FOOD DESERTS & MULTIFAMILY GREENHOUSE DESIGN

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ABSTRACT

World hunger, global climate change and human population growth provides the need to reinvent the built environment and the agriculture industry by combining both in a sustainable manner. This research project explores the challenges and provides clarity on growing food indoors with recycled rainwater. While simultaneously providing insights into the aspects of net-zero energy structures and their designs.

CAPLA - Senior Capstone Project

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Food Deserts & Sustainable Multifamily Greenhouse Designs in the Southwest.

"*La comida*," that is how we say food in Spanish, and the names we use for our dishes are often as unique as the ingredients themselves. Growing up in a Hispanic border town, I was thankful for our access to some of the best ingredients around, this shaped much of the culture in my family and the Southwest United States. Today many people in the world do not get to appreciate a food culture of their own, because globally many struggle to even obtain proper nutrition. *"The process of providing or obtaining the food necessary for health and growth."*[1] Nutrition is essential and a key part of life.

The problem is 1.9 billion people are food insecure in the world right now[2]. We must critically adapt our global food systems by simply reimagining how we grow food locally. If we fail, low-income communities in every country will suffer from global climate change. As the human population increases to 9.7 billion by 2050[3], land availability and water resources will become increasingly more difficult for this group of people to obtain. In the future, agriculture systems may struggle to produce an adequate supply of goods at an affordable price, leading to scarcity. This, of course, still includes an average of 30% food waste globally[4]. The 17 Sustainable Development Goals brought together by the United Nations includes hunger as number 2 on the list, after poverty at number 1[5].

One of the biggest problems facing impoverished people are food deserts, which are defined as a lack of access to healthy food within 1 mile in cities or 10 miles in rural areas[6]. According to the United States Department of Agriculture, "*areas with higher levels of poverty are more likely to be food deserts*."[7] The USDA also states that minority groups increasingly live in food deserts as their population density increases. Due to various factors, these communities often have poor urban planning, resulting in low education investment, creating cities with higher rates of crime and poverty. For economic reasons, many grocery retailers often avoid these locations, forcing residents to seek cheaper alternatives such as processed goods and gas station products that are simply not healthy. This, in turn, creates families with various health-related issues and puts health care systems under unnecessary strain.

Food deserts are damaging low-income communities, and the best way to solve this multifaceted problem is through our built environment. Multifamily apartment buildings with integrated greenhouses can provide sustainable food production at a fraction of the cost and

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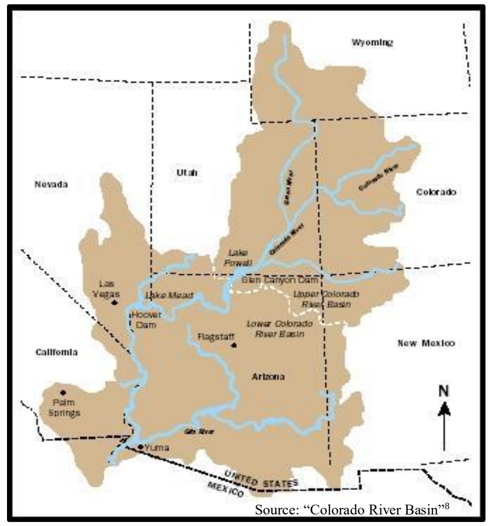
[1] Tammi Jantzen, "The Importance of Nutrition," Astarte Medical, October 15, 2019, https://astartemedical.com/the-importance-of-nutrition/.
[2] Max Roser and Hannah Ritchie, "Hunger and Undernourishment," Our World in Data, October 8, 2013, https://ourworldindata.org/hunger-and-undernourishment.
[3] "Population," accessed February 23, 2021, https://www.un.org/en/sections/issues-depth/population/.
[4] "New Online Platform Fosters Efforts to Curb Food Losses through Information Sharing," FAO, accessed February 23, 2021, http://www.fao.org/news/story/en/item/262504/icode/%20/.
[5] "#Envision2030: 17 Goals to Transform the World for Persons with Disabilities Enable," United Nations (United Nations), accessed February 23, 2021, https://www.un.org/development/desa/disabilities/envision2030.html.
[6] "Documentation," USDA ERS - Documentation, accessed February 23, 2021, https://www.ers.usda.gov/data-products/food-access-research-atlas/documentation/.
[7] Dutko, Paula, Michele Ver Ploeg, and Tracey Farrigan. *Characteristics and Influential Factors of Food Deserts*, ERR-140, U.S. Department of Agriculture, Economic Research Service, August 2012.

allow communities to take control of their health and food acquisition options. By including water recycling systems, simple growing techniques, passive design features, and maximizing land usage vertically; opportunities will arise for low-income communities empowering them to survive global climate change.

The main question to consider is, <u>how can we sustainably grow food?</u>

<u>Case Study Reviews:</u>

Global climate change will affect every community worldwide due to the already scarce supply of water. Currently, Northern México and many of the states in this region, such as Arizona, California, Nevada, New Mexico, Utah, Colorado, and Wyoming, rely on the Colorado River basin for water supply. The Colorado Rockies and its snowfall supply many of these tributaries; if the region warms and reduces snowfall potential many will be affected. Today, about two-thirds of the Colorado River water is used for irrigation in the agriculture industry, while only one-third is used for domestic urban needs.[8] About 17 million people depend on this water; 80 percent of residents in the region live in major cities, including Phoenix, Tucson, and Las Vegas.[8] Relying on uncertain weather patterns in the future is not a safe and viable option for the people in this region. We must first acknowledge the current limitations of traditional agriculture and housing if we hope to preserve this valuable resource efficiently.



Source: "Colorado River Basin"[8]

Figure 1 – Colorado River Basin.

Changing climate conditions would result in higher evaporation rates, leading to even more water usage and potentially shortages. In the traditional agriculture system, the main objective is often to produce as much as possible. Meaning the scale of quantity over quality is favored because efficiency is never truly maximized in the outdoor space. This current model would not be sustainable in the future. Additionally, harvesting rates for crops could be much lower, given that most crops require steady conditions to grow fully and properly.

So what about housing and its relationship to farming? If the typical household wanted to introduce farming at the residential level, they only have a few options. The most common method of growing food independently includes growing crops in the backyard with a garden, assuming that first, you live in a climatic region that offers plenty of sunshine and mild winters. Secondly, soil, which many regions do not offer adequate soil nutrition to support crop growth, which may require fertilizers. A technological adaptation to these concerns is the modern-day greenhouse meant to enhance food growth by creating climate-controlled spaces with adequate protection from wind and even pests. Greenhouse facilities have proven to be successful today due to efficiency. These advancements remain widely available to the public, but growing food requires time, space, money, maintenance, and knowledge.

Dutko, Paula, Michele Ver Ploeg, and Tracey Farrigan. *Characteristics and Influential Factors of Food Deserts,* ERR-140, U.S. Department of Agriculture, Economic

Figure 2 – Vertical Growing Towers.

A model for this innovative industry includes a company in Mesa, Arizona, named True Garden, owned by licensed pharmacist Troy Albright. He ventured into the farming industry only after seeing many of his patients lack the foundational nutrients needed to live healthier lives. Not only do they grow indoors, but they also grow upward as well—pioneers in vertical gardening with a system known as aeroponic growing towers. According to Troy, the "*benefit of having a vertical farm versus having a normal farm, with the vertical farm we're really saving on space, we can use ninety percent less land but we can grow ninety percent more food.*"[9] This growing style does not require soil that could be susceptible to pests. Instead, True Garden uses organic coconut husks, which acts as the growing medium for the crops. Meaning accelerated growth due to the hanging roots absorbing more oxygen in this aerated tower system.

Additionally, there is no tilling of weeds with up to "90 to 98 percent less water" use. True Garden aims to grow ten times more food on only 1/10 of an acre of land. Located in the greater Phoenix area with almost 5 million residents, True Garden has also reshaped the typical produce shipping system. By transporting live crops with root systems locally, vendors and restaurants can expect to receive the freshest produce possible. More popular options like lettuce can continue to grow given water supplementation, extending food value. With the average American meal being transported 1,500 miles before arriving at the dinner table, the potential to cut commercial transportation routes could reduce global CO_2 emissions drastically[10]. This is a true revolution in the way we grow and receive our produce.

