout residential buildings for air filtration, esthetic purposes, and community engagement. Because these plants will not be consumed, they can be grown with treated wastewater that will have been processed by our filtration system.

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[38] Hacking, Robert. "Achieving Energy Neutral Wastewater Treatment with Biological Hydrolysis." *Environmental Science & Engineering Magazine*. August 12, 2016. *https://esemag.com/wastewater/energy-neutral-wastewater-treatment-with-biological-hydrolysis/*

[39] Ibid.

[40] Malaeb, Lilian, and George M. Ayoub. "Reverse osmosis technology for water treatment: state of the art review." *Desalination* 267, no. 1 (2011): 1-8.

[41] Norton, Stephen. "Removal Mechanisms in Constructed Wastewater Wetlands." *ONLINE: http://home. eng. iastate. edu/~ tge/ce421-521/stephen. pdf* (2014).

Agricultural Irrigation & Drinking Water

Many Fordhamopolis buildings will be topped with green roofs, which provide multiple environmental services, including air filtration, cooling to mitigate the urban heat island effect, habitat for wildlife (notably pollinators) and natural water filtration. In fact, all roofs in Fordhamopolis, many of which will be green roofs but some of which may not, will be designed to collect rainwater that will be sent to a purification system for use as drinking water. On greenroofs, the rainwater collected will have already been partially filtered by passing through the substrate, while simultaneously irrigating the plants. In both cases, water will be collected and purified by a system similar to our wastewater treatment with added disinfecting to completely ascertain that the water will be safe for consumption. After activated carbon and sedimentation filtration, rainwater will be run through a UV sterilization followed by a final biocide disinfectant filter. Newly developed cellulose foam filter paper have proven to have excellent antimicrobial properties to yield potable water through a disinfectant filter using non-leaching biocides and will be used to remove any bacteria and render the water potable.[42] Systems present on every building will feed into holding tanks, be pumped to the purification systems, and the amounts of drinking water used will be monitored by A.I. so that only the amount needed based on usage pattern within each building will be kept on site and any excess will be sent to farm buildings. With the average yearly rainfall of approximately 480,312,342 gallons within the 2 square miles of Fordhamopolis, and assuming each person will drink 3 liters or 0.8 gallons of water a day, there is enough rainfall to provide drinking water for about 1.64 million people for one year. With rainwater collection systems atop buildings, just the 144 residential buildings alone will be able to collect roughly 36 million gallons of rainwater per year, enough drinking water for 123 thousand people.

Agriculture, specifically irrigated agriculture, accounts for the largest proportion of water use by humans (UN). In farming units, a water recycling system will be in place to constantly reuse water once the systems are filled with desalinated water. Although wastewater reclamation has been shown to be usable for irrigation purposes, the farming water systems will be filled by

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[42] Heydarifard, Solmaz, Kapila Taneja, Gaurav Bhanjana, Neeraj Dilbaghi, Mousa M. Nazhad, Ki-Hyun Kim, and Sandeep Kumar. "Modification of cellulose foam paper for use as a high-quality biocide disinfectant filter for drinking water." *Carbohydrate polymers* 181 (2018): 1086-1092.

desalinated water to avoid sacrificing the quality of the products and avoid any risk of contamination. An aquaponics system will allow for the cultivation of fish and plants in a symbiotic environment which relies on a circulation of water and minimal additional input beyond the initial filling of the system, while replenishing the water with nutrients (See Food Section). Any excess rainwater not needed for drinking water will replenish the systems in the event of water losses through evaporation. Should the rainwater collection from all of the buildings in the city not be sufficient, which will be the case here due to the relatively low rainfall of the local climate, the desalination plant can provide new water. Finally, to mitigate water loss through evaporation during plant cultivation, farm buildings will be equipped with ambient air condensers, or dehumidifiers, to extract and condense humidity in the air and feed it back into the irrigation system.

FOOD

Our design concept for Fordhamopolis is based principally on the question, “How are we going to meet the demands of the population while maintaining our commitment to do no harm to the environment?” Agriculture is a leading cause of water pollution, habitat destruction, and greenhouse gas emissions worldwide, and current mainstream agricultural practices involve the use of vast expanses of land, heavy carbon emitting machinery, large amounts of agrochemicals, and wasteful irrigation methods.[43] John Steinbeck writes of the growing agricultural-industrial machine in *Grapes of Wrath*, a prophetic American classic. The bank and the tractor, obvious symbols for the system they represent, “breathe profits; they eat the interest on money. If they don't get it, they die the way you die without air, without side-meat”.[44] The suffering of the Joad family proves that divorcing food production from ecology and wedding it to commerce is a verified formula for disaster. It is clear that imagining the future of food production requires a transition away from most contemporary methods of food production and towards new, creative, and sustainable methods of supplying food to an urban population.

[43] Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being: Synthesis* (Washington, DC: Island Press, 2005), 1-6.
[44] Steinbeck, John. The Grapes of Wrath. New York: Penguin Classics, 1992. Print.

Agriculture will be integrated into the urban fabric to allow Fordhamopolis to mimic the primary productivity and nutrient recycling of ecosystems that has sustained life on earth as we know it for 400 million years and has proven to be a highly resilient system. Food production in Fordhamopolis will occur primarily in vertical farms, with peripheral production occurring in community gardens for the social benefits they provide. Vertical farming employs controlled-environment growing methods in a multi-story building, ensuring a stable supply of food while minimizing land use. This allows food production to remain inside the city limits, eliminating the need for additional ecosystems to be converted for agricultural use. Ecosystems cannot exceed the limits of their bioproductivity, which is determined by the amount of energy captured and cycled throughout the food chain, starting with primary producers.[45] Fordhamopolis must follow this rule of self-sufficiency, which means that vertical farms will employ cutting-edge technologies and innovative design techniques to maximize energy efficiency, recycle water, and eliminate waste. In addition to spaces for raising food and managing water and waste, vertical farms will include a nursery for germination and propagation, a quality-control laboratory for monitoring food health and safety, a control center for monitoring the whole facility, offices for management, locker rooms for personnel hygiene, an education center, a grocery store, a warehouse for distribution vehicles, and restaurants. All forms of food production will be carefully monitored by artificial intelligence to efficiently ensure food safety and quality.

Commercial Food Production

The design of Fordhamopolis's vertical farms follows the principle "form follows function," which defines the process of evolution and determines the physiology of all forms of life.[46] The function of vertical farms is to maximize food production while creating a closed-loop system, which means all waste from one process must be used as in input to another process, and no inputs may come from external, nonrenewable sources.[47] In addition to creating optimal growing conditions for plants, key considerations

[45] Dickson Despommier, *The Vertical Farm: Feeding the World in the 21st Century* (New York: St. Martin's Press, 2010), 17-19.
[46] Despommier, *The Vertical Farm*, 180.
[47] Mark Gorgolewski, June Komisar, and Joe Nasr, *Carrot City: Creating Places for Urban Agriculture* (New York: Monacelli Press, 2011), 22.

are maximizing the potential of sunlight for primary productivity as well as maximizing efficiency in terms of water and electricity use, decreasing the inputs needed of these limited resources.

