

Clay 3D Printed Hydroponics

A Paradigm to Address Global Food Insecurity

Abstract

Clay 3D Printed Hydroponics is a novel, replicable, deployable, environmentally conscious urban farming solution, and architecture proposition. The model is posited to address broader concerns of food deserts and food insecurity in urban and rural areas in light of climate change, water scarcity, soil infertility, food supply chain issues, and civil unrest exacerbated by a growing population. Mitigating global hunger and increasing sustainability and resilience are among the greatest challenges and opportunities of our time. This paper introduces additively manufactured clay hydroponics as a promising soilless agriculture technique, fostering a dialogue on urban farming and food self-sufficiency and reporting on a pilot study conducted in Atlanta, Georgia. By harnessing the power of technology and innovation, the paper, the first in a series of technology implementations, integrates machinery, materiality, and ecology, aspiring to create deployable systems capable of addressing pressing challenges while deepening human connection to the natural world.

Keywords: Global South, additive manufacturing, urban farming, food desert

1. Introduction

Rising global temperatures lead to intense, prolonged, and frequent droughts that impact the agricultural sector, causing substantial crop losses, while declining soil fertility from extensive farming practices diminishes crop productivity and nutritional quality.¹ Fig. 1 illustrates unprecedented worldwide demands for food as the global population is projected to surge by additional 3 billion people by 2050, necessitating an extra 109 million hectares of farmland.² However, only 80% of the Earth's arable land is currently suitable for farming, with significant portions rendered unusable due to poor management and climate change.³ According to the United Nations, about 2.4 billion people worldwide endured prevalent moderate to severe food insecurity in 2022, with 900 million experiencing severe food insecurity.⁴

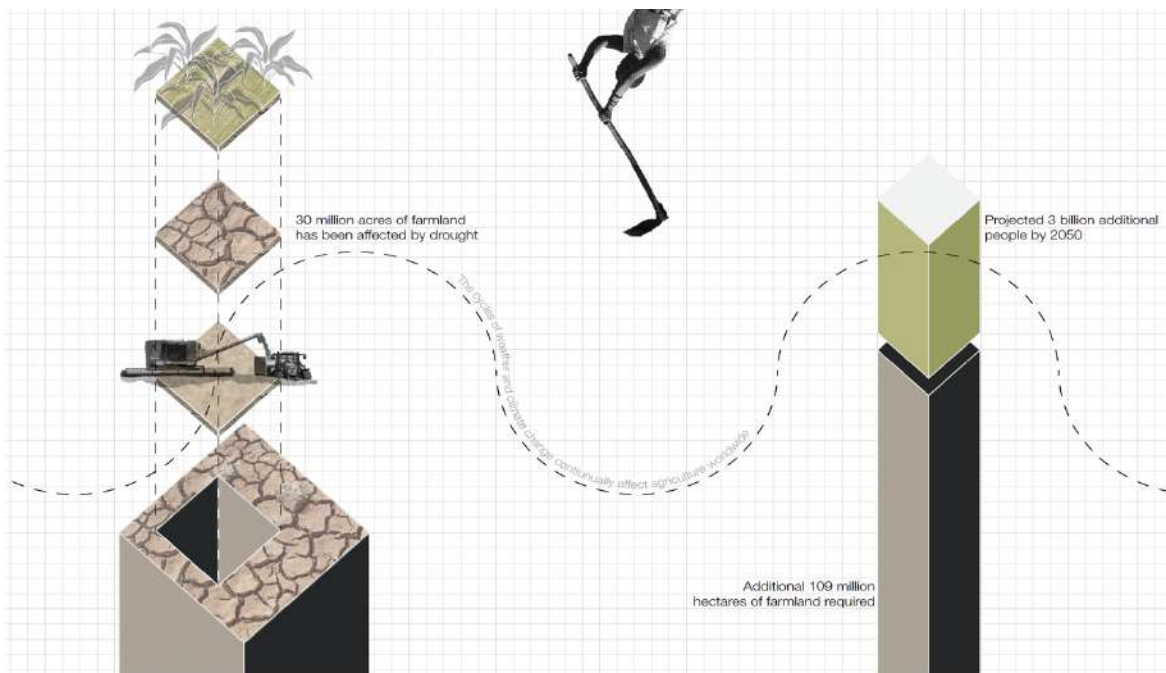


Fig.1. Worldwide population growth and climate change effects on arable land.

Increasing urbanization casts significant changes in agri-food systems in the rural–urban continuum as seven in ten people will be living in cities by 2050.⁵ Urban expansion and increased demand for food also affect people having access to affordable healthy diets. It means insufficient availability of vegetables and fruits to meet the daily requirements of fresh food and healthy diets for everyone; in the year 2021, more than 3.1 billion people, or 42% of the world population, were unable to afford a healthy diet.⁶

In the United States alone, there are over 6,500 food deserts scattered across the country, mostly in run-down and impoverished neighborhoods, affecting 13.5 million households.⁷ More than 53 million or 17% of Americans are considered low-income and have little to no access to supermarkets or similar large food stores, according to the US Department of Agriculture.⁸ More than 33% of residents in the United States must travel inconvenient distances to reach the nearest supermarket or grocery store; at least 1 mile in urban areas and 10 miles in rural areas (Fig. 2).⁹ The lack of accessible supermarkets or food shops in certain locations impairs inhabitants' ability to maintain a healthy and balanced diet, albeit awareness of healthy eating is another barrier as well. Localizing healthy food and enabling accessibility should be married to innovative solutions that foster dialogue and awareness within the domain of public health.