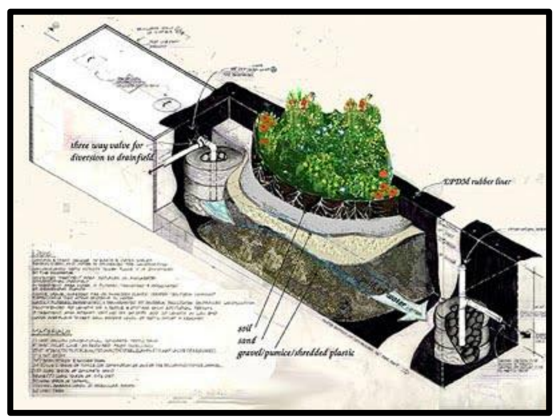


Figure 3 – Bioreactor

Earthship Biotecture in Taos, New Mexico, founded by Architect Michael Reynolds, has developed a system that passively grows food within your home. These completely independent off-grid homes provide the opportunity to maximize crop production efficiently. By utilizing passive solar design, rainwater harvesting, and sophisticated water recycling systems, living independently is finally made possible. Developed in the 1970's Michael Reynolds wanted to create structures with recycled materials, which was deemed trash, to advance the evolution of building design. The State of New Mexico finally allowed these structures in

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Research Service, August 2012.
ng Without Soil and 90% Less Water," GRATEFUL (USA Today, September 21, 2019), https://www.youtube.com/watch?v=3Ww2TP_tU7o.
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ng Without Soil and 90% Less Water," GRATEFUL (USA Today, September 21, 2019), https://www.youtube.com/watch?v=3Ww2TP_tU7o.
text=It%20is%20estimated%20that%20the,large%20quantities%20of%20fossil%20fuels.

2007 with few permitting or building codes as the designated region was established as the first **Sustainable Test Site Act**. Over the years, Taos has grown to become a community and, most importantly, a biotecture research academy that focuses on sustainable living. The main principles for life in the high mountain sierras include food production, energy capture, freshwater, shelter, garbage management, and sewage treatment[11]. Over 50 years of research and development finally allows reclaimed gray water from our sinks and showers to be naturally filtered, which aids in plant growth. According to Michael, the microbes from the gray water allow vegetation to grow at rates he has never seen before, to the extent that growing organic bananas in Taos' cold desert is seen as achievable.

Additionally, by incorporating a greenhouse inside the south-facing side of the home, oxygen production is maximized, allowing the cleanest, freshest air to be inhaled. The downside to these amazing net-zero energy structures is their cost. These structures require plenty of human labor to build, which can be expensive. The only positive includes building these homes with recycled materials such as bottles, reclaimed wood, and even tires which lowers the total cost. For the average family, this type of home may be unobtainable due to local permitting. However, these design and system principles are noteworthy as applying them to larger structures such as apartment buildings which reduce costs per person. Allowing more individuals to live healthier lifestyles inside these green homes.

Figure 4 - Earthship Source: Earthship Biotecture[11]

[11] Michael Reynolds, "Offgrid Sustainable Green Buildings," Earthship Biotecture, February 19, 2021, https://earthshipbiotecture.com/.

Currently, building codes and zoning regulations limit this type of mixed agricultural-housing. In general, the housing industry must expand its building opportunities for the sake of socio-economic diversity. When large suburb communities become limited to only single-family residences, they create large groups of individuals with similar needs and routines. This becomes problematic because these regions are usually constructed outside of city limits lacking commercial/retail space at walking distances. Leading to urban sprawl and the urban heat island effect. Essentially forcing residents to travel greater distances producing more CO_2 emissions.

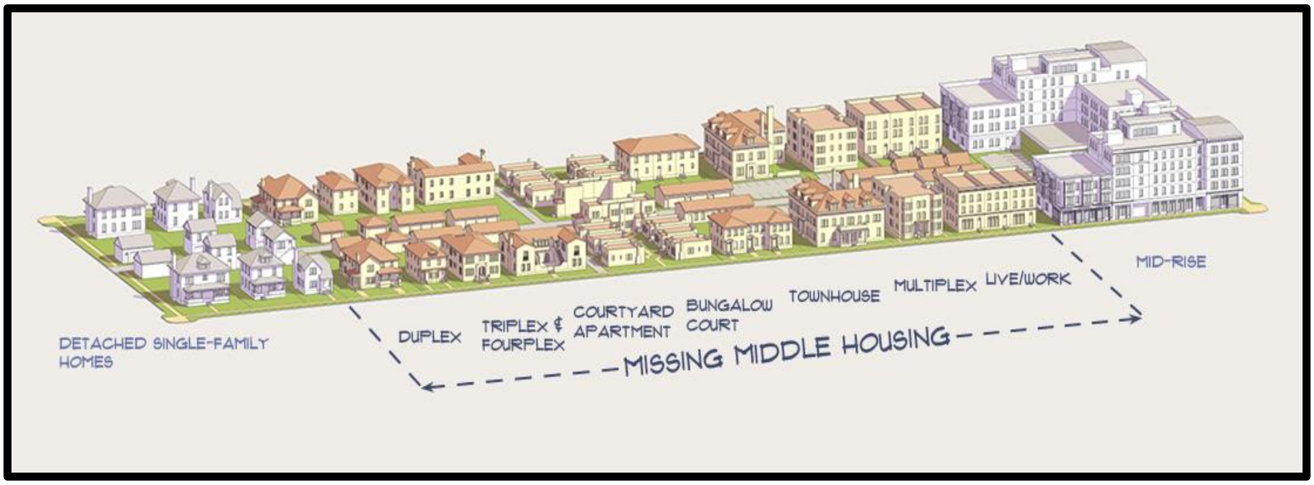

Figure 5 – Middle Housing. Source: Opticos Design

Middle housing[12] incorporates various compact building sizes varying from duplex to courtyard apartments to townhouses to live-work buildings within city limits. In this missing middle housing, individuals give up some of the luxuries of single-family residences, such as backyards, for proximity to local services. This density helps create more diverse communities as these types of residents are different in age, size, and income. These differences help neighborhoods and their activities become strongly interconnected, creating more economic incentives. Middle housing could easily become one of the largest building styles if more zones accepted such density. Buildings that accommodate small businesses and housing under the same roof open the door to a changing economy; this is especially critical in small towns. In the United States, the 2020 Covid-19 pandemic displaced many small businesses, resulting in an online, work-from-home structure. Many individuals were forced to turn their homes into workspaces and offices. Unfortunately, the pandemic displayed the importance of open spaces and food accessibility in our built environment. Fortunately we can retrofit many of these outdated business spaces back into residential living in order to revitalize our communities for adaptive mixed use.

Lastly, combining agriculture and housing to serve the community is largely based on individuals' needs and wants. Mixed agricultural housing is meant to supplement food acquisition options while providing micro job opportunities for local residents. Depending on the economic stability of a community, these types of buildings have evolving opportunities within them. Therefore, it is important to consider building space as a zone of mixed everchanging use depending on community residents' needs.

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[12] Parolek, Karen. Opticos Design. The "Missing Middle" Housing Affordability Solution. August, 16, 2016. https://opticosdesign.com/blog/the-missing-middle-affordable-housing-solution/

Methodology:

Growing sustainable food largely depends on what kinds of meals we want to consume and how easily we can produce it. My investigative research was partly 1/3 qualitative data and 2/3 quantitative data.

Qualitative - The first primary data collection method included a digital survey sent to college students, family members, and friends. In total, over 40 submissions were received. The series of questions included food accessibility and preference, housing and proximity to food sources, and interests in growing food. These questions allowed me to determine the relationships between housing, travel, and food production/acquisition within the state of Arizona.

Quantitative - Questioning how much food we can grow largely depends on space, sunlight, and water availability, as crops vary by size, harvesting length, and various other inputs. For the second method of data collection, my focus included water, energy, and building design. A great way to measure resource consumption and management includes performing a water use intensity (WUI) audit. This strategy allows me to classify every water feature and accurately predict its usage on a daily and yearly basis. This baseline measurement is extremely useful to know as it would then allow me to further improve upon the water design features, incorporating *water sense* considerations to create a refined and efficient water design layout. After investigating water use, I could then calculate crop growth potential.