Indoor food production allows for total control of humidity, temperature, and light, allowing food production to occur at optimal rates year-round, and for some crops even 24 hours a day, regardless of external conditions. Compared to traditional outdoor agriculture, which is seasonal and experiences losses in productivity due to adverse weather conditions, vertical farming dramatically decreases the area needed for food production by virtue of being more productive. They also provide a more stable food supply, which is especially important as climate change increases the incidence of extreme weather events, like hurricanes and droughts, that can have devastating effects on crop yields. By eliminating the season- and location-specific limitations of crop production, vertical farming allows locally grown, culturally significant foods to be available to the multicultural population of Fordhamopolis year-round. Since growing conditions can be customized to suit delicate or exotic crops, these vertical farms will also be used to grow medicinal plants, improving public health by creating better access to plant-based medicines, especially those derived from plants that are rare or have been harvested to near extinction in the wild.

Fordhamopolis's vertical farms will employ mainly hydroponic and aeroponic growing methods, which use 70 and 90 percent less water than traditional soil-based methods, respectively, since the water can be continuously recycled.[48] Soil is only necessary as a structural support system in which plants can spread their roots, given that plants can access nutrients through some other medium. Hydroponics was developed in 1937 by Dr. William Frederick Gericke, and it uses nutrient film technology to slowly pump a thin stream of nutrient-laden water over the root systems of crops.[49] Aeroponics, which was developed by Richard Stoner in 1982 through research funded by NASA, uses small nozzles located under plants to spray a fine mist of nutrient-laden water onto their roots, which are enclosed in a chamber that maximizes humidity.[50] Hydroponic and aeroponic systems are much lighter than soil, making them more practical for buildings, which have load limits. Virtually any plant can be grown through

[48] Despommier, *The Vertical Farm*, 208.
[49] Despommier, *The Vertical Farm*, 36-165.
[50] Despommier, *The Vertical Farm*, 165.

hydroponic or aeroponic systems, and they accelerate plant growth by optimizing the aeration of plant roots,[51] doubling or tripling biomass yields per square foot compared to soil-based agriculture.[52] Piping for these systems is typically made of low-cost plastic such as polyvinyl chloride, or PVC. A more innovative option, which would be employed by the vertical farms of Fordhamopolis, is piping made of bamboo since it is one of the strongest natural materials, does not rot in water, grows very quickly, and can be harvested to any diameter of choice. This alternative limits the production of non-biodegradable waste and eliminates the risk of the leaching of toxic phthalates from the PVC into the nutrient solution.[53] Nutrients dissolved in the water will be carefully tailored to the specific nutritional requirements of each plant, allowing for the production of any crops regardless of the soil quality of Cyprus. The concentration of elements in the solution, as well as temperature, light, and humidity levels, will be automatically monitored through artificial intelligence to ensure uniform plant growth under ideal conditions.

The configuration of growing systems in the vertical farms will depend on the type of crop that is being grown and its exposure to sunlight based on its position in the farm. An additional advantage of non-soil-based growing systems is that they can be arranged in three dimensions to make the most efficient use of vertical as well as horizontal space.[54] Crops like tomatoes, lettuce, spinach, and green beans are comfortable growing in traditional hydroponic piping with evenly spaced holes, while corn is better suited to being grown hydroponically in large tubs, typically with six plants in each. Potted plants like strawberries, eggplants, and avocados can be grown in hydro-stackers, which use a form of hydroponic drip irrigation and save floor space.[55] Stacked tower configurations with a central axis can be turned to provide plants with an even distribution of sunlight. Plants located in areas that receive little sunlight will be grown on omega garden carousels, which rotate plants around central LED lights. These devices use 99 percent less water than traditional agriculture to raise crops, and the rotation develops oils in the plants that encourage faster growth and enhanced taste.[56]

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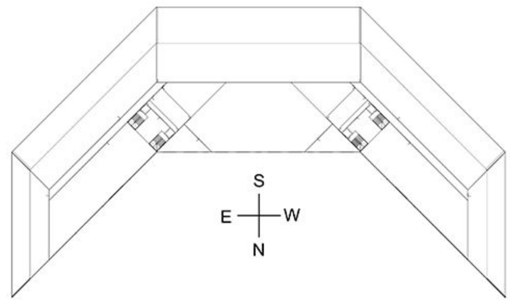
[51] Gorgolewski, Komisar, and Nasr, *Carrot City*, 209.
[52] Kubi Ackerman, *The Potential for Urban Agriculture in New York City: Growing Capacity, Food Security, and Green Infrastructure* (New York: Columbia University, 2012), 15.
[53] Despommier, *The Vertical Farm*, 204-5.
[54] Ackerman, *The Potential for Urban Agriculture in New York City*, 15.
[55] Despommier, *The Vertical Farm*, 203.
[56] Ibid.

Animals will also be raised in the vertical farms of Fordhamopolis. Aquaponics, a system that simulates the nutrient cycling of wetlands, will be used in conjunction with hydroponics to raise seafood. To create this artificial symbiosis, the nutrient-rich water produced from raising fish is fed to hydroponically grown crops, which then purify the water before it is returned to the fish tanks, preserving a healthy aquatic environment. Waste portions of cultivated plants are fed to worms, the worms are then fed to fish, and the compost generated by the worms provides additional nutrients to the plants, creating a completely closed-loop system.[57] Ten 5,600 liter tanks located in the basement of the farm could raise a total of 8,000 fish at once.[58] Fish farming is environmentally beneficial as the majority of the world's fisheries are severely overfished,[59] and the local nature of fish production means fish do not have to be frozen before they are sold. On farms with open air rooftop areas, bees will be raised to produce honey in insulated hives like Beehaus by Omlet, which maintains the constant 95 degrees Fahrenheit environment that bees need to thrive year-round.[60] Chickens will also be raised in the vertical farms, but since the prospect of raising four-legged animals indoors is more dubitable in terms of practicality and ethics, pigs and cattle will be raised on open land outside the vertical farms. Due to the more intense resource use required for raising these animals, dairy, pork, and beef must be considered specialty foods and will generally be more expensive than in other foods comparable in nutritional value.

The design of Fordhamopolis's vertical farms will also increases food safety and security by protecting crops from insects and microbial pathogens. Since preventative measures cannot be effectively implemented outdoors, these pests and diseases are a much greater threat in traditional agriculture, which relies on environmentally harmful pesticides and fungicides as a response. Security measures in vertical farms will be similar to those designed for intensive care units in hospitals, such as positive-pressure buildings, filtered air supplies, secure entryways, and strict hygiene requirements for farm workers.[61] To increase the security of Fordhamopolis's vertical farms, each will have two sets of stairwells: one that leads to public areas, like the grocery store and the education center, and one that leads to agricultural areas. Entrances to the latter will be securely locked at all times and accessible

[57] Gorgolewski, Komisar, and Nasr, *Carrot City*, 209.
[58] Despommier, *The Vertical Farm*.
[59] Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being,* 2.
[60] Gorgolewski, Komisar, and Nasr, *Carrot City*, 204.
[61] Despommier, *The Vertical Farm*, 169-70.

only to farm personnel. The vertical farm will be also equipped with locker rooms to allow personnel to shower before changing into sterilized uniforms.