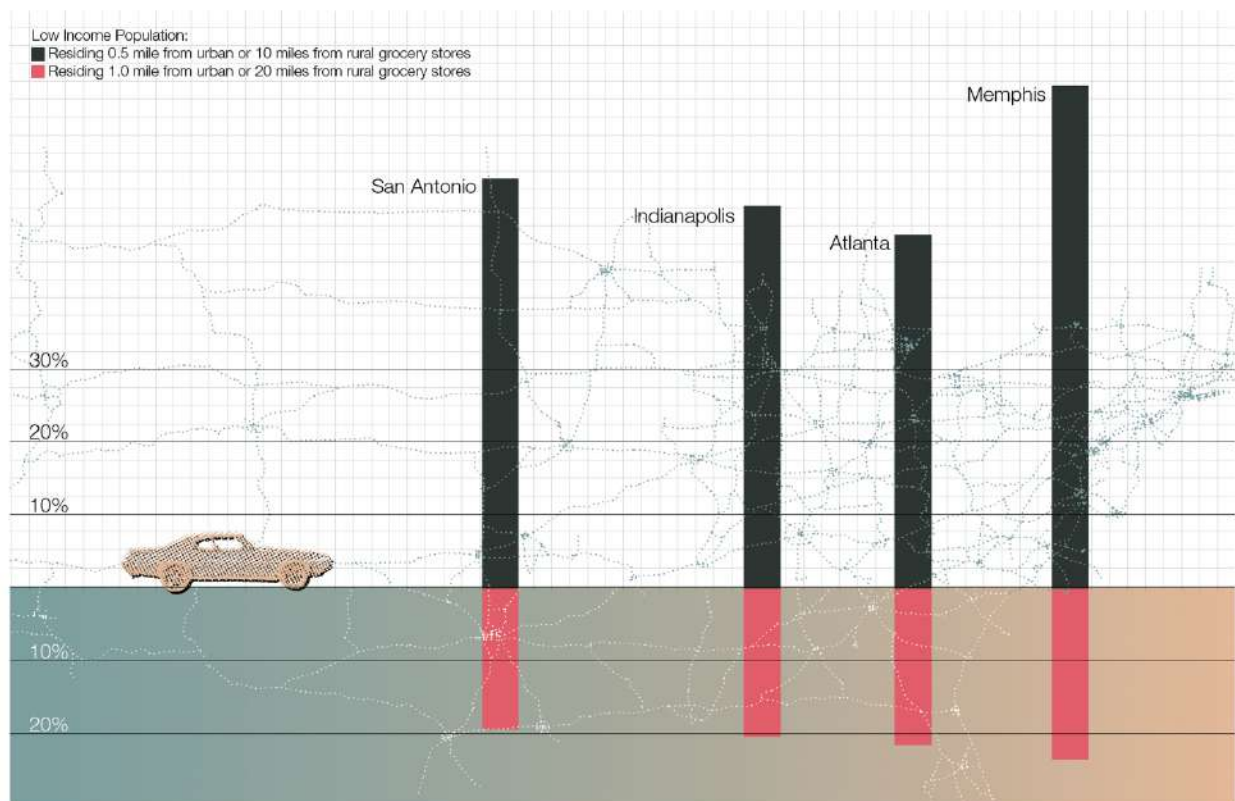


Fig. 2. Food Deserts in USA. This infographic map presents food deserts in metro-urban areas. Charting low-income populations ranging from those living 0.5 miles from urban grocery stores, or 10 miles from rural grocery stores in black. While charting low-income populations ranging from those living 1 mile from urban grocery stores, or at least 20 miles from rural grocery stores in red. Input data adopted from USAFacts.¹⁰

The Global South (Fig.3 and 4) bears the brunt of hunger, particularly Sub-Saharan Africa. Arable land limitations, water shortages, famine, and socioeconomic challenges compound hunger issues and have led to the emergence of 'Climate Change Refugees', underscoring the urgent need for sustainable, local, and equitable food systems globally. The World Bank estimates that climate change will displace over 140 million people in the Global South by 2050, with Sub-Saharan Africa expected to witness the highest number of climate migrants, around 86 million, 80% of whom are women.¹¹