In this design, water waste is directly correlated to crop quantity and gardening space. The energy to volume ratio in this design is also critical because overcrowding can lead to food production failure. In order to mitigate these concerns, I used virtual 3D modeling software to design the building structure and to properly allocate water plumbing lines, gardening space setup with building design layout that maximizes sunlight and ventilation. A 3D model provides a visual interpretation of water and energy systems as they work together within the building to explain the interconnected relationships of growing food indoors. Additionally, modeling provides the chance to see other sustainable design features in action. Addressing a multifaceted problem requires designing various systems at once while making the entire network cost-effective. A 3D building design allows for realistic building cost estimations as well.

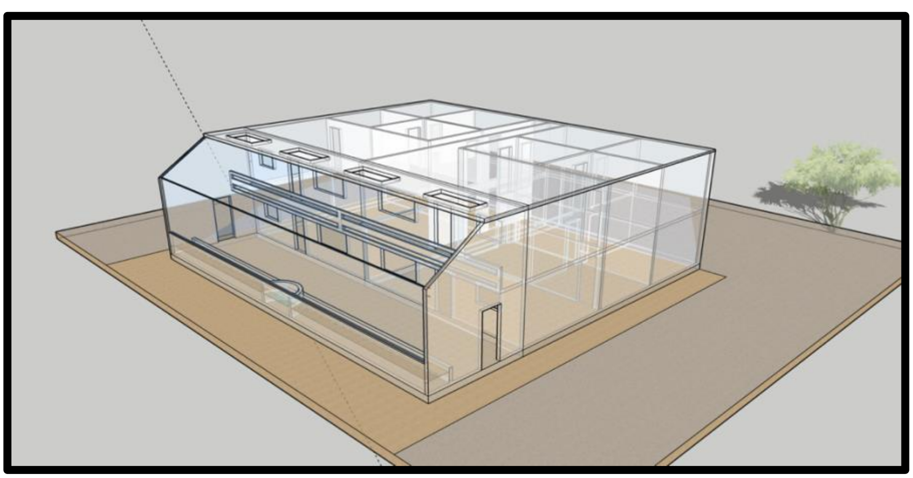

Figure 6 - Proposed buildings design in preliminary stage.

Survey Results:

Figure 7 – Importance of Essentials.

When considering the main costs for an individual today, housing, food and travel tend to be the largest expenses. The data suggest people are considerably more worried about the cost of their housing than food. This could be for a couple of reasons, but more than likely due to living expenses being a generally larger bill than an average grocery food bill. Despite the individual purchasing food more often than the monthly living expense bill. This data also suggests there is plenty of room for improvement in building our structures today; as we may need to reduce building costs in order to offer individuals affordable housing. If they could potentially pay less per month on housing, would they use this income on other alternatives such as healthier foods, which they may currently be holding back on?

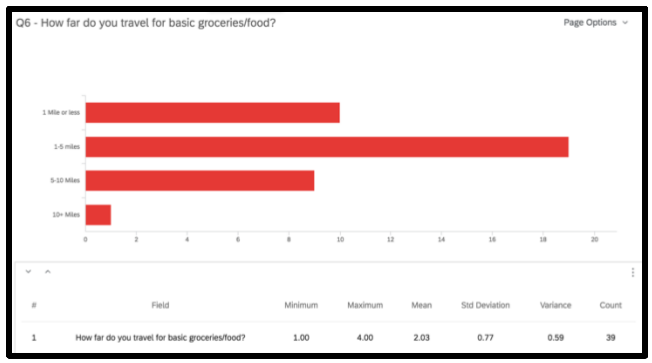

Figure 8 – Distance Traveled.

The travel data suggests that most individuals travel an average of one to five miles to acquire basic groceries. After that, individuals report having access to food within one mile or less. Individuals reporting more than 10 miles were seen least.

What about participation with local gardens? The data here suggest most individuals would be neutral to slightly motivated to purchase goods from local sources regardless of an organic option. However, when you introduce physical participation as a form of compensation instead of just purchasing, there is a much larger spread. Overall it can be said that individuals who may want to participate is 50/50. This could be expected as the traditional model in society today requires currency for an exchange of goods, not personal time. This also gives insight into the possibility of growing your crops as it also requires time and participation. It may appear that half the population is not interested in growing crops but solely purchasing from a local source. The tables below, left includes purchasing, right includes participating.

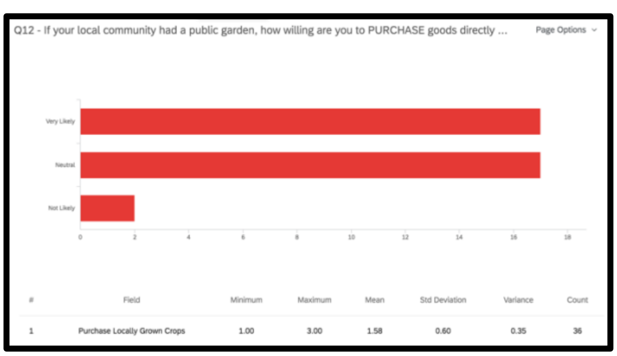

Figure 10 - Purchasing Locally.

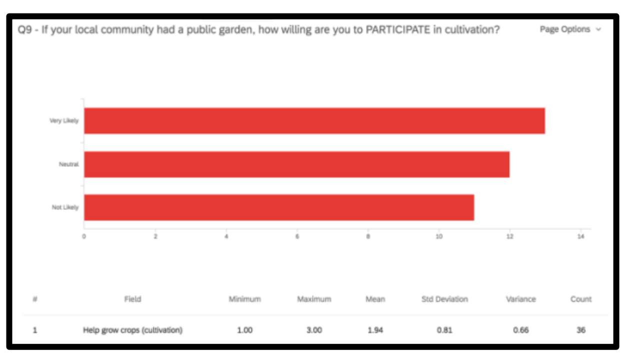

Figure 9 – Participation.

Now food preference, this was certainly the most interesting as every individual has their taste. I first asked the individual to choose between fruits and vegetables, and surprisingly fruits were chosen almost three times as much. This could be due to the sugar content and sweetness. I also asked individuals to input their favorite foods, with the only options being fruits or vegetables once again. The answers were, of course, very diverse; see figure 11 below. Amongst the most popular options were apples, bananas, and mangos. Given this data, some challenges would become present, such as growing fruit trees and other smaller crops in the same environment. Some of these more popular options are tree-related crops, which implies that new developments would take years to finally fruit. Unlike vegetables that can be grown and harvested within months, most fruits require more gardening space.

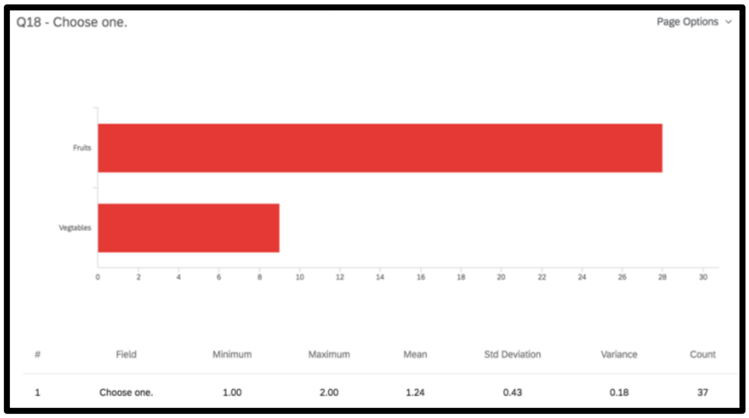

Figure 12 - Fruits or Vegetables.

1	Q17 - List some of your favorite foods (Fruits & Vegetables only)
2	Bananas, apples, broccoli, oranges
3	Strawberries, pineapples, bananas, broccoli, asparagus.
4	Watermelon, pineapple
5	Apples oranges carrots
6	Asparagus, broccoli, carrots, potatoes, brussels sprouts, bean sprouts
7	Papaya, mango, berries
8	Apples , peaches
9	Cauliflower, apples, mangos,
10	Apples, bananas, celery
11	Apples
12	like all of them besides broccoli
13	Brussel sprouts
14	Bananas, berries, mangos
15	Apples, avocados, cucumbers
16	Watermelon, banana, peaches, broccoli, olives
17	Broccoli, asparagus ,mango
18	Mango watermelon
19	oranges, mangos, lettuce, potatoes
20	Tomatoes, lettuce, cucumbers
21	Broccoli, asparagus, green beans
22	Pineapple, banana's, broccoli, apples, carrots, onions
23	Bananas spinach broccoli Brussels sprouts asparagus corn zucchini apples watermelon cantaloupe
24	Grapes, bananas, strawberries, oranges,
25	Spinach, beets, mushrooms, celery, pomegranate
26	Apples , mango , pears
27	Pizza, Sushi, Steak
28	Strawberries

Figure 11 - Provided Food Choices.