Energy

Since vertical farm technologies depend on a constant supply of electricity, and since plants require abundant energy in the form of light to perform photosynthesis, ensuring that energy needs are met is a critical component of farm design. The coastal regions of cyprus receive well over 3000 hours of sunshine per year, ranging from an average of about 6 hours of sunlight per day in the winter to about 13 per day in the summer,[62] allowing vertical farms in Fordhamopolis to rely primarily on sunlight to grow crops. These vertical farms will be arc-shaped and oriented to follow the daily progression of the sun from east to west. The exterior of the farm will consist of a light steel frame, condensed wood, and a triple-glazing of high-tech plastic along the entire south side to allow for maximum exposure to sunlight while providing good insulation to reduce energy use for heating and cooling. Plastic is lighter and more durable than glass, requiring less use of steel, and emerging varieties, such as ETFT, or ethylene tetrafluoroethylene, have a high tensile strength and are resistant to yellowing over time due to UVB radiation from sunlight. ETFT was used to build the Beijing National Aquatics Center in 2008, which remains in good shape today.[63] The plastic walls of the vertical farms will also be equipped with technology inspired by the Solar Bubble Greenhouse to regulate solar radiation and indoor

[62] Republic of Cyprus Department of Meteorology, "Climatological Data, Paralimni, 1991-2005," http://www.moa.gov.cy/moa/MS/MS.nsf/DMLclimet_reports_en/DMLclimet_reports_en?OpenDocument&Start=1&Count=1000&Expand=1.
[63] Despommier, *The Vertical Farm*, 189-91.

temperatures. In the Solar Bubble system, liquid soap bubbles generated at the top of the greenhouse structure flow between two layers of plastic that form its exterior. In the winter, the bubbles serve as an insulating layer, and in the summer, they act as a screen that reduces solar radiation while drawing excess heat out of the farm through a process similar to transpiration in plants.[64] Transparent walls and windows will also be photochromic, automatically responding to high sunlight intensity by modifying their transparency to ensure that plants are not exposed to excessive solar radiation and heat. Plastic parabolic mirrors and fiber optics leading from these collecting mirrors will be used to direct sunlight to plants near the interior of the building that would not receive direct sunlight when the sun is high in the sky.

Plants will be supplemented with light from organo-light emitting diodes, or OLEDs, made of thin, flexible plastics containing stable organic compounds that produce a very narrow spectrum of light. OLEDs exclusively emit the wavelengths of light that chlorophyll A and B absorb to facilitate photosynthesis in plants, conserving energy that is lost as heat and wasted generating a broader spectrum of light in the case of conventional light bulbs.[65] Artificial lighting will be crucial to facilitating the growth of plants in the north side of the farm, which will never receive direct sunlight, as well as providing light for all plants at night and during the colder months. Lighting conditions will be monitored by AI, and OLEDs will be turned on automatically when natural lighting is not sufficient. To power these OLEDs and other technologies that require electricity, vertical farms will rely mainly on solar power collected from perovskite solar cells covering the exterior of each farm since Paralimni receives abundant sunlight. Horizontal double-propeller wind turbines attached to the roof of the vertical farms will provide supplemental electricity, especially on less sunny days. These turbines, which resemble an old fashioned hand-driven lawn mowers, are quieter and more attractive than traditional windmill-shaped turbines, and since they are lighter and require less wind speed to operate, they can be added to almost any building.[66]

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[64] Gorgolewski, Komisar, and Nasr, *Carrot City*, 212-13.
[65] Despommier, *The Vertical Farm*, 186-87.
[66] Despommier, *The Vertical Farm*, 195.

For most crops, the ideal indoor temperature for growth is around 70 to 75 degrees Fahrenheit, and plant growth is significantly hindered at temperatures lower than 65 degrees.[67]In Paralimni, mean daily temperatures generally remain above 70 degrees May to October, so solar thermal energy, captured through passive solar design, will supply adequate heat to the vertical farms for around half of the year.[68] Effective insulation and thermal mass will help to retain heat in the farms after the sun goes down. During the colder months, geothermal heat pumps will provide supplemental heating. Waste heat generated by restaurants and bakeries will also be circulated throughout the farm. During the hotter half of the year, optimal growing temperatures will be maintained by passive and low-energy cooling systems, including ventilation, shading, geothermal cooling pumps, and evaporative cooling. In standard evaporative cooling systems, hot, dry air from outside enters the evaporative pad wall, where it is met with water, increasing the humidity of the air while lowering its temperature after it passes through the wall.[69] Evaporative cooling should be very effective in Cyprus since its climate is dry during the hotter months. On the hottest days, air conditioning powered by renewable energy may be required to maintain appropriate growing temperatures.

Waste and Water Management

In order to function as a closed-loop, biomimetic system, vertical farms must produce zero-waste. Recycling wastewater is an especially important process given Cyprus's relatively dry climate. Rainwater catchment systems will be installed on vertical farms and rooftop community gardens to collect rainwater and store it in cisterns for later use, but this will only supply a small fraction of water needs for food production since Paralimni, on the west coast of Cyprus where Fordhamopolis will be located, receives only about 14 inches of rain per year, with almost no precipitation in the summer. To meet the rest of their water needs, vertical farms can take advantage of the natural water purifying processes of plants to convert wastewater to potable freshwater for use in the farms. Greywater, which is sewage with the solids removed, will be pumped to vertical farms from other parts of the borough to be fed hydroponically to plants that can be sold as decoration or burned for energy, as it would be too risky to eat

[67] Cornell University Agricultural Experiment Station, "Energy Use and Savings in Greenhouses and Growth Chambers," *Cornell University*, https://cuaes.cals.cornell.edu/greenhouses/sustainable-greenhouses/energy-use.
[68] Republic of Cyprus Department of Meteorology, "Climatological Data, Paralimni, 1991-2005."
[69] Ackerman, *The Potential for Urban Agriculture in New York City*, 69.

produce grown with greywater. Nutrients in the grey water will help plants grow, and through transpiration, these plants will release pure water vapor. Since the vertical farm is an enclosed, indoor environment, dehumidifiers can be used to collect this purified water, which would then be pumped throughout the farm to meet its various water needs. One wing of each vertical farm will be devoted solely to this purpose.

Solid waste generated by vertical farms will consist mainly of the inedible parts of crops that are left over postharvest. These can in some cases be used for animal feed and in others incinerated through plasma arc gasification to generate electricity for the farms. Incinerating one ton of solid waste through plasma arc gasification would generate about 800 kilowatt-hours of electricity, making it the most efficient way to recover energy from the waste parts of crops or any form of solid waste generated in the farms, including man made materials.[70] However, it can also be valuable to facilitate the decomposition of organic waste to produce fertilizer. This is most efficiently performed by anaerobic digesters, which will be included in vertical farms to turn organic waste into a nutrient-rich digestate while collecting biogas generated from this process. The digestate will then be used as fertilizer in soil-based food production, and the biogas will be as fuel for distribution trucks or to heat vertical farms in the colder months

Additional Social Benefits

As secondary sources of food production, community gardening will be integrated into residential and outdoor public spaces for the additional social benefits they bring to the Fordhamopolis community. Though these gardens will not employ the most efficient methods of food production, they are valuable in that they foster social interaction and community building. Since community gardens appeal to people of a wide range of ages, genders, abilities and cultures, they provide a space for diverse groups of people to learn from each other and develop relationships.[71] This is especially beneficial to people that are often socially isolated, like immigrants, those with special needs, and the elderly. Community gardens that grow culturally significant produce

[70] Despommier, *The Vertical Farm*, 198.
[71] André Viljoen, Katrin Bohn, and Jow Howe, *Continuous Productive Urban Landscapes: Designing Urban Agriculture for Sustainable Cities* (Burlington: Architectural Press, 2005), 85.

can be a powerful means of expressing a local or ethnic identity.[72] The physical and mental health benefits of community gardens have been recorded in many studies. In the study "Growing Urban Health: Community Gardening in South-East Toronto," researchers observed "better overall nutrition, improved mental health, a sense of community cohesion, and increased physical activity" of those who participated in the gardens.[73] Researchers at the University of California's Cooperative Extension also observed that "community gardens beautify neighborhoods and help bring neighbors closer together" while improving air quality.[74]