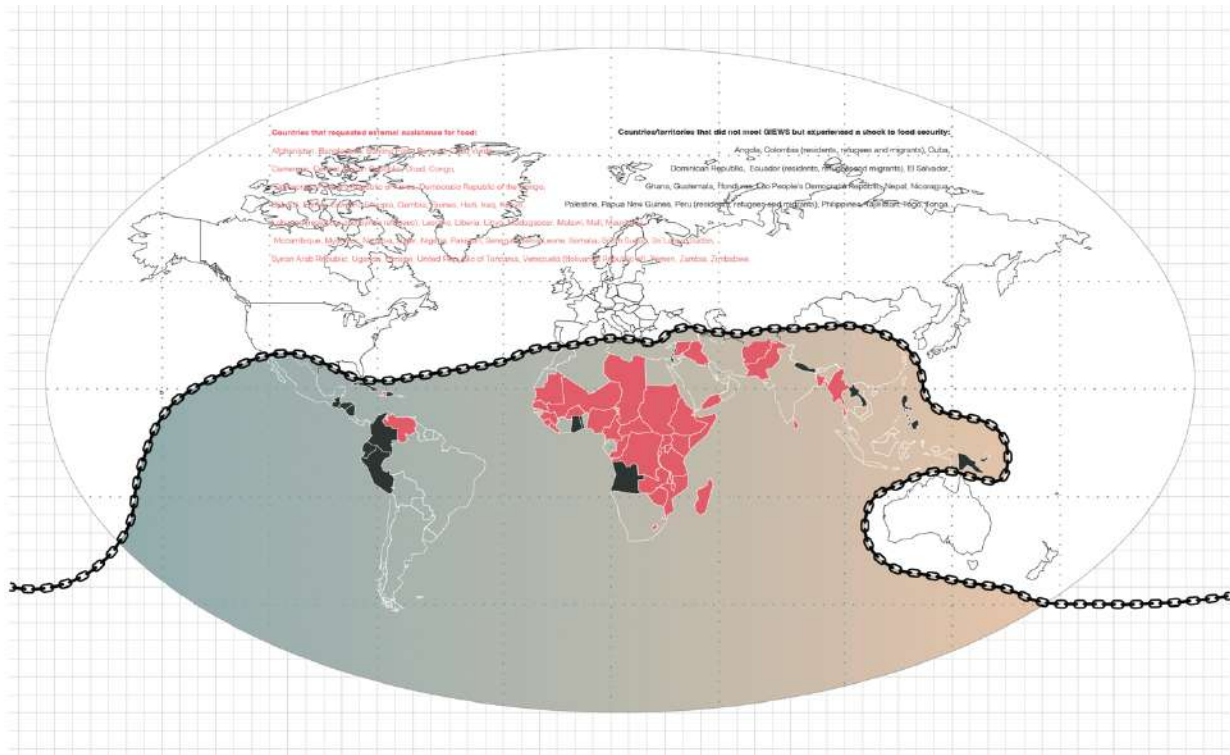


Fig.3. The Global South. The red color represents countries in the Global South that requested external assistance for food. The black color represents countries/territories that did not meet the GIEWS but experienced a shock to food security. Input data adopted from Global Report on Food Crises (GRFC) 2023.¹²

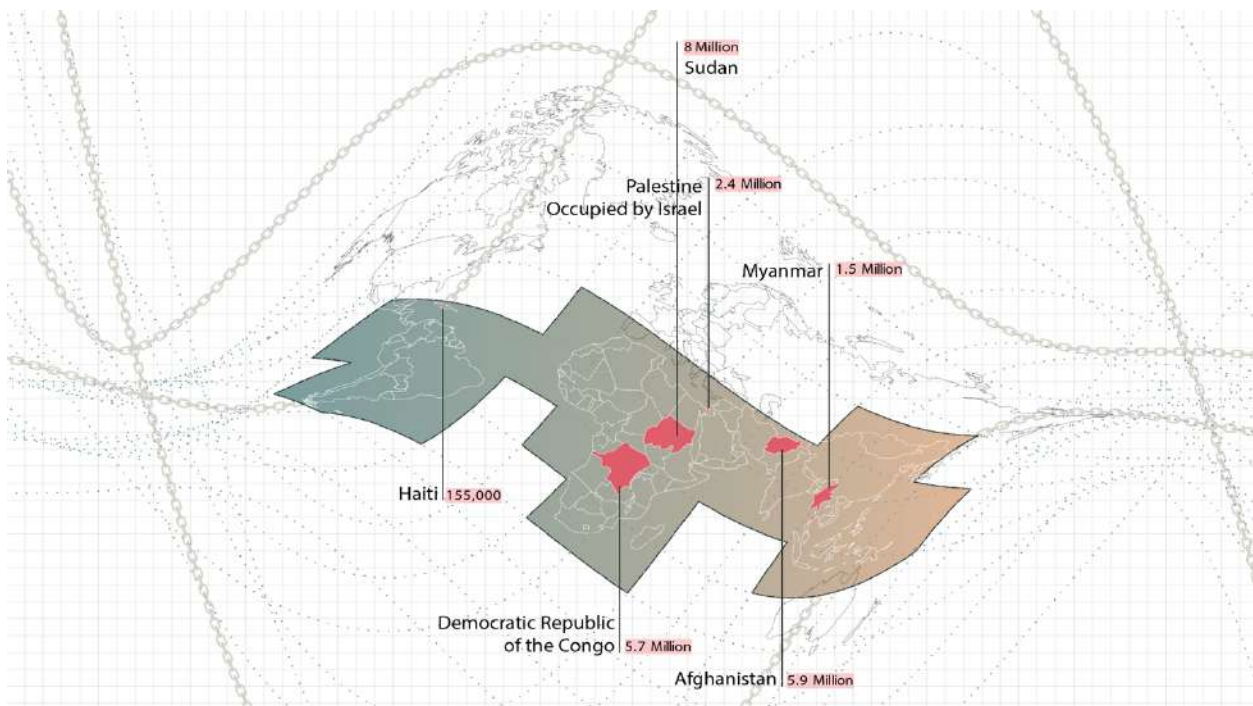


Fig.4. The Global South. The diagram highlights countries that endured the most mass displacement due to food insecurities and other systemic issues. Input data adopted from WFP.¹³

In a time of dire challenges and hopeful opportunities, the focus on sustainable creative solutions to ensure food security while promoting learning and economic growth is highly sought after. Hydroponic systems offer promising avenues to tackle fresh food scarcity, especially in resource-constrained regions and urban food deserts in densely populated and low-income neighborhoods. Hydroponics can also effectively bypass some of the effects of climate change on agriculture farming, especially in the Global South and Sub-Saharan Africa. Hydroponics conserves water by recycling and delivering nutrient-rich solutions directly to plant roots, eliminating the need for soil and significantly reducing water consumption compared to traditional farming methods.

By leveraging clay additive manufacturing as a method of fabrication and material sourcing, hydroponic systems can be efficiently deployed, enabling plant growth in resource-drained contexts and challenging environments. Employing clay as a prime material for fabrication localizes production and addresses issues of supply chain. Clay is widely available and eco-friendly due to its renewability, biodegradability, and nontoxic nature.

The proposed 3D printed system discussed in this paper celebrates a juxtaposition of low-tech and high-tech innovations that makes the system deployable, agile, and easy to integrate into local craftsmanship cultures, ensuring accessibility even for people with limited technical expertise. The configuration of the farming system combines and reintroduces a 4,000-year-old practice in pottery and clay coiling and non-soil farming technique in a modern and efficient way (Fig. 5). With its modularity, users can set up and assemble the system efficiently, reducing adoption barriers. By sourcing materials and skills locally, communities can diminish dependence on external sources, customize the system to their specific needs, and enhance sustainability, resilience, and economic stability within their communities.