While dwarf versions of fruit trees can be readily obtained in regards to space concerns. The data shows most individuals are not interested in growing food personally due to time constraints. It is quite clear that food production here must happen as passively as possible. Meaning there must be almost no energy input from people in order for them to consider this food option valuable- which results in a building design that must be more technologically capable than most structures today partly due to convenience.

Discussion:

A **net-zero** building is a structure that ultimately produces as much as it consumes, balancing its ecological footprint to zero. Triple net-zero which includes water, energy and waste systems within a structure creates opportunity for all. Because agriculture and simply growing food are very energy-intensive, we must appropriately design our housing facility to accommodate this production, essentially creating a global sustainable food and housing model. If possible, we can make it cost-effective and simple to build anywhere, regardless of materials, climate, or location. At the same time, we are keeping in mind water and energy usage, social equity, the environment and other opportunities for growth within our communities.

This quantitative data is based on secondary sources provided by both federal agencies and public water utility companies. The average family can expect to use 400 gallons of water per day, based on five members with individuals using 80 gallons per day[13]. Therefore based on

[13] Statistics and facts. (2021, March 18). Retrieved March 31, 2021, from https://www.epa.gov/watersense/statistics-and-facts

Earthship Biotectures water system, in one day, this family could save 60 gallons of water per person, a total of 300 gallons, by recycling their gray water[14]. They paid for the water once at an average price of $0.00235 per gallon of water in Arizona and can be used multiple times, extending the value to grow crops[15]. In one year, a family could expect to use 146,000 gallons but save 109,500 gallons of water, estimated at a savings value of $336 given the Arizona retail value. Almost a 75% savings in total water usage for one year alone. With water being one of the most expensive resources for growing crops, the potential to use "free" water from the beginning would drastically reduce the cost of any crop production. Regardless, if the household chooses not to participate in crop production, this water could be used for exterior irrigation. Such as for shade trees and other vegetation, which would also save energy by creating micro-climates.

Water Recycling Potential - Family of 5

YEARS	AMOUNT OF WATER USED (GALLONS)	AMOUNT OF GRAY WATER SAVED (GALLONS)	DIFFERENCE (BLACK WATER)	VALUE OF SAVED WATER
1	146,000	109,500	36,500	$336
2	292,000	219,000	73,000	$672
3	438,000	328,000	110,000	$1,006
5	730,000	547,500	182,500	$1,680
10	1,460,000	1,095,000	365,000	$3,360
20	2,920,000	2,190,000	730,000	$6,720
30	4,380,000	3,285,000	1,095,000	$10,081

Figure 13 - Water Recycling Chart.

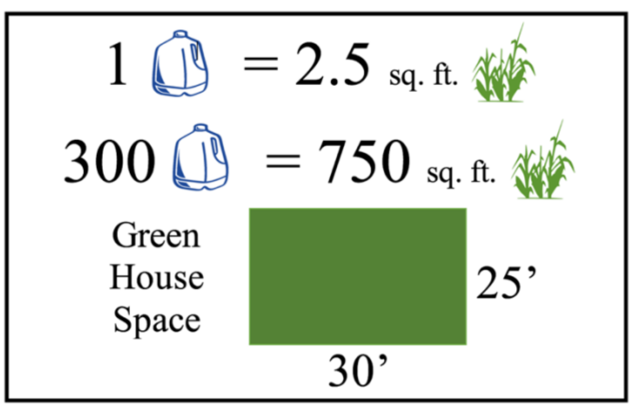

Figure 14 - Water to Space Equivalency.

[14] Reysa, Gary. BUILDITSOLAR. *Earthship Water System*. https://www.builditsolar.com/Projects/SolarHomes/Earthship/Visit/WaterSystem.htm

[15] Herndon, L., 23, G., 23, W., & *, N. (2014, September 26). Conservation water rates in Arizona. Retrieved March 31, 2021, from https://efc.web.unc.edu/2014/09/23/conservation-water-rates-arizona-utilities-using-rates-discourage-discretionary-water-use/#:~:text=The%20median%20water%20marginal%20price,per%20thousand%20gallons%20in%20Alabama

So then, how much food production is possible as a result of this recycled gray water? Well, given the constraint of space for one single crop and the total water that is permeable. An average plant requires 1 to 1.5 cubic feet of soil to grow[16]. It is generally accepted in the farming community that 0.4 gallons of water is required for every square foot of crop space[17]. This means that our previous estimation of 300 gallons of saved water for an average household could support 750 square feet of gardening space. To put that into perspective, 750 square feet would include a stand-alone greenhouse with a size of 25 feet wide by 30 feet long. This greenhouse space would then support 500 to 750 crops depending on the selected species. The biggest issue with greenhouses is that they can be costly to purchase or build and require a large space. On average, a small and simple greenhouse structure purchased at a local hardware retailer can vary in price from a few hundred dollars to a few thousand. By combining a large greenhouse space within an apartment building that multiple families can share, the cost per person dramatically decreases, making food production more obtainable to the individual. Additionally, by combining the gray wastewater from multiple families into a single large common greenhouse space with its filtering bioreactor, the price of recycled water becomes insignificant. An ideal design to address middle density and food production is a four-unit, family apartment building with each unit hosting two bedrooms, two bathrooms, a living space, and a kitchen. An eco-friendly four-plex, the **Eco-plex**. This building can accommodate families, businesses or both.

Water Use

In order to perform a water use audit, we must first identify all fixtures in the building. In this proposed Eco-plex design, we can see below in figure 15 that we will place a total of 24 gray water fixtures that will supply our gardening operation. Daily water use is calculated with the water flow rate, gallons per minute or gallons per flush. This duration is multiplied with uses per day then multiplied with occupants, which is a recommended max of 16 full-time residents.

By incorporating *water sense* features in our plumbing system, we can efficiently reduce water consumption by regulating pressure flows and volume. In this building, we aim to use less water so that we also treat/filter smaller volumes. Low-flow plumbing can have considerable impacts on total water conservation. This building incorporates *water sense* technology to save an estimated 88% of water use. One drawback to these new implementations are higher initial costs, as many of the efficient technologies save in the long term.

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[16] Albert, S., RAJ, M., Ed, Saurabh, Ghosh, T., Elaine, . . . Hello Spring! Now Let's Get to the Good Part! – Getaway Gardens says:. (2020, March 18). Container and Pot Sizes: How much Soil Do I need? Retrieved May 03, 2021, from https://harvesttotable.com/container-and-pot-sizes-how-much-soil-do-i-need/

[17] Bartok, J., Jr. (2016, October 26). Sizing the greenhouse water system. Retrieved May 03, 2021, from https://ag.umass.edu/greenhouse-floriculture/fact-sheets/sizing-greenhouse-water-system

(WUI)	Gray Water			Black Water
Fixture	Outdoor Taps	Sinks	Showers	Toilets
Unit A1	1	3	2	2
Unit A2	0	3	2	2
Unit B1	1	3	2	2
Unit B2	0	3	2	2
Exterior	2	0	0	0
Total	4	12	8	8
Grand Total	24			8
Water Use Intensity	Gray Water			Black Water
Fixture	Outdoor Tap	Sinks	Showers	Toilets
Gallons per Minute	0.21 GPM	0.21 GPM	2.0 GPM	1.1 GPF
Duration	5 Min	1 Min	10 Min	N/A
Uses per Day	1	3	1.5	3
Daily Water Use (Gal)	17	10	480	53
Total Daily Water Use (Gal)	507			53
FTE= Full Time Resident @ 1 FTE * **Occupancy** 16 Max				
Daily Water Use = (GPM)*(Duration)*(Uses)*(16 * 1 FTE)				