Greenhouses and rooftop gardens of residential buildings will grow mostly shallow-root vegetables in raised beds. Some of the beds will be elevated to allow greater accessibility for wheelchairs. Workshops held in these gardens will teach the residents of Fordhamopolis about sustainability while providing them with practical skills. A compact, customizable, low-maintenance hydroponic growing system by Bohn and Viljoen Architects, called the Urban Agriculture Curtain, will be installed in the windows of residences, offices, and cafes. The system consists of eight trays hung by a cables and connected to tubes that supply them with nutrient-laden water stored in a tank nearby, and it provides the benefits of convenient harvesting, shade, privacy, improved indoor air quality, and biophilic design in small spaces where food production is not the primary function.[75] Greenhouses with smaller-scale versions of vertical farm technologies will be integrated into every school. Similar to the Sun Works Center for Environmental Studies built on the Manhattan School for Children, these greenhouses will include raised soil beds, hydroponics and aquaponics, evaporative cooling, integrated pest management, insect hatching areas, and a weather center so that students will have access to state of the art environmental education year round.[76] Drawing from Jean Giono's The Man Who Planted Trees, native fruit-bearing trees, such as citrus and olive trees, will be planted throughout the city's green spaces, enhancing the aesthetics and urban biodiversity of Fordhamopolis.[77]

[72] Viljoen, Bohn, and Howe, *Continuous Productive Urban Landscapes*, 57.
[73] Gorgolewski, Komisar, and Nasr, *Carrot City*, 60
[74] Ibid, 60.
[75] Gorgolewski, Komisar, and Nasr, *Carrot City*, 211.
[76] Ibid, 179.
[77] Jean Giorno, *The Man Who Planted Trees*, 1953.

By actively reconnecting people with the origins of food, Fordhamopolis fosters a profound understanding of the principles of human ecology, biomimicry, and self-sustenance. By providing opportunities for citizens to participate in food production as a social activity, the city also promotes social inclusion, community involvement, and local pride and identification, which encourages people to engage in public affairs.[78] Equipped with a comprehensive knowledge of environmental concepts and motivated to shape the future of their communities, the residents of Fordhamopolis will be sure to maintain a deeply democratic society united in promoting sustainable development for generations to come.

ENERGY

Energy usage is prevalent in all urban conditions including transportation, food and water production, waste management, and infrastructure. Large amounts of energy will be needed for Fordhamopolis to function as populations will require housing, food, clothing, transportation, and heat. In order to promote sustainable living on a larger scale, Fordhamopolis will reduce natural resource usage, shift energy usage to renewable sources, adapt to urban agriculture, and promote the use of energy efficient public transportation. Through both active and passive energy efficiency techniques, Fordhamopolis can significantly reduce its environmental footprint. Passive energy techniques involve less action or intervention through concepts of solar orientation or increased insulation.[79] In contrast, active techniques require technology to alter buildings or systems to provide maximum efficiency.[80]

Biomimicry and The Bauhaus

A method that will be used in designing an energy efficient city includes the notion of biomimicry. Biomimicry involves utilizing nature's natural processes as a guide in solving problems in the human built environment. Biomimetic design allows for

78 Viljoen, Bohn, and Howe, *Continuous Productive Urban Landscapes*, 84-85.
79 David Bergman. Sustainable Design: A Critical Guide. (New York: Princeton Architectural Press, 2012),44.
80 Ibid., 66.

designers to innovate new spaces derived from concepts in nature and incorporate sustainability into his or her design. As nature is constantly evolving to adapt to problems or inefficiencies, urban planners can adapt to environmental issues by creating more sustainable buildings. In Peder Anker's book, *From Bauhaus to Ecohouse,* he describes an objective set forth by the Bauhaus School to create a space for refuge from industrial society.[81] These microcosms were to be designed as self-sustaining in a future world that is no longer suitable for life. Bauhaus thinkers proposed that earth would soon become a lifeless planet like mars if there was no intervention for our polluted planet. These sanctuaries were known as bio-shelters or eco-arks and would be designed in a way that promoted harmony between humans, animals, and plants present in various ecosystems.

Energy Consumption Statistics per Building

At the core of most buildings in the city of Fordhamopolis, as it is with many high density urban areas, residential space will be the main priority. Each building will be primarily residential, containing fourty floors of residential space while still being multi-use. The bottom ten floors of each building will be mixed between commercial, office, and whatever non-residential purpose space could be needed by the public or businesses. In order to figure out how much energy each building is estimated to consume on a day-to-day basis, it is important to calculate the total number of residents living that can live in the space as well as the average use of energy that an office or commercial space uses. Combining these numbers, it is possible to find a total energy footprint for each building.

For each residential floor, there are five apartments that can house four people in each. Spread across forty residential floors, this allows for eight hundred people to live in each of the buildings in Fordhamopolis. Here is a quick rundown of the simple calculations done giving this number:

4 Residents per Room x 5 Rooms per Floor = 20 Residents per Floor x 40 Floors =
800 Residents per Building

With having a residential capacity of eight hundred people for each of the buildings, this is a good jumping point in order to figure out the total use per building. The U.S. Energy Information Administration (EIA) states that the average residential utility customer,

81 Peder Anker. From Bauhaus to Ecohouse: A History of Ecological Design. (Louisiana, NY: Louisiana State University Press, 2010), 6.

based by household energy use, consumes an average of 10,766 kilowatt hours (kWh) annually.[82] Assuming that an average household across the United States contains four people, it could be fair to directly correlate this average to each four-resident apartment. This average estimate converts to around 2,691.5 kWh per capita annually. Based on this, calculations can be made to find the total average energy use for the residential part of the skyscraper:

2691.5 kWh Used Annually per Capita x 800 People per Building =
2,153,200 kWh Annually Used per Residential Part of Building

Over 2 million kWh of electricity are consumed by the residential part of the building.

The next step is to figure out how much energy is consumed by the rest of the building, that being the commercial/office space. The EIA website gives another average for how much energy an office space uses annually based on square footage. The estimate per square foot from 2012 was around 75,000 British thermal units (Btu) which, to keep the numbers consistent, converts to around 21.98 kWh used per square foot annually.[83] Based on this number, we can calculate the estimated annual energy use for the office section of the building, with a 28,900ft^2 footprint:

170ft x170ft = 28,900ft^2 x 10 floors = 289,000ft^2 x 21.98 kWh per square foot= 6,352,220 kWh per Office Section of Each Building.

Based on the national Commercial Buildings Energy Consumption Survey from a few years ago, it is estimated that just the commercial sections of the multi-purpose building will consume close to 6.5 million kWh worth of energy over the course of a year, totaling to over eight million kWh to be consumed per building yearly. That is a fair bit of energy, and measures are going to be taken to cover this abundance of energy and then some within the building and the city as a whole. For comprehensive purposes, it is useful to figure out how much energy all of the buildings in the city will consume each year.

Each neighborhood of buildings consists overall of twelve buildings, with four neighborhoods per district and three districts. This totals to 144 of our multipurpose residential buildings in Fordhamopolis. To calculate the total energy use from these buildings, its a simple equation:

[82] https://www.eia.gov/tools/faqs/faq.php?id=97&t=3
[83] https://www.eia.gov/consumption/commercial/reports/2012/energyusage/

144 Buildings x 6.5 Million kWh = 936 Million kWh Total

From these buildings alone, the average energy consumption annually for these buildings will be close to a billion kWh. It is our goal to reduce this number drastically through making these buildings as energy efficient as possible, using both our passive techniques and more active techniques. From there, we need to be able to produce the energy that is left and needed to power them.