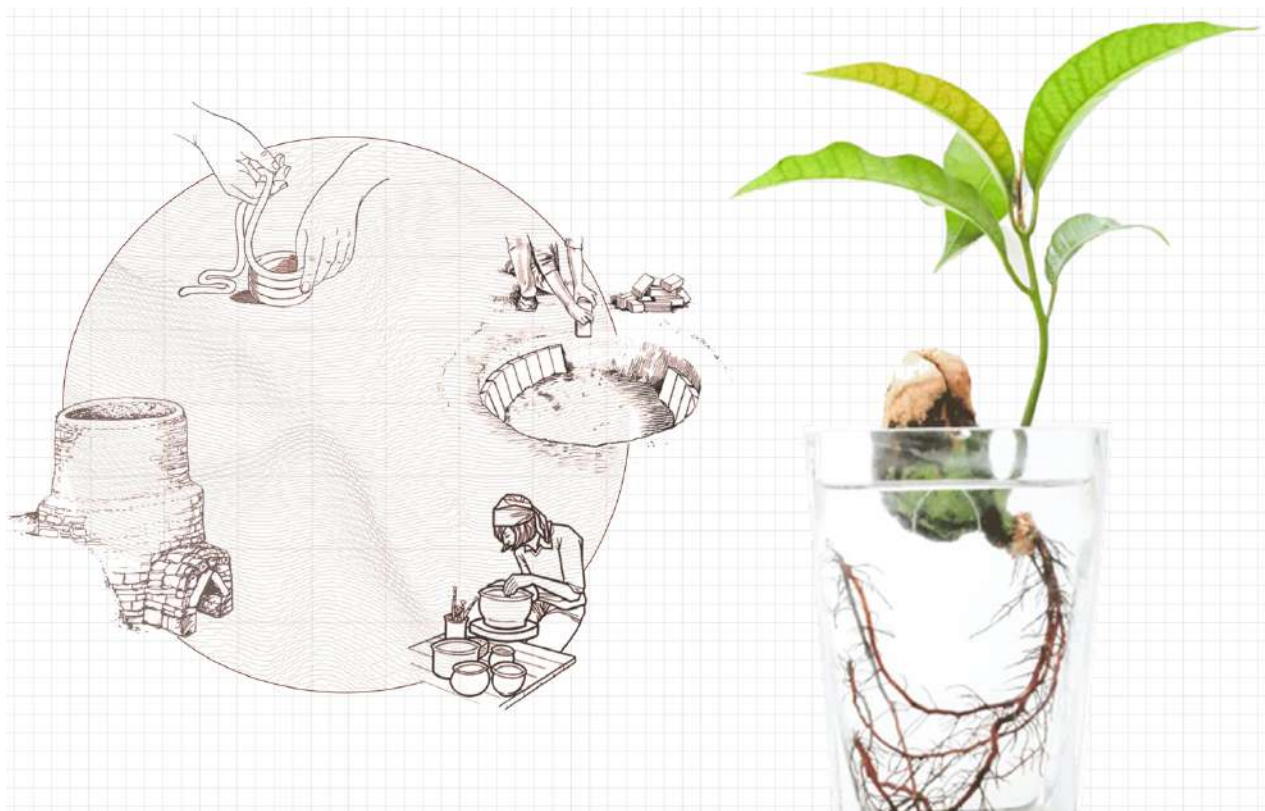


Fig. 5. Conceptual Clay 3D Printed Hydroponics juxtaposes pottery and non-soil farming technique.

2. Background

Hydroponics represents a cultivation method devoid of soil, whereby plants receive vital nutrients directly at their roots through a nutrient-rich water solution. In contrast to conventional soil-based agriculture, which relies on soil as the primary source of nutrients for plants, hydroponics obviates the necessity of soil by configuring a meticulously controlled growth environment. This innovative approach circumvents the limitations of traditional agriculture and provides a sustainable solution for enhancing food production in resource-constrained regions. Within hydroponic setups, plants typically inhabit inert growing substrates such as perlite, coconut coir, or rock wool.¹⁴ A meticulously formulated nutrient solution, comprising of a balanced amalgamation of crucial nutrients, is systematically circulated, or dripped onto the plant roots. Such precise administration enables stringent regulation of nutrient concentrations, pH levels, and other pertinent environmental parameters, thereby fostering an environment conducive to optimal plant development.¹⁵

Hydroponic methodologies encompass a spectrum of typologies, each characterized by distinct attributes and operational modalities. For instance, the Nutrient Film Technique (NFT) entails the deployment of a slender film of nutrient solution that courses over the plant roots,¹⁶ whereas Deep Water Culture (DWC) immerses the roots directly within a reservoir brimming with nutrient-rich water.¹⁷ Aeroponics, yet another methodological variant, envelops the roots in a mist of nutrient solution. The selection of a particular system hinges upon considerations such as spatial constraints, resource optimization, and the botanical varieties under cultivation. One of the salient merits of hydroponics pertains to its applicability in urban and indoor agricultural paradigms. By abstaining from traditional soil mediums, cultivators can efficiently leverage available space and engender crops within meticulously controlled settings, thereby facilitating year-round production cycles and mitigating reliance on arable expanses. Hydroponic frameworks adopt water conservation principles by virtue of their capacity to recycle water resources, thereby curtailing wastage and redressing apprehensions associated with water scarcity within agricultural contexts. Collectively, hydroponics epitomizes a sustainable and pioneering ethos in botanical cultivation endeavors.