Figure 15 - Water Use Intensity Audit

(Gallons)	Water Sense	Baseline
Outdoor Tap	17	176
Sinks	10	106
Showers	480	600
Black Water	53.0	77.0
Daily Total	560	959
Yearly Total	204,000	350,035

Figure 16 - Water Comparison Table

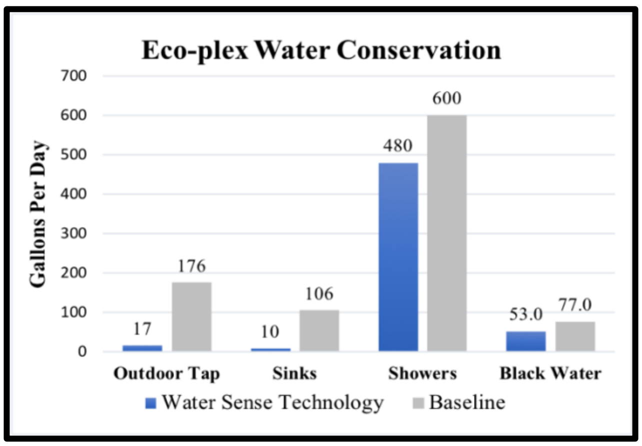

Figure 17 - Water Conservation Graph

When considering the multi-use aspect of buildings today, water availability is largely dependent on location and climate. In rural areas, this building would have to rely on seasonal rainfall for potable water use. Ideally, capturing, processing, and recycling water on a micro-scale which can help reduce strain and costs for city wastewater treatment centers.

In the Southwest United States, the monsoon season brings heavy rainfall in short periods of time. Meaning capture must be maximized on every opportunity. With a total annual rainfall of 12 inches per year[18], this building design with a large flat roof of about 60 feet by 48 feet (2,880 sq. ft.) can collect an estimated 21,530.88 gallons annually[19]. Traditionally water storage tanks are constructed from metals, plastics, clay, and even wood. Larger sizing provides more storage but also higher initial cost, so for that reason, you can expect to see storage volumes of a few hundred gallons to only a few thousand on larger projects. An unconventional yet efficient approach to larger water storage includes a shipping container tank retrofit. These containers can be found globally at reasonable prices for their capacities. They include airtight welded construction and core-ten steel, which only rusts at the surface, creating a protective patina. A standard 40-foot container can be sealed with a non-toxic liner capable of holding 20,000 gallons, very cost-effective. A shipping container will cost only a few thousand dollars, while a manufactured tank of this capacity, tens of thousands of dollars. Plus Shipping[20].

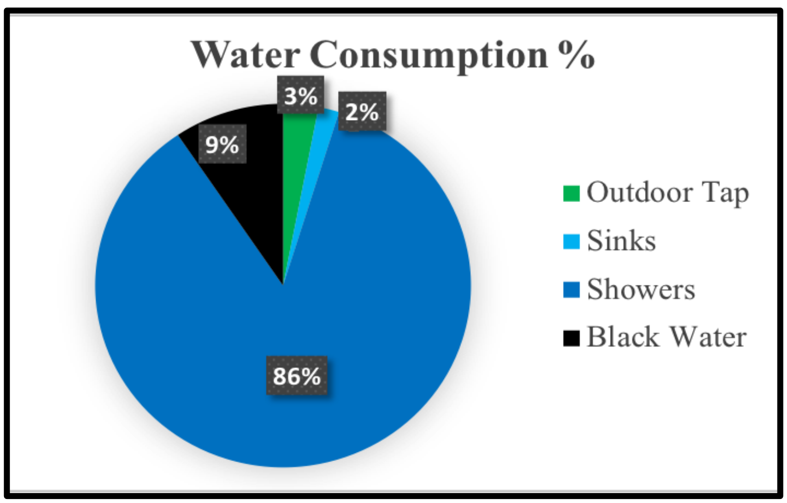

Figure 18 - Water Consumption %

18 Climate change in the southwest. (n.d.). Retrieved May 03, 2021, from https://www.nps.gov/articles/climate-change-in-the-southwest-introduction.htm

19 Maxwell-Gaines, C. (2020, August 14). Rainwater harvesting calculator, formulas, and equations. Retrieved May 04, 2021, from https://www.watercache.com/resources/rainwater-collection-calculator

20 40' shipping containers for sale - Rent 40' storage containers. (2020, May 26). Retrieved May 03, 2021, from https://westerncontainersales.com/shipping-container-prices/40-foot-shipping-container/#:~:text=Used%2040'%20containers%20start%20as,to%20%247%2C000%2C%20depending%20on%20availability.

Clouds provide free natural rain that we can harvest for potable use. We must first separate the contaminants from our roofs and other debris before storing this rain water. The first water flow draining into the gutter system will usually include smaller debris, which can be redirected in a first flush system. Mesh screens on the gutter system only removes large physical debris such as leaves. As more rainfall lands on the cleaner roof surface, this water becomes increasingly clean. This water must then be filtered with a simple sand filter and recommended ultraviolet (UV) light disinfection before arriving at the main freshwater tank. This 20,000 gallon reserve is meant to supply all internal and external water features in an off-grid scenario when municipal water utility is not available.

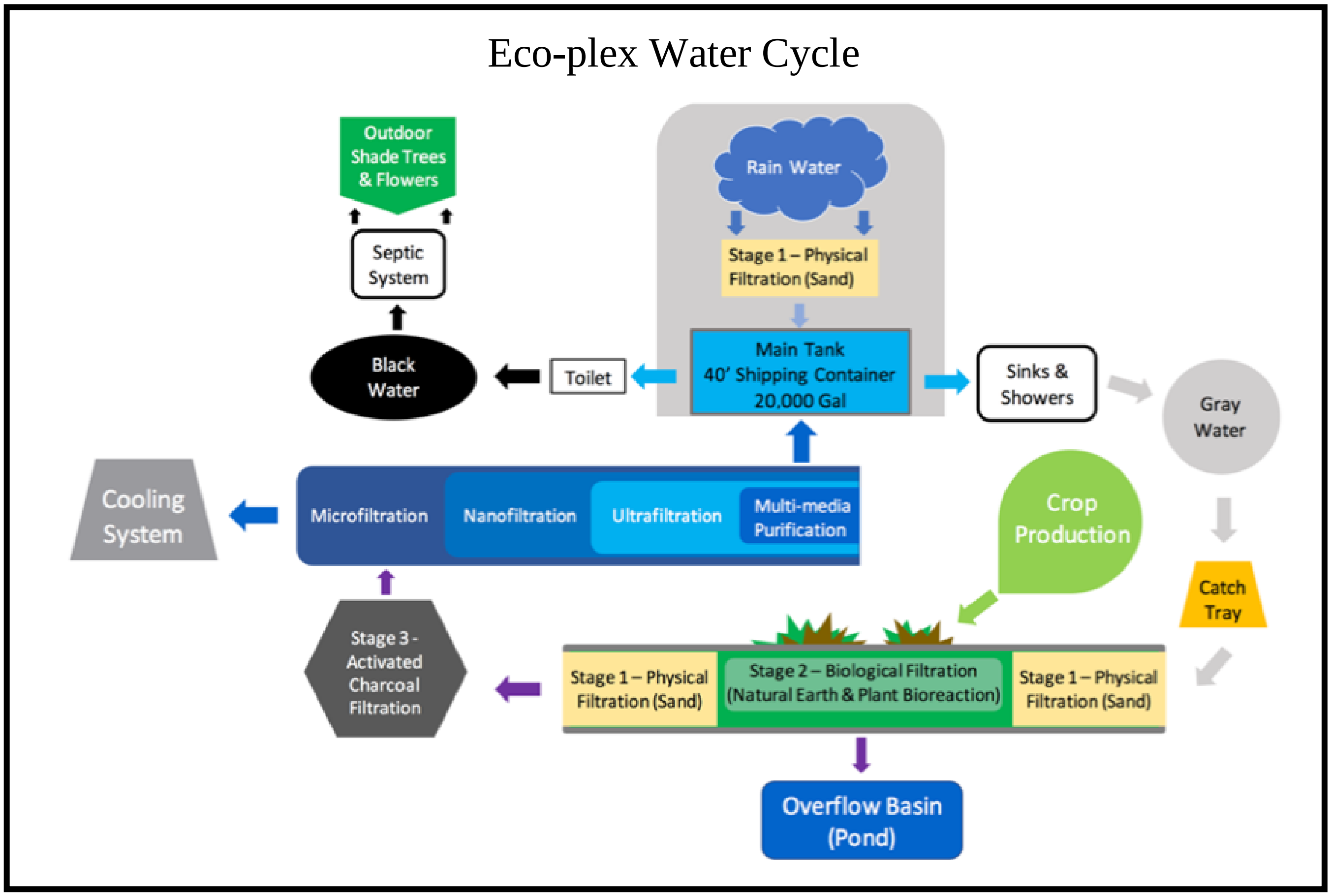

Figure 19 - Water Cycle

Sinks and showers create gray water, which first runs through a catch tray to prevent any hair or small valuables from clogging the bioreactor. Ultimate water filtration follows three stages. The first stage is <u>physical</u> filtration, the second stage is <u>biological</u> filtration, and the third stage which is often not needed <u>chemical</u> filtration[21]. Followed by various purification strategies for drinking