Passive Techniques

Considering sun energy when constructing a building is vital for energy efficiency as solar radiation varies throughout the year in angle, direction, and latitude.[84] The first component of a passive solar heating building involves an aperture, or large window that receives sunlight from outside. Next, an absorber is present which allows for the absorption of solar energy. The next component in a passive building is a thermal mass which is material that retains the heat present from the sun. Then, a distribution method is present which allows for heat to circulate around the building. Finally, control methods are in place such as roof overhangs to shade the aperture in warmer months. Deciduous trees can act as controls as they provide shade in summer months and allow for sunlight in winter months. In our ideal city of Fordhamopolis, all windows would be facing the sun and numerous trees would be planted to allow for natural shade.

The next concept in Fordhamopolis' energy efficient buildings is known as double envelope construction.[85] Buildings will be constructed with an additional layer that allows for optimal energy efficiency and provides heating and cooling. Between the two layers, solar radiation allows for air to be warmed and used for heating. In summer months, hot air can be vented outside the building for cooling effects.

84 David Bergman. Sustainable Design: A Critical Guide. (New York: Princeton Architectural Press, 2012),46.

85 Ibid., 50.

Window placement and solar orientation are vital components that go into energy efficient buildings.[86] Most buildings in Fordhamopolis will be oriented on an east to west axis, as sunlight can be oriented towards the south to receive maximum sunlight and heat energy. Windows on the north side of the house should be minimized to reduce heat loss and impact of strong winds. Windows greatly affect the interior space of a home due to the size, insulating properties, transmittance, and condensation resistance. A type of window that provides increased energy efficiency is one where gas is filled between panes of insulated instead of air. Heat movement is then reduced between the panes which allows for less heat loss.

When planning the sustainable city of Fordhamopolis, it is ideal to have single story, tall building to reduce surface to volume ratios, which allow for smaller exterior surfaces. When less surface is present with increased interior volume, less energy is passed into the building for heating and cooling. Similarly, tall buildings allow for increased sunlight exposure, more aesthetic views, and increased ventilation.[87]

Insulation will be vital when constructing buildings in Fordhamopolis in order to avoid energy and heat loss. Many buildings currently use of fiberglass as an insulant which is highly unsustainable as it contains formaldehyde, contains gaps, and has toxic irritants. A substitute to fiberglass will be mineral wool or recycled denim, as it is made from plants, renewable, biodegradable, and is not hazardous.[88]

Impervious surfaces in cities prove to heat the surrounding area as pavement and roofs have low albedo, or low reflectivity, and tend to absorb large amounts of heat. In Fordhamopolis, regulations would be put on the amount of impervious surfaces allowed and increase green space as much as possible. Additionally, cool roofs will be implemented, or roofs that have lighter colors to reflect sunlight in summer months to aid in cooling the building. In order to avoid heat loss in the winter, ideal roofs would be able to change color to vary reflectivity in changing seasons. Another option for reducing heat absorption are

86 Ibid., 53.

87 Ibid., 54.

88 Ibid., 57.

radiant barriers, or surfaces that reflect sunlight and are placed below a rooftop. These barriers prevent heat from entering the building in colder months.[89]

Lastly, natural ventilation can be utilized when outside temperatures are pleasant as it does not require any additional energy consumption. As hot air rises, many buildings implement chimneys to aid in this natural ventilation. As hot air leaves the building through the chimney or vent, cool air from outside replaces warm interior air. These chimneys are called solar chimneys and can be warmed to increase rates of ventilation and painted with dark colors to absorb radiation from the sun. Persian Wind Catchers can aid in solar chimneys as openings cause wind to flow into the building which creates pressure and promotes warm air to leave. In addition to these catchers, Iranians implement Qanats, or underground water reservoirs that trap air, cool it down, and released into the building to aid in cooling. Solar chimneys are an example of biomimicry, as termites creates mounts with many openings and ventilation hole at the top for cooling.[90]

Active Techniques

The first active technique that I would implement in Fordhamopolis are solar thermal panels. Solar collectors work by solar energy heating up tubes filled with liquid and covered by glass panels. These heated liquid tubes can be used for water heating or space heating. In addition to solar panels, photovoltaics are panels that convert solar radiation to electricity through heat absorption. Photovoltaic panels contain a crystalline silicon cell that converts light to electricity. When light is not present outside on a cloudy day, a solution is a battery system that can store excess light and distribute it. A new photovoltaic panel that is less cumbersome is known as amorphous silicon panels. These thin panels can be built into the building itself in a process known as building integrated photovoltaics.[91]

89 Ibid., 59.

90 Ibid., 61.

91 Ibid., 69.

Wind energy is the next active technique that would be implemented in Fordhamopolis. Wind can generate electricity as it powers the wind turbine which powers a generator to distribute electricity. Wind energy is an example of renewable energy and is a great source of electricity. Turbines can now be incorporated into building designs as appendages of small turbines are added to building facades. An alternative to wind turbines that are more aesthetically pleasing are vertical axis turbines which can also be implemented into the construction of a building.[92]

Heat pumps are mechanisms that allow for the movement of heat rather than energy intensive heat production. These pumps function through evaporation of liquids or condensation of gases. Air-source heat pumps work by obtaining energy from outside air with indoor and outdoor coils. Ground source heat pumps function through circulating liquid through underground pipes and back into buildings to cool or heat a house using ground temperature.[93]

In order to obtain hot water in an energy efficient way, an on demand heating system can be used instead of energy consuming electric or gas tanks. These water systems work by heating water immediately when needed, instead of maintaining high water temperatures at all time. A system is also available to retain energy from hot water that is sent down the drain called a drain water heat recovery system. This system contains copper coils that routes back to the water tank provider[94]

Lighting a whole city requires much energy, however the use of CFL bulbs, or compact fluorescent lamps can promote energy efficiency and light. Current incandescent bulbs are not energy efficient as much energy is lost as heat when metal filaments are electrically heated to glow. CFL lights can last four times longer than incandescent lights and are much more energy efficient. A problem with CFL lights is they require mercury to function and cannot be easily dimmed. Light emitting diodes or LED

92 Ibid., 73.

93 Ibid., 76.

94 Ibid.,76.

lights are a more energy efficient light based on solid state electronics and do not require mercury for operation. LED lights will be implemented throughout the city of Fordhamopolis.[95]

Sustainable transportation in Fordhamopolis can be accomplished through the use of bicycles or electric bikes. Bikes are the most energy efficient methods of transportation as they do not emit pollution into the air or require use of renewable or nonrenewable energy. For the elderly portion of the city, electric bikes would be available or mechanical energy provided by legs can power a partial electric bike for coasting. Any form of public transportation would be powered strictly through electrical energy. There will be no parking spaces available for cars in this city.

Photovoltaic Panels

Photovoltaic cells function as a collection system of the sun's solar power that can provide energy to lighting systems without the use of grid electricity.[96] Photovoltaic lighting works as electricity is generated from photovoltaic panels or solar panels when sunlight is absorbed. Components of a photovoltaic lighting system include batteries, PV panels, battery charge controller, inverter, timer, light source, and luminaires. A photovoltaic panel collects solar energy, stores this energy in batteries, and then releases the energy to power a light source. Benefits of a photovoltaic system include environmental sustainability, energy savings, and off grid power generation. In Fordhamopolis, grid electricity, or power plants that transmit energy to an area, will be avoided as all buildings will be self-sufficient. In nature, all ecosystems function as a self-sufficient system where all living and non-living things coexist and thrive without intervention. Our city will mimic nature's design as our buildings and people will thrive and be self-sustaining. Photovoltaic cells are absorptive materials that take in photons, or electromagnetic energy, and convert them into electrical energy. A photovoltaic cell on a PV panel consists of two layers, including a thin sheet of negatively charged n- type silicon and a thicker sheet of positively charged p type silicon. The top layer contains phosphorus while the bottom layer contains boron. When these two layers join together, a positive-negative junction is created, or an area where light is produced.