Hydroponics has a rich history dating back to ancient civilizations. One of the earliest instances of hydroponic principles in practice can be seen in the Hanging Gardens of Babylon around 600 B.C.¹⁸ These gardens, one of the Seven Wonders of the Ancient World, utilized a sophisticated chain pull system to irrigate plants, overcoming the challenges of the dry Babylonian (modern day Iraq) climate. Similarly, Ancient Egyptian hieroglyphics show scenes of plants being grown along the Nile River without soil suggesting early experimentation with soil free farming methods.¹⁹ In the 11th century, the Aztecs created floating gardens called "chinampas" on Lake Tenochtitlan in Mexico.²⁰ These ingenious systems consisted of rafts made from stalks and roots, layered with sediment from the lake bottom, upon which plants were grown.²¹ During his journeys, in the 1200s Marco Polo came across floating gardens resembling those found in China showcasing the adoption of hydroponic techniques in various cultures and societies.²² However, the scientific investigation into hydroponics traces back to Leonardo da Vinci's observations in the 15th century.²³ Da Vinci acknowledged the significance of minerals in supporting plant growth, setting the stage for further research development. In 1600s, Belgian scientist Jan Baptist van Helmont carried out experiments proving that plants derive nutrients for growth from water, contributing to the progress in plant nutrition research.²⁴

During the 17th century, significant advancements were made in hydroponic research. Sir Francis Bacon contributed to soilless cultivation techniques that sparked interest in the scientific community. John Woodward showed that plants actually thrive better in impure water than distilled water, which

challenged existing beliefs about plant nutrition.²⁵ Hydroponic farming became more popular during World War II when it was used to grow crops for soldiers on the Pacific Islands.²⁶ In the following years, hydroponics was widely adopted for farming and greenhouse cultivation worldwide. The 1970s marked a milestone with the mainstream use of plastics, which made hydroponics cost-effective and led to the development of various hydroponic systems still used today.²⁷ Over millennia of innovation and experimentation, hydroponics has become an efficient method for plant cultivation, offering solutions to agricultural challenges.

Clay 3D Printed Hydroponics is a continuation of this farming technology evolution, offering yet another pioneering non-soil farming solution by facilitating the growth of healthy food locally, especially fruits and vegetables. This pioneering farming technique breaks away by entirely dispensing with traditional growing mediums, opting instead to nourish plants in custom ceramic 3D printed substrates that are biofilm accommodative, deployable and architecture integrative.

3. Methods

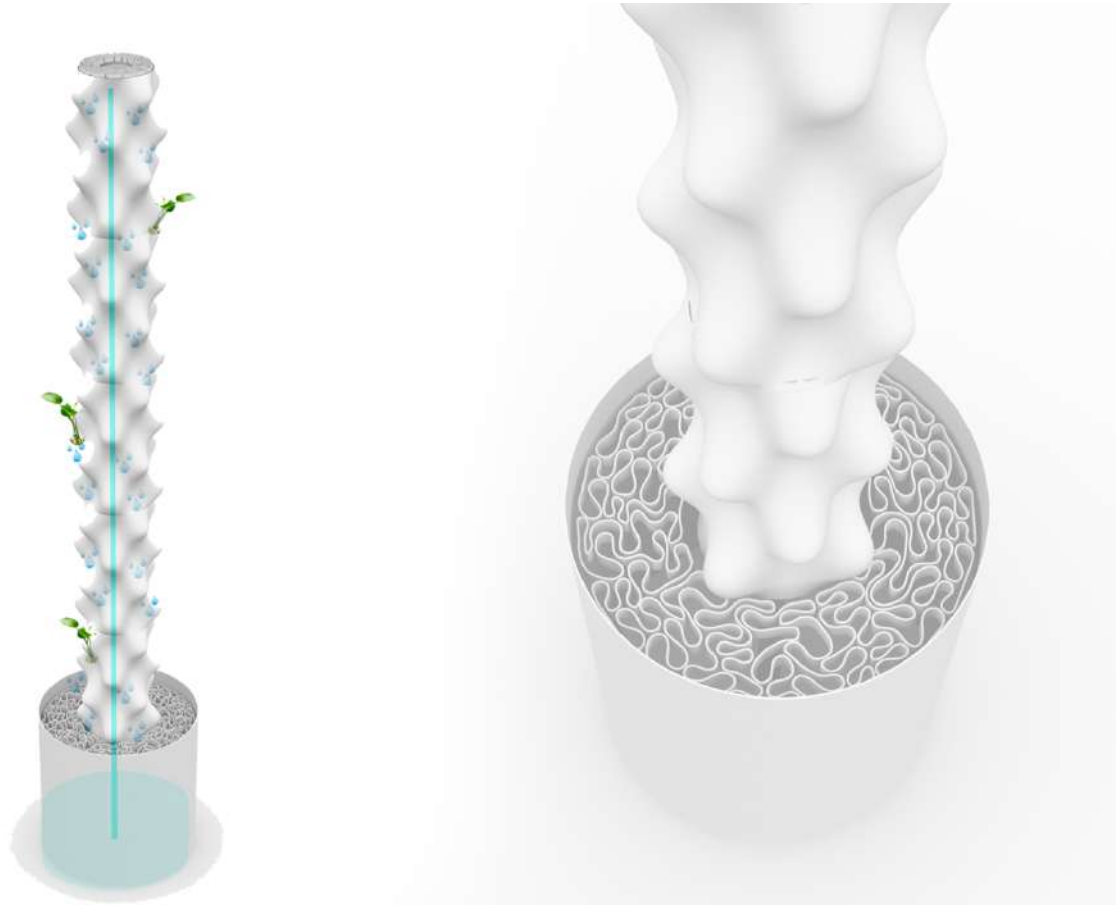


Fig. 6. water circulation and nutrient uptake concept.

The multi-level units are geometrically designed with bumps as habitats to accommodate seedlings' rhizosphere.

3.1. Verticulture

Clay 3D Printed Hydroponics configures itself as an alternative verticulture (vertical farming), where plants are housed in ceramic 3D-printed multilevel towers. The system integrates solar-powered

atomizers to recycle and deliver nutrient-rich water to the roots of the plants. Micro-droplets of water are periodically circulated in a low-pressure and closed loop configuration to create a rich misted environment inside the ceramic towers conducive to the plants' growth, (Fig. 6 and 7). Within this innovative approach, which leverages the aeroponic concept, plant roots are suspended in the air inside ceramic 3D printed enclosures, receiving periodic sprays of a nutrient-dense solution. While technically the roots of the plants are openly hung in the air inside the hollow ceramic 3D-printed growing chambers, the leaves are exposed to the indoor/outdoor ambient environment for a better photosynthetic response.