[21] Filtration-purification levels and stages. (2021, January 13). Retrieved May 03, 2021, from https://waterwithoutwaste.org/filtration-purification-levels-and-stages/

use quality. Most municipalities are only required up to level two filtration because most ground sources are not contaminated with chemical toxins. As the gray water flows into the botanical cell where crop production occurs. Physical sand filtration blocks diluted hygiene products such as toothpaste, soaps, etc. This water can passively travel through the gardening space in stage 2, a biological filtration where natural earth and plant bioreaction occur, cleaning our gray water. Microbes breakdown water waste allowing plant roots to process the water organically, much like a pond or lake. Excess water flow can be redirected to the exterior overflow basins for additional irrigation of shade trees in heavy storms. After this biological stage 2 filtration, this reclaimed “purple water” is often used for flushing toilets; however, this method includes additional plumbing costs and does not fully extend water value. At this point, many building code regulations limit such water use; however, we still have value at this point. If we simply direct reclaimed purple water to flushing toilets, we create black wastewater. From this point water use becomes extremely limited.

Instead, I propose more extensive purification in order to recycle this reclaimed purple water back for potable drinking use. Essentially, a micro water cycle that can occur continuously becoming smaller only as toilets eject black wastewater that cannot be reused. In order to extend purple water value, stage three would be necessary, such as activated charcoal filtration, which helps reduce residual disinfectants. Finally, purification which is extensive given the multistage process. Multimedia purification can be so effective that it can eliminate bacteria, pesticides, salts, and even viruses up to 0.1 microns[22]. Ultimately, the 88% of recycled water entering the main water tank for a second time is purified beyond any rainfall water quality.

Energy Use

Unlike water, energy is very abundant as the sun consistently provides solar radiation to our planet. Given this free source of energy, the management of such resource could ether make or break an environment. Too much sun or not enough seems to be a very general trend around the world. The proposed Eco-plex design aims to control the solar energy by various design strategies.

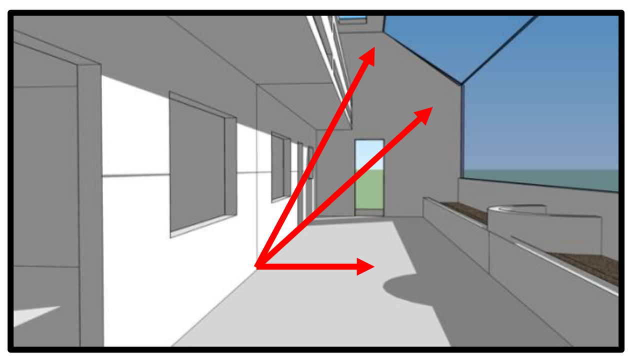

Figure 20 - Greenhouse Preliminary

Passive solar design takes into consideration many important seasonal events and solar paths that must be acknowledged when trying to create a comfortable indoor climate. Such as the winter solstice, the equinox, and the summer solstice[23]. These three solar paths are important as they can support or hinder energy management with solar gain or shading. The **solar geometry**

[22] Culligan. Physical Water Treatment: Water Filtration: Multi-media filtration. https://www.culliganindustrialwater.com/physical-water-treatment-types/

[23] The carbon neutral design Project: Society of building Science educators: American Institute of Architects - carbon neutral design strategies. (n.d.). Retrieved May 03, 2021, from http://www.tboake.com/carbon-aia/strategies1a.html

of the winter solstice produces a very low sun angle of about 47.5 °, this can help introduce warm light into the building from the south. The solar geometry of the summer solstice produces a very high angle of about 93.5 °. The angles of these sun rays play a crucial role in energy management. Such that in the winter the low sun angle can charge walls with thermal mass, releasing this energy as heat later in the day. While in the summer exterior shading structures and roof pitch regulate energy exposure within the interior.

A **cool tower** is a passive design feature based on middle eastern design principles that slowly cools outdoor air. It functions with the use of water and humidity pads. As air enters the cool tower it comes into contact with wet pads that compresses the air making it much heavier. As the air falls through the moist padding it becomes cooler.

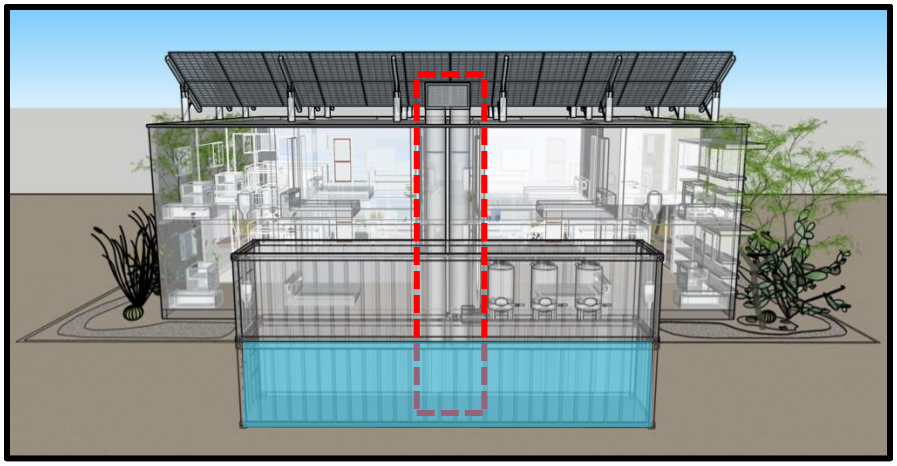

Figure 21 - Cooling Tower

Natural ventilation is a passive design feature that does not require energy when heating or cooling the interior space. The main source of this phenomena is the natural wind patterns which can be efficiently utilized and funneled to refresh or exhaust indoor air. Window placement and size is critical in order to allow airflow within the building layout. Vegetation near these windows can also aide in cooling by providing transpiration and humidity.

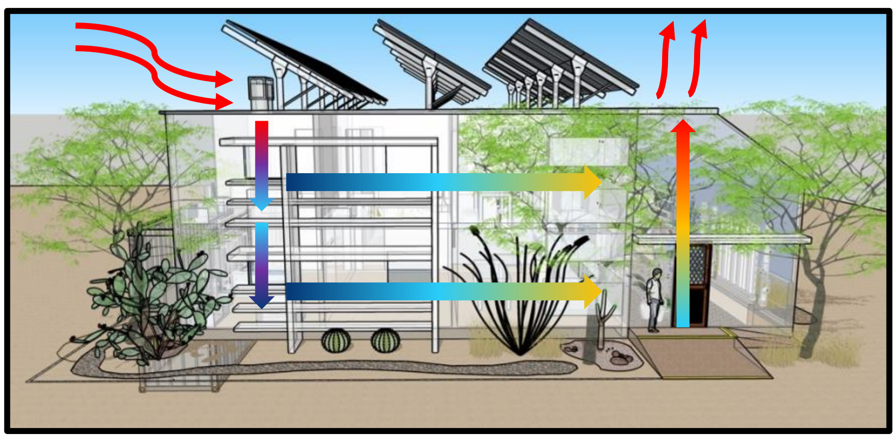

Figure 22 - Natural Ventilation

This proposed building design uses the greenhouse chamber in accordance with the cooling tower system to provide <u>continuous free cooling</u> even in the Southwest. This is extremely important as buildings consume a lot of energy just to heat and cool spaces. This functions because as the greenhouse becomes warm, the ceiling vents exhaust this hot air creating a shift in air pressure. This resulting vacuum within the building requires an adjustment, meaning air must be pulled in. In summary hot air will enter the cool tower becoming temperate then cool. It then travels through the central hallway of each living space cooling the residents. This airflow warms slightly near the kitchen and then finally enters the greenhouse where only heat rises and becomes exhausted passively. The cool tower will require that water be transported to the inlet, then sprayed in a mist via a solar pump. In the winter this pump can be shut off and the cool tower outlet can be closed. The indoor climate zones can be separated by sleeping space (65 - 70°F), living space (70 - 75°F) to the greenhouse space (75 - 80°F).