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95 Ibid., 77.

96 "How PV Panels Work | Photovoltaic Lighting | Lighting Answers | NLPIP." Lighting Research Center. Accessed May 04, 2018. http://www.lrc.rpi.edu/programs/nlpip/lightingAnswers/photovoltaic/04-photovoltaic-panels-work.asp.

At this junction, an electric field can create electricity when sunlight shines on the cell. When sunlight is available, electrons in the p-type silicon layer are stimulated and move across the pn junction to the n-type silicon layer, which allows for the p-type junction to have high voltage. This electron movement allows for an electric current and the production of light.

Perovskite Solar Cells

In Fordhamopolis, the most advanced solar cells, perovskite solar cells, will be used on our buildings and will produce electricity for the town. Perovskite cells are highly efficient with low costs of materials and fabrication. Perovskite structures have high conversion efficiencies and have high photon energy utilization, meaning energy loss is minimal during the light conversion process. This solar cell's material consists of absorptive perovskite structures such as methylammonium lead trihalide, $CH_3NH_3PbX_3$, where X can be atoms of iodine, bromine, or chlorine. Perovskite structures consist of the form ABX_3 and contain a large cation of type A in the center of a cube while the corners of the cube contain type B cations. The surfaces of the cube contain smaller type X anions. Type A atoms include an organic cation such as methylammonium. Type B atoms contain a big inorganic cation such as lead. Finally, type X atoms are smaller halogen anions such as trihalide or chloride. Perovskite solar cells have high absorption of the electromagnetic spectrum, ultrathin film, are lightweight, and are very flexible. These cells are produced through a one step process, where methylammonium halide is dissolved in a solvent, spin coated onto a substrate, and produced through evaporation and self assembly. A perovskite solar cells consists of a metal back, electron interface layer, perovskite, hole interface layer, indium tin oxide, and glass.[97]

Amorphous Silicon Photovoltaic Glass

An aesthetically pleasing option in solar energy panels includes amorphous silicon photovoltaic glass. This photovoltaic glass is important because it can produce electricity while also offering a pleasing appearance to the inhabitants of Fordhamopolis.

97 "Perovskite Solar Cells." Research Team Engineers a Better Plastic-Degrading Enzyme | News | NREL. Accessed May 04, 2018. https://www.nrel.gov/pv/perovskite-solar-cells.html.

The architectural glass has many positive features such as visible light transmittance, flexibility, power generation, and a sleek appearance.[98]

Solar Energy Totals

Assuming that the new perovskite solar cells continue to be the most powerful solar cell on the market, having an efficiency of 22.1%, then it is safe to say that will be graded higher than 380 watts, possibly around 400 watts, or .4 kWh.[99] The majority of each residential building will be clad in these solar cells, so it is necessary to find the outer surface area of the building:

10' x 14' = 140 ft^2 (area of one face) x 18 faces on building = 2,520 ft^2 per floor x 50 floors = 126,000ft^2 total surface area.

From here it is necessary to figure out how much of this surface area is give access to the sun over the course of the day, my estimates giving me around 70% of the building will receive direct sunlight throughout the day.

$$126{,}000ft^2 \times .7 = 88{,}200ft^2$$

An average square foot of this solar cell could produce anywhere around 22 watts an hour. Multiplying this by the surface area receiving direct sunlight will get the total wattage produced from the building over the course of an hour.

$$88{,}200ft^2 \times 22\ w/ft^2 = 1{,}940{,}000\ w \text{ or } 1{,}940\ kWh$$

Now converted into kWh, it is important to calculate how many hours of sun the building receives a day during certain parts of the year. For these calculations, winter months will receive 8 hours of sunlight, and summer months will receive 12 hours of sunlight.

12 hrs of sun (Summer) x 230 days = 2,760 hrs x 1,940 kWh = 5,354,400 kWh

8 hrs of sun (Winter) x 135 days = 1,080 hrs x 1,940 kWh = 2,095,200 kWh

98 "Amorphous Silicon Solar Panels." Energy Informative. Accessed May 04, 2018. http://energyinformative.org/amorphous-silicon-solar-panels/.

99 https://www.perovskite-info.com/perovskite-solar

Based on these numbers, one building, from solar cells alone, could produce close to 7.5 million kWh per year. From the high-ball, lower efficiency calculations earlier, a building would consume around 8 million kWh of energy per year. As energy collection technologies get better and the more efficient passive and active technologies are placed into the building itself, it will be easy to assume that the building could produce all of the energy that it needs and then some. If need be, it will have reserve power sources that it can tap into in order to receive the rest of the energy it needs.

Wind Turbines

As an additional form of energy collection is the use of wind turbines. An average wind turbine can produce 6 million kWh of energy over the course of a year.[100] Based on the amount of space allotted, these turbines that are being used can generate a substantial amount of energy for Fordhamopolis. On Cypress, a speculated ideal spot for these turbines is along the Troodos Mountains on the western part of the island. Research has been done showing that being along hilly areas of land is more efficient when placing the turbines themselves. Hui Hu, an aerospace engineer from Iowa State University, says that "wind making its way over hilly terrain recovers its power potential more quickly as it moves from turbine to turbine."[101] This means that the turbines can be placed closer together than they would on a flat surface. Not only will this region of the island receive more wind than other parts of the island due to wind getting funneled between the mountains, but the turbines can be denser due to how the wind reacts to the grade of the area.

This section of mountain might be very efficient when it comes to collecting wind energy, but it is certainly not the greatest location in terms of proximity to Fordhamopolis itself. Sending electrical wiring across the island can be expensive and difficult to upkeep, but there are possible solutions that can be taken to skip this step while being able to transfer the energy to the city. Wireless charging has become prominent over the past few years with cellular devices, allowing for small portions of electricity to be transferred from the wall to the battery of the cell phone without a direct connection. It is this sort of technology

[100] http://www.ewea.org/wind-energy-basics/faq/

[101] Dorminey, Bruce. "Should the Wind Turbine Industry Head for the Hills?"

that could be beneficial to this operation with the wind turbines. There has been a developing technology called the "Rectenna," which is pretty much a wireless transmitter for large portions of electricity. Containing an RF-to-dc rectifier, the Rectenna is able to convert RF frequencies from the air into useful DC power. [102] In theory, using this new technology, the Rectenna will be able to send collected wind energy through the air to a receiving Rectenna in Fordhomopolis. From there, the collected DC energy can be collected and stored into reserve batteries for later use. With all of these considered, the hills of Cypress can be utilized for their energy potential and their energy can be collected and stored efficiently, making wind turbines a useful backup energy source for our city.

PUBLIC TRANSPORTATION

Public transportation is vital to the growth and sustenance of cities. The ability to travel and access all areas of the city promotes economic development, contributes to the health and well-being of the population, and instills values of community and interconnectedness. Historically public transportation was a primary focus for city developers and systems and for cities especially, as densely populated areas, this manifested in the development of road networks and subway systems. The demands and needs of cities depended on their geographical location, areas of density, and how to most efficiently connect residential zones to commercial and industrial zones. Rapid industrialization and fueled by oil and gas, public transportation systems have a massive carbon footprint. Carbon dioxide makes up 95% of all transportation-related greenhouse gas emissions.