Fig. 7. multilevel 3D printed ceramic structures.

3.2. Germination and Transplanting

To promote successful plant habitation and accelerated growth in the system, seeds are first uniformly germinated in an inert mineral water culture. After germination, the seedlings are then transplanted into the towers. This off-site germination process allows the seedlings to develop adequate and strong roots with sufficient length, enabling them to directly access the nutrient-rich water circulated in the tower.

In this experiment, leafy greens were separately germinated in inert mineral rockwool submerged in water with 40 ppm (1 mM) calcium (Ca). Germination was carried out in indirect sunlight between 20 and 50 $\mu\text{mol m}^{-2}\text{s}^{-1}$. Less light might be inadequate and can lead to hypocotyl elongation.²⁸ The temperature was between 20 and 25°C. Higher temperatures can accelerate germination time, but they might also decrease root elongation uniformity because the oxygen solubility in water will plummet at such temperatures.^{29 30}

3.3. Design Parameters

In general, the design and configuration of hydroponic systems should largely be informed by the performance criteria of the implemented technology in addition to many other parameters such as plant species, local climatic conditions, aesthetic considerations, etc. Clay 3D Printed Hydroponics, the first in a series of technology explorations, presents one of many potential design approaches. Subsequent papers will explore different system configurations and forms, focusing on various plant types and hydroponic technologies.

In this episode of Clay 3D Printed Hydroponics, which leverages aeroponic concept and verticulture, multi-level units are precisely designed to support leafy greens transplantation. Every module is geometrically designed with bumps and apertures to provide the optimum habitat suitable for the leafy greens' rhizosphere (Fig. 6 and 8). The topographical nature of these geometries (alternating peaks and valleys) also increases water turbulence and, therefore, improves aeration and oxygenation opportunities.



Fig.8. modular multilevel Prototypes.

3.4. Fabrication (Additive Manufacturing)

Additive Manufacturing Technology, the industrial application of 3D printing, has spurred materials explorations, leading to the development of clay hydroponic farming systems. The computer and printer make it possible to use “particles of light, jets of water, and bits of data” to transform dust into utilitarian outcomes and products.³¹ Such transformation involves high means of technical innovation in additive manufacturing and mundane materials such as clay, engaging opposing ends of the technological spectrum.³² Such a practical fabrication process comprises successive incremental deposition of clay paste, layer by layer, directly driven from 3-dimensional data. This automotive process is no different than the traditional manual clay coiling concept (Fig. 5) except the fact that robotic fabrication follows a toolpath that represents an already scripted geometry, while hand-coiling builds a geometry in real-time and is heavily influenced by the actions of the potter in response to material behavior i.e. clay.

Fig. 9 illustrates the manufacturing method, which involves machine craft informed by a series of computational moves. To 3D print the hydroponic model, geometries that make up the system configuration must first be scripted and sliced then translated into a toolpath, which represents points in the 3-dimensional sphere (x, y, z). These 3-dimensional points are then computed to generate a g-code language, marking a threshold between digital fabrication and machine craft. Eventually, the g-code pack, which includes toolpath variables and cartesian coordinates are sent to a paste dispenser (ceramic 3D printer). The g-code also includes instructions such as homing, movement speed, extrusion rate, etc. to command the printer. This seamless workflow made it possible to efficiently produce custom, intricate, and modular multilevel ceramic substrates capable of accommodating plant growth.

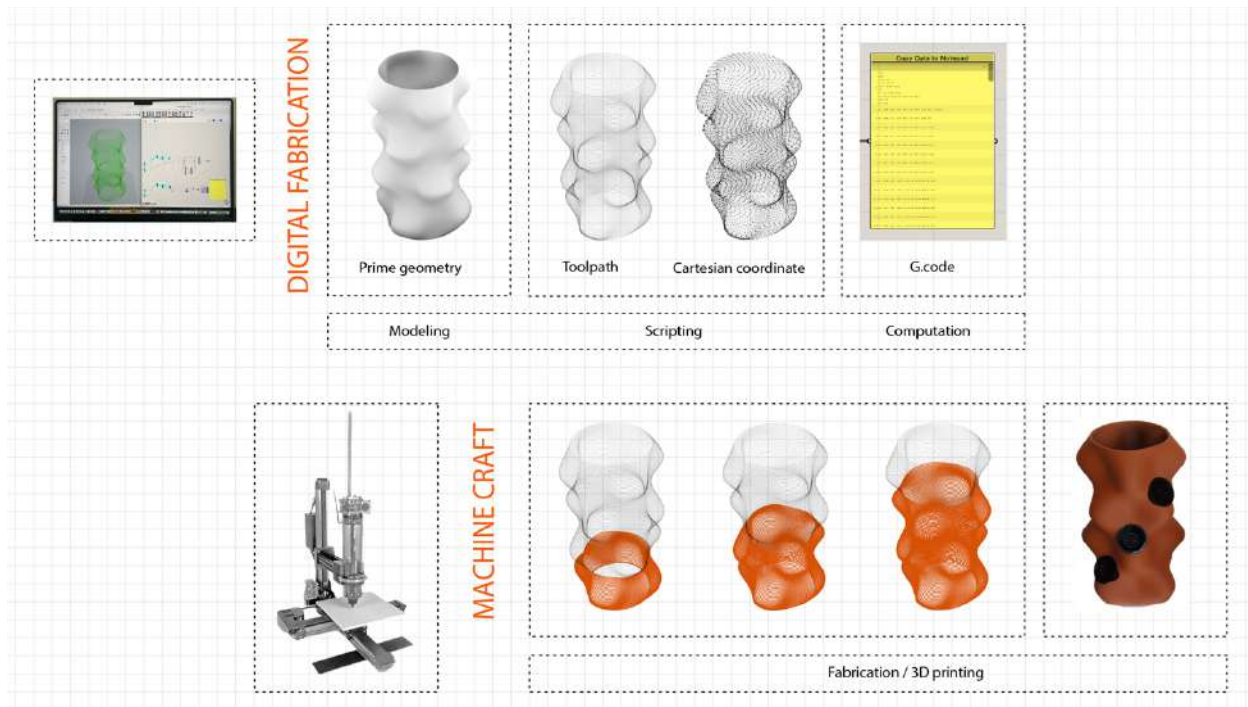


Fig. 9. Manufacturing workflow: digital fabrication and machine craft.