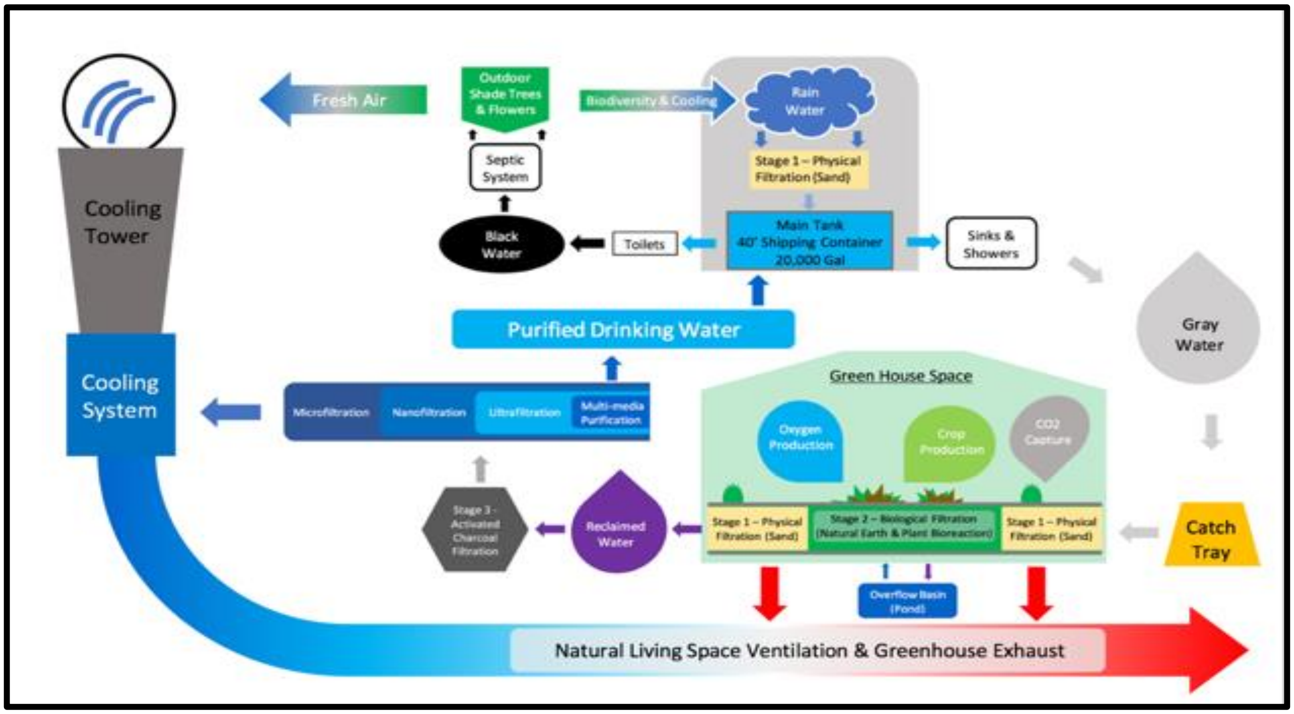

Figure 23 – Energy Cycle

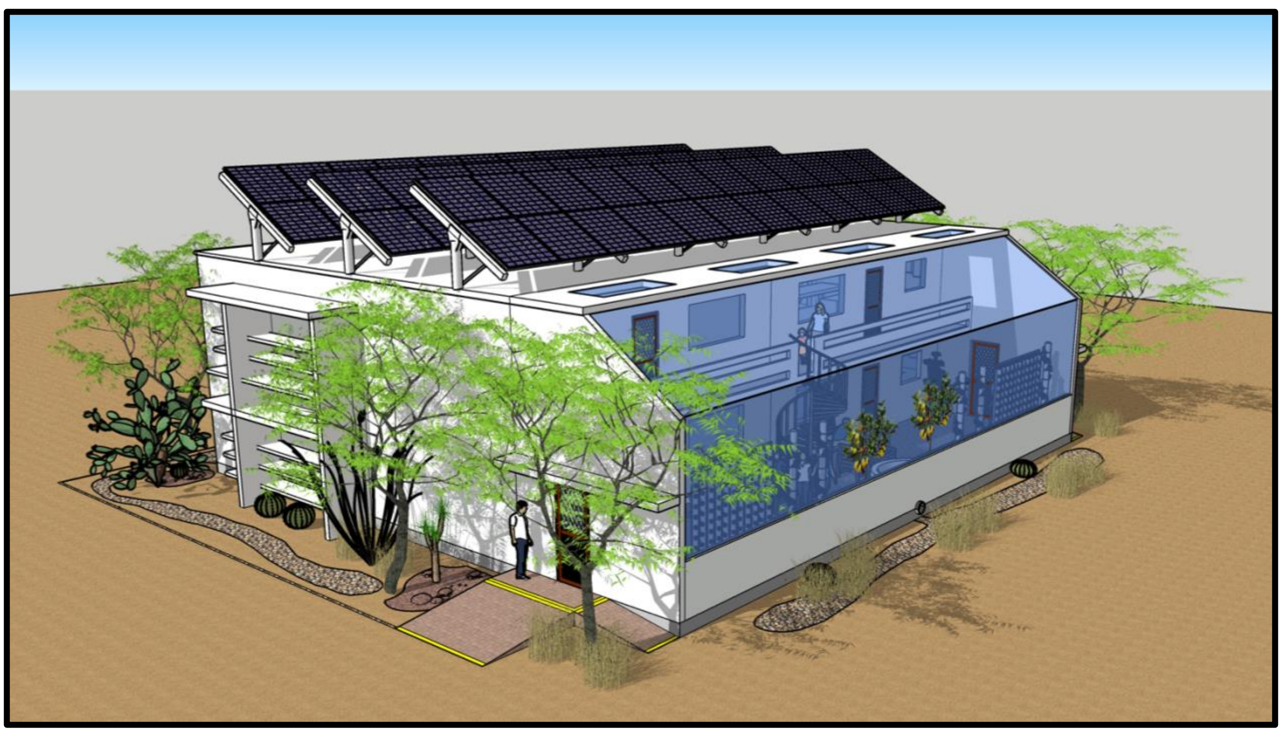

Figure 24 - Main Corner View

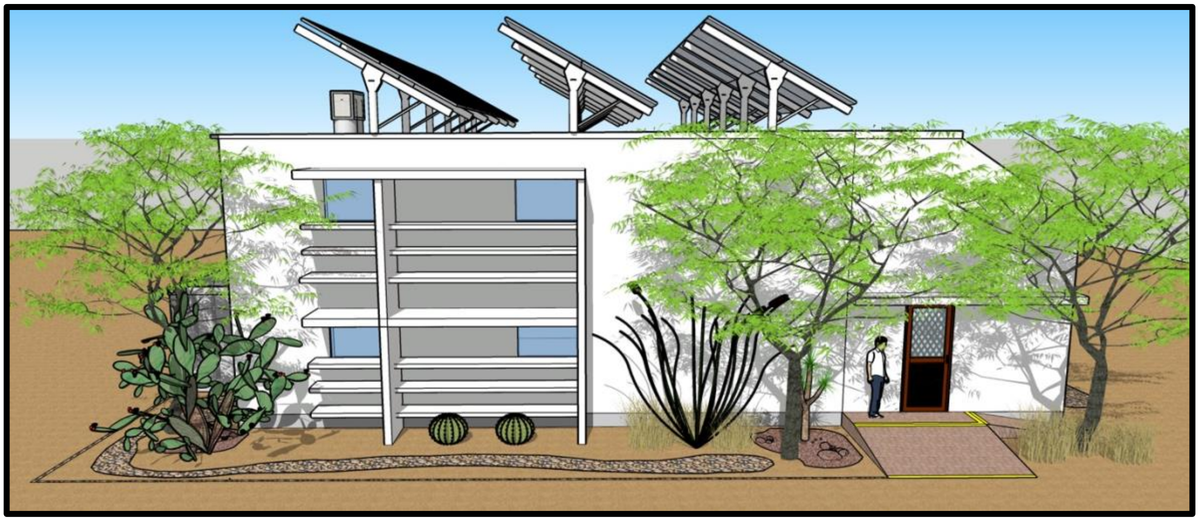

Figure 25 - West Profile View

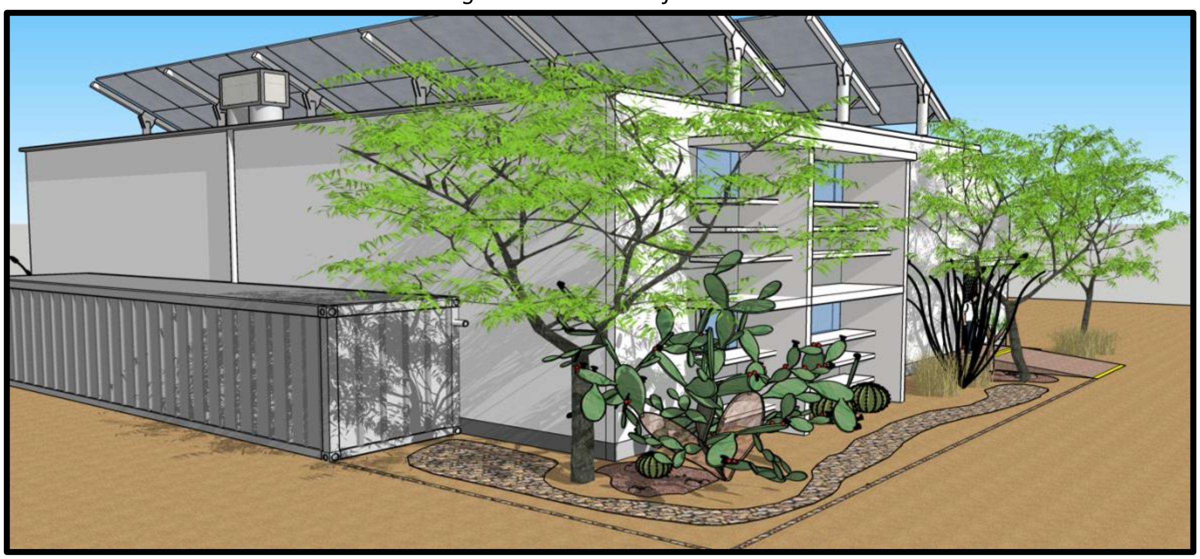

Figure 26 - North West View

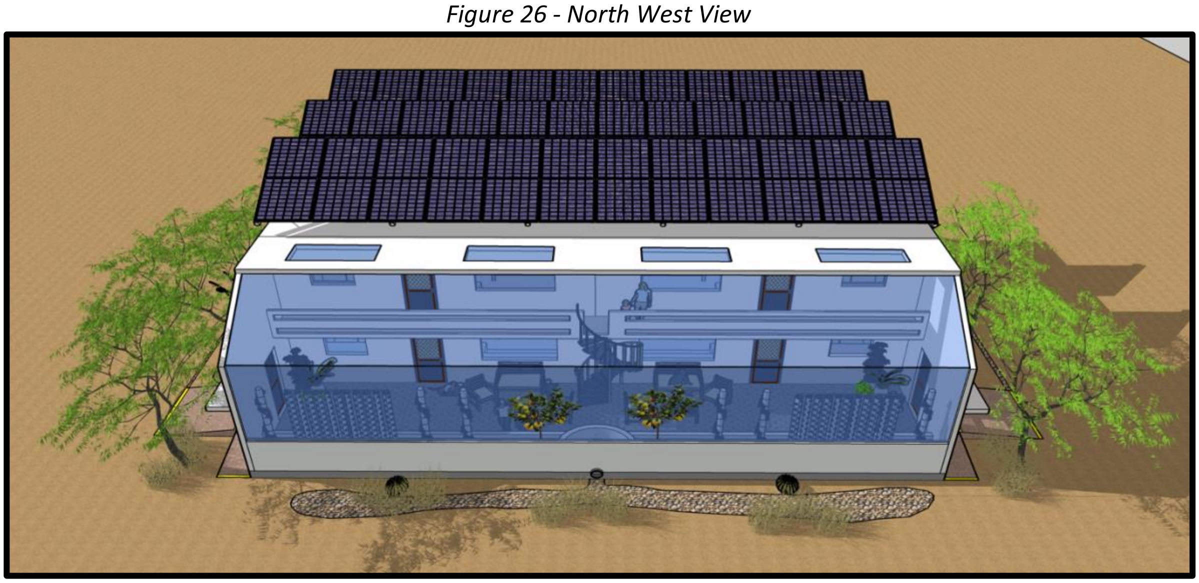

Figure 27 - South View

Figure 28 - Greenhouse 1

Figure 29 - Greenhouse 2

Lastly, addressing fertilizers and food waste. Leftover organic matter from kitchen scraps can be given directly to farm animals like chickens to produce organic fertilizer. If animals are not permitted, then this organic material can be compiled to create compost tea. Which can be directly reused in the gardening process as the essential micro-nutrients support plant growth.

Conclusion, Limitations & Recommendations:

Based on the collected data, research, and the current global climate crisis trajectory, this capstone project could be used to begin the conversation around integrating greenhouse spaces with modern-day residential buildings. It has been successfully integrated in Taos, New Mexico, as previously mentioned, but this building style can often be described as radical or too extreme. It is essential to keep in mind that the future may require more extreme designs and building regulations that allow humans to live in a space that can survive harsh, ever-changing conditions. We simply cannot wait until natural events like hurricanes and droughts open our eyes to better building principles. We must be open to emerging ideas, technologies, and designs that prepare for global climate change. By introducing the aspects that save water, energy, and money to public communities, designers, architects, and even builders could use this research when considering new building ideas. The public may not be aware of such need for adaptation in the built environment; therefore, it is the duty of those within the real estate industry to challenge the norm.

My findings indicate that individuals are interested in locally sourced goods, but may not be interested in cultivation. The biggest challenge for designers would have to include passive food production systems that operate for us without the traditional hassles of cultivation. Our global society would benefit from these advancements because food could be grown at home passively while we work on other aspects that allow us to give back to future generations, like promoting net-zero energy buildings that provide vast benefits. This organic food production system can address urban food deserts by providing an independent sustainable food source in the community that is fresh and locally grown - all thanks to water recycling, which lowers the cost of crop production, making harvesting profitable.