As the disastrous impacts of climate change become more and more prevalent, cities are faced with the harsh reality of coming up with more efficient and environmentally conscious means of transportation. Modern day cities have implemented various models of transportation and with a plethora of demands to be met, this has manifested in diverse ways. In the design and layout of public transportation in Fordhamopolis, we established a system that meets the criteria for sustainability, accessibility,

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[102] Shire, A. M., et al. "Design of Rectenna for Wireless Energy Harvesting."

and efficiency while keeping in mind practicality, simplicity, and opportunity for growth. With this in mind Fordhamopolis will have two major forms of public transportation; a public bike share program and a Rapid Autonomous Mobility System aka the RAMS.

In urban cities, too often residents become frustrated while traveling on their daily commute. In an INRIX study they calculate, "Angelenos spent an average of 102 hours last year in traffic jams during peak congestion hours, costing drivers $2,828 each and the city $19.2 billion from direct and indirect costs."[103] In New York City, about 13% of driving time is spent in congestion.[104] The major reason why all these cities lack efficient mobility is due to a reliance on automobiles. A reliance on automobiles has only brought upon poor health effects in the surrounding major-road communities, pollutants into the environment, and high traffic accidents. This unsustainable model must be replaced with a new, efficient means of transportation.

Fordhamopolis Bike Share Program

Biking will be a major method of transportation at Fordhamopolis. Since biking is Fordhamopolis' predominant means of transportation, it will also be the most accessible. To ensure accessibility, a "Fordhamopolis Bike Share Program" will be put in place. The bike share program's purpose is for that if anybody wants to ride a bicycle, they can.

At the "Fordhamopolis Bike Share Program" docking stations, there will be four types of bicycles available. These four bicycles are meant to ensure that people of all ages and disabilities can ride a bicycle. The four different types of bicycles are: adjustable-seated bicycles, bicycles with child seats, tricycles, and electric bicycles. Therefore, children will be able to get around using attachable child seats. The older generation or handicapped will have a choice between regular bicycles, electric bicycles, and tricycles. The electric bicycles will run on the solar energy collected by the docking stations. All four bikes will be located at each docking station.

However, just having these bicycles exist will not be enough. AI will also make sure all bikes are *available* to people. To do this, AI will be incorporated using a Fordhamopolis Bike Share app. In order to use a Fordhamopolis Bike, one must download the

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103 INRIX. "Los Angeles Tops INRIX Global Congestion Ranking | INRIX." INRIX - INRIX. Accessed May 03, 2018. http://inrix.com/press-releases/scorecard-2017/.

104 INRIX. "Los Angeles Tops INRIX Global Congestion Ranking | INRIX." INRIX - INRIX. Accessed May 03, 2018. http://inrix.com/press-releases/scorecard-2017/.

app. The app will tell you how many and what types of bikes are available a particular biking station. Then, the app will allow people to reserve a specific bike. People have up to 15 minutes to reserve a bike. Another feature of the app is a GPS. The GPS shows city's docking stations, amount of bike traffic, and what the best bike route is. Overall, AI will make sure that the bike share program will be extremely accessible.

Using a Bike Share Program bike will be both an easy and reasonable choice. For instance, the bike share program's purpose is not to make money, but to ensure accessible transportation for everyone. Having that said, the first hour of using a Fordhamopolis Bike Share Program bike will be free. However, each hour after will be $5. If the bike is lost, the person must pay for the bicycle's replacement. The "Fordhamopolis Bike Share Program" app will be hooked up to the user's credit card. Therefore, people can read their "Bike-Bank statements" on a section of the app. All the money collected from the program will be used towards keeping up the maintenance of the bicycles.

Residential & Major Roads

Residential roads will be comprised of only bike paths and walking paths. The biking paths will be located alongside walking paths. The bike road will be 20 ft wide. Each lane will have 5 feet of space. Therefore, there will be 2 lanes per direction. Walking paths will be 10 feet wide. All together, there be 30 feet of road devoted for transportation.

Figure 1. A visual representation of what our roads will look like

Road Materials

Fordhamopolis roads will be constructed by poured Earth concrete. At the Auroville Earth Institute in Auroville, India, they have conceptualized how to use CSEB (Compressed Stabilized Earth Blocks) as building material. After much research, it has been found that CSEB can also serve as a sustainable option for constructing roads.

Figure 2. July 2011, Auroville – Blocks on the Realization road

The Fordhamopolis roads will use the Auroville Earth Institute's method for constructing CSEB. Therefore, the blocks will be 24 x 24 x 8 cm. The components of the blocks will include: 130 liters of soil, 40 liters of sand, 40 liters of chip gravel, and 1 cement bag.[105] To perform at maximum efficiency the soil will be tested and adjusted for: strength, low moisture absorption, limited Shrink/Swell Reaction, high resistance to erosion and chemical attack, and availability.[106]

The CSEB blocks will be extremely durable and resilient. For instance, the institute's CSEB was tested by the Falcon Industrial Testing Laboratory and given a compressive strength of 9.6 MPa (1392 psi). Meanwhile, on average a "Compressed

105 Webmaster, Auroville Earth Institute. Auroville Earth Institute. Accessed May 03, 2018. http://www.earth-auroville.com/blocks_for_the_road_en.php.

106 Earth Materials. Accessed May 03, 2018. http://earth.sustainablesources.com/#Soils.

Earth Block with addition of 5-10% cement can easily pass the Uniform Building Code standards for compression with an average of 960 psi."[107] Due to CSEB's high MPa, the building material can withstand high pressure before it cracks or fails.

There are many benefits towards choosing rammed earth concrete. For one, it is far more sustainable than its alternative, cement. Cement contributes to about 5% of global carbon dioxide emissions. However, using CSEB will reduce roughly 60% of the emissions produced from the decarbonization process of regular cement.[108] This is because rammed earth in nontoxic and non-polluting. Its major components are natural materials that you can find in the environment, like soil, sand, and chip gravel.

Rapid Autonomous Mobility System

Bikes however are not always feasible and the need to transport multiple people and materials necessitates another option. Fordhamopolis will have solar powered, self-driven, electric pods capable of carrying up to 10 people. This is the Rapid Autonomous Mobility System or R.A.M.S. Autonomous, solar powered, electric pods will drive on circular tracks encircling the city in a cyclical loop system. Each of these pods will drive on raised tracks that encircle neighborhoods and encompass the city. These tracks will be embedded with perovskite and photovoltaic cells which will harness solar energy and provide electricity to the pods. The tracks will incorporate a series of embedded R.A.M. stations that can incrementally recharge electric pods carrying mobile receivers as they drive by.[109] We will incorporate Clemson University's International Center for Automotive Research (ICAR) concept of stationary wireless charging technology which uses magnetic resonance to create a field between a ground charging coil and a copper coil embedded in a vehicle through which electricity can pass. Key to the technology is the Wi-Fi communications system, created by researchers at Oak Ridge that allows the ground and vehicle charging systems to talk to one another.[110] Additionally the makeup of the pods themselves, recycled aluminium and photovoltaic glass will allow individual pods to generate up to 50% of their own energy. In times of low sunlight, high volume of transportation, when energy levels might be running low,

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107 Earth Materials. Accessed May 03, 2018. http://earth.sustainablesources.com/#Soils.