3.5. Material exploration

Clay 3D Printed Hydroponics takes advantage of a novel, inexpensive, and locally harvested clay as a prime material for fabrication. Clay, one of the earliest materials used by humans, remains integral to modern construction and fabrication. Some of the pottery fragments found date back to around 14,000 BC.³³ Besides traditional ceramics and pottery products, clay is widely used in many modern industrial processes, including painting, paper making, chemical filtering, cement production, medical applications, cosmetics, etc.³⁴ Clay is unique among types of soil with its size and mineral makeup. It can also include varying levels of minerals on or around planetary surfaces, such as metals, alkaline earth, magnesium, iron, and other positively charged ions. Though clay has different compositions with different minerals and formations, it has similar characteristics with slight variations. Clay is characterized by its plasticity and malleability when hydrated and its ability to harden when dried, albeit susceptible to fragility. When fired, clay crystallizes, changes its structure, and binds its particles to become ceramic.

Clay is low-cost, widely available, and environmentally benign with little to no ecological footprint. Another key advantage of the material in juxtaposition with additive manufacturing lies in the unparalleled design and production flexibility. Recycling clay in 3D printing underscores an environmentally conscious and sustainable approach to additive manufacturing. Clay, unlike some non-biodegradable materials utilized in 3D printing, is naturally recyclable, which helps reduce its impact on the environment. The growing focus on sustainability across sectors has brought attention to the potential of using clay in 3D printing for recycling purposes, showing a dedication to manufacturing and holding promise for supporting the growth of plants.

Versatility is another salient benefit of clay 3D printing, offering applicability across a spectrum of creative farming technologies and space design configurations. A notable advantage lies in the innate aesthetic qualities that clay imparts to printed items, evoking an organic and earthy ambiance, and enriching the visual allure of farming technology as artwork and architecture with palpable and authentic essence.

Perhaps the most favorable attributes that align with clay's potential benefits for plant growth and development is its physical, chemical, hydrologic, and geological composition properties. The slow absorption and release of water by ceramic helps maintain a level of moisture in the rhizosphere, preventing both waterlogging and drying. This reduces water circulation frequencies and over-reliance on atomizers. Its aeration porosity helps to oxygenate plants' root zones. Furthermore, clay's ability to enhance plants' nutrient uptake is superior to that of other commonly used materials in hydroponics.

In this experimental project, specimens of raw ultisol clay were harvested from local sites in Darfur, Sudan, to make up the optimum clay body suitable for 3D printing and, more importantly, to enhance plant growth. Like expanded clay aggregate, hydrated ultisol was processed to be inert, pH-neutral, and low-dense. After fabrication, the multilevel models were then sun-dried, and bisque fired. Afterwards, the models as ceramic substrates were post-processed by adding a layer of glaze outside the ceramic surfaces only. These processes reduce water loss via evaporation at the outer surface of the ceramics while maintaining a porous structure at the inner side, creating a perfect biofilm growth environment. The inner surfaces of the ceramics regulate moisture and provide essential minerals due to their porous nature, which facilitates optimal root aeration and prevents waterlogging, thereby fostering healthier plant growth and higher crop yields.

Introducing 3D printed ceramics as growing mediums along with the working air maintains a high rate of photosynthesis by managing oxygen levels in the air and around the plants. This condition, coupled with the uniformity of nutrient concentration in the water droplets and pH values accelerates plants growth. The presence of minerals inherent in the clay body can supplement nutrient deficiencies in the soil, contributing to improved crop quality and resilience against environmental stressors. The comparative advantages of clay, in general, over commonly used plastic and other mediums in supporting plant growth warrant exploration regarding their impact on nutrient and oxygen delivery as well as photosynthetic performance.

3.6. Assembly



Fig. 10. Mechanical joining details and assembly.

Each tower of the Clay 3D Printed Hydroponics is made of kit of parts that includes a water reservoir and several modular multilevel units stacked on top of each other. It also includes a vertical pipe with a dual purpose that serves as a vital instrument to circulate water and mechanically knit the modular multilevel units (Fig. 10). Critical objectives such as deployability, stability, safety, and leakage prevention were addressed during both design and fabrication as well as assembly phases. An emphasis on agility and deployability requires an alternative platform, in which case a network of wooden bases was introduced. The multilevel towers were anchored to this alternative ground. The resiliency of the whole system's configuration facilitates assembly, disassembly, and reassembly (Fig. 11,12,13).



Fig. 11,12,13. Onsite assembly.

4. Results & Discussion

4.1. Clay 3D Printed Hydroponics Pilot

Clay 3D Printed Hydroponics was deployed as a pivotal pilot project in the Atlanta Metropolitan Area (Fig.14,15,16). The pilot comprises 100 modular units assembled into variant 20 towers. From June to August 2023, where average temperature, humidity, and rainfall were 77 Fahrenheit, 73%, and 4 inches respectively, 600 seedlings were transplanted and flourished under the system and these conditions. The pilot yielded over 160 pounds of fresh vegetables crucially supplied to local food pantries in the Atlanta Metro Area. The yield, which includes a harvest of cabbage, chard, green sorrel, arugula, lettuce, bibb lettuce, and kale, contributed to feeding over 500 homeless individuals.

In addition to overhead, the 20-tower pilot cost about 30 thousand US dollars to fabricate, assemble and maintain. Such cost includes sourcing and processing clay, production, erection, plant germination and transplantation. It also includes solar power system installation in addition to supplies such as automizers, timers, wiring, etc.