In general, the proposed eco-plex solves several issues, including the missing middle density, water reuse, energy efficiency, and food production. The proposed design results in a savings of 146,035 gallons of water per year and reduces water consumption to 88% by recycling reclaimed water. Additionally 507 gallons of daily use allows for 1,267.5 square feet of growing space or approximately 845 crops. This housing facility would be easy to construct and, while slightly more expensive upfront, would pay for itself in future savings.

This research is a general understanding of some of the challenges addressed when combing the agricultural and residential housing sectors. Many of the estimations were based on averages, and no actual multifamily design is currently in use. However, there is plenty left to be explored within this topic, such as implementing hydroponics, straw bale gardening, better energy-efficient designs, and the policy surrounding such innovations. Communities need diverse micro-economies that only the missing middle sector can provide. Bringing farms and gardens into our urban spaces allows the fundamental exchange of goods between neighbors. We can help reduce global hunger by simply sharing sustainably produced crops.

Future Steps:

Having been a professional builder since 2012 near the Mexican border, I understand the unique perspective on some of the challenges in both the housing and agricultural sectors. So in the future, I hope to continue my research surrounding better building solutions that allow individuals the freedom to produce their own goods at an affordable price. This would include eventually building a structural model based on this research data that could eventually serve as an educational resource for communities that struggle to obtain food. By eventually building such a model, more data could be collected to ensure the next model is even better, resulting in a self-sustained community through its built environment. Resilience is established from within, but there must always be solid foundations for growth.

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