108 "Alternative Cement." Drawdown. July 18, 2017. Accessed May 03, 2018. http://www.drawdown.org/solutions/materials/alternative-cement.

109 Ibid 98

110 "Researchers developing roads that charge your electric car while you're driving" Mearin. Oct 27, 2015. Accessed May 03, 2018. https://www.computerworld.com/article/2998356/telematics/researchers-developing-roads-that-charge-your-electric-car-while-youre-driving.html

the RAMS system will be able to harness energy from storage batteries that are supplied with the excess energy generated by other public systems such as the water desalination plant, or the energy from buildings. Because each of these pods will be self driving, AI will play a crucial role in maintaining efficiency and preventing accidents. Cameras and monitors situated intermittently throughout the tracks will relay information back to individual pods which will have their own computers and ensure proper speeds, safety measures, and pod efficiency are being upheld. AI will gauge rush hours and adapt to learn and better perform. AI will be able to determine the future possibility of accidents and act to prevent them. AI will be able to contact authorities and will relinquish control over the RAMS system once overridden by human commands. Citizens of Fordhamopolis will be able to request pods and select options that best cater to their needs. For example, number of passengers, destination, comfort, etc. RAMS stations will be located underground and emerge onto raised tracks. The track of the RAMS will encircle neighborhoods and rise 3 stories above ground level. The pillars which hold up the tracks will be formed of rammed earth and will allow natural flora and fauna growth. The processes of nature will not be disrupted in anyway.

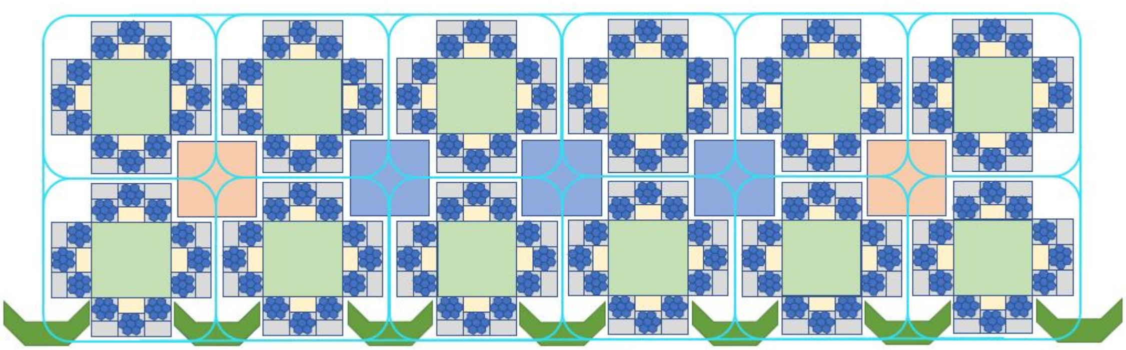

Figure 3: R.A.M.S. network overlaid on city plan

ARTIFICIAL INTELLIGENCE

The AI network in Fordhamopolis will play a valuable role in all major systems described. AI will not only collect data on resource use, but will also control and improve the smart operation of all aspects of resource use in the city by learning usage patterns and optimizing functionality. The goal of this smart network is to maximize all systems such that little responsibility is placed on individual residents for things like monitoring their own resource use, disposing of waste properly, or acquiring optimal quantities of food. In addition, the AI network will optimize the functions of utility systems and public transportation to benefit the resident by improving quality of life and accessibility in the city.

Upon relocating to Fordhamopolis, new residents will be given access to a digital application that will allow them to seamlessly navigate and use all of the city's systems, notably transportation, and view A.I. collected insights regarding their energy, water and food usage. As citizens are made aware of their resource use, suggestions will be proposed via the app to reduce their individual footprint, although all data collection will take place on an entirely anonymous basis to protect privacy. Without mandating limits or forcing sanctions on resource use, the AI system will aim to inspire behavioral changes as residents become conscious of the implications of their daily activities and strive to lower their footprint for the sake of the city's efficiency and the environment's health. Fordhamopolis' sustainable nature will not rely on the control of personal activities through invasive supervision, but rather seek to instill and cultivate values of resource optimization through awareness, education, and community building, all of which stem from a common understanding of the importance of sustainability and environmental consciousness as pillars for the future of humanity.

GOVERNANCE

(Inspired by Pauline Kern, Political Consultant)

Fordhamopolis is a "communal democracy"-- wherein human nature and potential is seen as politically dependent and nurtured. This new model of democracy would incorporate different aspects from developmental, social and participatory democracy, in order to create a framework that is geared towards refining its citizens for inclusionary political participation and other government initiatives to improve them for the sake of a better democracy. Communal democracy provides a method for shaping an intelligent and lucid citizenry that actively participates in political affairs, to ensure a representative and egalitarian government that is truly for the people. Communal democracy will ameliorate and empower citizens through necessary political, social, educational, economic, and healthcare programs, in order to help citizens grow and develop into refined and informed political actors. The important features of communal democracy are centered around the grassroots, where political involvement is not hindered or restricted by elaborate bureaucratic and hierarchical chains of power. With this in mind, transparency will be enforced at all levels of government so that voters may retain their right to political inclusion. It will grant citizens the opportunity to directly participate in the functions and decision-making processes of the state, such as directly electing government officials and voting for proposed laws and legislation to name a few. At all levels of administration, local, state, and federal, people will be the determining factor of decision making. Moreover, communal democracy will heavily stress citizen equality, especially in terms of rights, liberties, education, healthcare and opportunity. While communal democracy asks for the decentralization of bureaucratic power, and the decentralization and redistribution of political power, it assumes that the government will use its remaining power to legally provide basic needs and supplemental benefits for citizens. Overall, communal democracy will aim to remodel and rebuild social, economic and political structures on the basis of transparency, accountability, and an informed public. First and foremost, education would be a primary issue of concern. In order to cultivate and form an active and knowledgeable citizenry capable of taking a more acute interest in government affairs, education should be seen as a human right and governmental responsibility to ensure equal access to higher education is mandatory. Fordhamopolis would mandate accessibility to all levels of education-- primary, secondary, and advanced-- by raising federal funding towards education and making it free, so that all may participate in continued education. Fordhamopolis would also aim to increase political knowledge of citizenry and future voters by implementing new and updated curricula. These would incorporate classes in civic virtue and pluralism where students would learn about community and be taught tolerance and open-mindedness. Courses in environmental studies, political theory, and human relations would take a globalised approach to create a well-informed and socially aware public. In addition, the new curricula would include political student oriented programs in which children unable to vote would learn about the functions and processes of government.

In regards to healthcare, Fordhamopolis would introduce a universal healthcare program. Health care is necessary for a well-functioning society and should be universally provided for by the government. Citizens have the right to life and health, and consequently, this right should be respected by the government. Providing equal access to healthcare on a national level sustains the community and allows for the physical and mental wellbeing of the population as a whole. Guaranteeing medical treatment allows for citizens to make more socially conscious decisions and focus on technological and humanitarian advancements. In addition, universalization of political participation, in order to truly promote direct participation and involvement of citizens would be implemented. A communal democracy would institute automatic voter registration by the government and through internet connectivity allow citizens to directly vote on issues and make their voices heard. Artificial intelligence would allow for a secure and private voting process wherein citizens can express their political views through their phones. To ensure the long lasting existence of these programs that drastically improve the general welfare, it would be most reasonable to increase income taxes. By focusing taxes on public amenities such as infrastructure, schools, hospitals, and recreation areas, the general populace will be more understanding of high taxes and welcome improvements for the community at the expense of lower pay.

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