This pilot project marks a significant stride towards addressing food insecurity as it achieved exceptional performance metrics, notably saving up to 90% of water compared to traditional soil-based cultivation methods, while also requiring 50% less time for cultivation cycle. The verticultural configuration of the model and its soil-free nature significantly reduces risks of soil-borne diseases, pathogens, and pests. This revolutionary approach to farming efficiency improves agricultural practices and reduces dependence on chemical pesticides and herbicides, promoting eco-friendly farming principles.



Fig.14,15,16. Clay 3D Printed Hydroponics pilot: fresh vegetables for food pantries.

The pilot in Atlanta provides a tangible pathway towards creating eco-friendly and robust food production systems that can adapt to environmental obstacles and navigating uncertainties. It asserts the potential scalability of Clay 3D Printed Hydroponics to address larger issues of food insecurity and food deserts. As it continues to evolve, this innovative approach holds strong promise for communities worldwide, ushering in a new era where access to nutritious food is no longer a luxury but a fundamental right. The deployability merit of the model facilitates its placement and integration into the built environment in urban centers and around human settlements, reducing transportation costs and bolstering local economies. The rapid prototyping capabilities of the technology make it more adaptable, allowing for effective custom adjustments to meet the requirements and circumstances of clay hydroponics. Localization of production and material sourcing, in alignment with the sustainable additive manufacturing practices, addresses issues of supply chain and contributes to the affordability and adoption of farming technology. Moving forward, the technology could be disseminated in the Global South and post-disaster regions where it is needed the most. At its core, Clay 3D Printed Hydroponics is a horizontal knowledge and technology transfer. Given its rapid deployability and agility, the system could be responsive to dire and urgent situations like refugee crises and natural disasters.

4.2. Clay 3D Printed Hydroponics as Architecture, Meditation and Educational Agency

Clay 3D Printed Hydroponics not only supports sustainable food production but also heavily speculates on the wider implications of farming technology on the built environment. A dedication to creating physical environments and postulating on technologically informed ceramics as disruptive to the culture of buildings and farming is paramount. Rooted in the principles of innovation and environmental consciousness, this horticulture example serves as a living laboratory, community hub, social utility, educational platform, and an example of ecological design all in one, fostering discussions on sustainable agricultural practices and community resilience.

Wide implementation and integration of Clay 3D Printed Hydroponics into urban contexts contribute to mitigating Urban Heat Island (UHI). Research suggests that urban vegetations lower temperatures by 2.9°F.³⁵ The flexibility and easy, quick integration of the system into the built environment, facilitates strategic deployment of Clay 3D Printed Hydroponics in locations that makes the difference in UHI mitigation. Installing the system around buildings, paved areas, and parking lots can contribute to lowering surface and air temperatures via shading, evapotranspiration, and evaporative cooling.



Fig. 17. Clay 3D Printed Hydroponics integrates architecture and speculates on the wider implications of the system in the built environment.

As architecture, Clay 3D Printed Hydroponics frames physical spaces where humans, technology, and nature all cohabit and thrive (Fig. 17). This merging of nature and technology represents a harmonic combination of modern design and natural components. The elegant simplicity of the spatial configurations improves the overall functionality and visual appeal of the environment and establishes dynamic communal areas in between that encourage guests to explore and connect.

The introduction of the system as a meditative space amplifies its impact, inviting individuals to engage with nature in a contemplative and immersive manner. Extensive research has shown that regular access to green spaces, natural environments, and the outdoors engages humans physically and psychologically, improving their health and well-being.^{36 37}

Clay 3D Printed Hydroponics offers a wide spectrum of therapeutic experiences by communicating to the soul, mind, and spirit of our bodies through multitudes of sensations: sighting, hearing, smelling, touching, and tasting – the five human senses. From the moment individuals encounter the system, whether in an educational setting or a public space and horticulture garden, they are fully involved in a sensory experience that transcends mere food production.

Visual engagement emerges as a key element of this urban farming model. The vertical configuration of the garden optimizes space and creates a captivating showcase of ceramic elegance and lush greenery. By including a range of plant types including ornamentals and edibles, the pavilion caters to our aesthetic sensibilities while also promoting both biodiversity and food choices. The system not only stimulates touch sensory but also dictates physical engagement through transplanting and harvesting. The system

offers olfactory stimulation through the cultivation of fragrant plants. When people engage with the garden, they can smell the scents of herbs and flowers, enhancing their journey and heightening their sensory experience, creating a stronger bond with nature. The auditory dimension allows people to enjoy the musical sounds of water trickling through the ceramic structures. Such spiritual sound not only enhances the ambiance of space, but also acts as a gentle nudge and reminder about the system's dependence on water — a valuable resource that needs careful handling and preservation.

5. Conclusion

In conclusion, the advent of Clay 3D Printed Hydroponics marks a transformative milestone in sustainable agriculture and urban farming. By integrating additive manufacturing and ceramic fabrication, this novel innovative system not only addresses food insecurity but also reimagines the relationship between technology, nature, and human habitation.

Through its deployment as ecological levers and architectural elements, Clay 3D Printed Hydroponics cultivates nutritious food locally while also serving as a platform for learning, mindfulness, sensory-therapeutic experience and leisure activities within an environmentally conscious framework. Its adoption offers immense potential for revolutionizing urban farming, providing solutions to food insecurity through enhanced design flexibility, reduced material waste, rapid prototyping capabilities, customization options, and cost-effectiveness.

While the system represents significant progress, its full potential remains to be realized. Moving forward, improving and scaling up the system for wide implementations, especially in regions facing water and food shortages in developing countries, requires concerted efforts. This involves streamlining fabrication and assembly processes, maximizing resource efficiency, and customizing the system to fit the factors and cultural backgrounds of the areas targeted.

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Declaration of conflicting interests

The Author declares that there is no conflict of interest.

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