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City Harvest: Smart Service and Place Design with Collaborative Communities on Food Production

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Abstract
Food Insecurity is worsening due to climate change, and agriculture contributes to an estimation of 37% of global GHG emissions. Next, food loss and waste related activities emitted 9.3 Gt of CO2-e in 2017, which accounted for about half of the global annual emissions from the whole food system. Although many policies have been designed, it is still unclear how cities can do their parts. The objective of this paper is to introduce a data-driven and sustainable urban food service design that extends beyond decarbonization: 'City Harvest'. Integrated design elements at neighborhood scale are: 1) soil based vertical farming structures; 2) residential indoor growing kits that also process organic waste; 3) AI and Web-GIS based knowledge platform for community co-creation activities.

Keywords: Urban Food Production; AI; GIS; Co-Production; Urban Innovation.

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Urban Food Insecurity, Climate Change and the Role of Cities

In recent decades, global trends indicate alarming news in malnutrition, including a rapid rise in food inaccessibility. Although there are many global, national and local calls for the new ways of thinking about equality in food access and food insecurity, problems still remain. According to FAO (Food and Agriculture Organization of the United Nations), “Food Insecurity” is defined as the lack of regular access to enough safe and nutritious food for normal growth and development and an active and healthy life (FAO, 2023). In addition to the complexity of the concept, scientific evidence also indicates that food insecurity is worsening due to climate change, and agriculture contributes to an estimation of 37% of global GHG emissions (Mbow et al., 2019). Besides, food loss and waste related activities emitted 9.3 Gt of CO_2-e in 2017, which accounted for about half of the global annual emissions from the whole food system globally.

Although many policies have been designed and applied to reduce food insecurity, it is still unclear how cities can do their parts. Being one of the significant attempts by city governments around the world, City of Toronto leads many initiatives that improve food security for residents. Among such policies, “GrowTO, ‘Poverty Reduction Strategy[1],‘Toronto Food Charter[2], ‘Black Food Sovereignty Plan[3] and ‘Reconciliation Action Plan[4] play critical roles. Similarly, the City of Montreal has also developed a project that can support food system resilience towards a commercial urban agricultural strategy and action plan (Ville de Montreal, 2018[5]). Another attempt has been made by Milan officials in 2015, known as “Milan Urban Food Policy Pact”, and called on other cities to join them (Milan Urban Food Policy Pact, 2015). According to the policy statement, the planetary crisis of unsustainable environments would surely affect “the task of feeding cities” (Stahlbrand and Roberts, 2022).

Next, there have been some studies that address concerns on food and climate change and adaptation. For example, climate change increases the spatial and temporal variability in food production patterns, which affects food availability. Food prices may also fluctuate to a greater degree, which will have implications for accessibility. Many knowledge gaps exist in terms of how climate change will influence the volatility and stability of global food systems and food security, especially with respect to food access and use (Myers et al., 2017) << Municipal strategies that consider food security in the context of climate change often focus on increasing the self-sufficiency of local and regional food systems; food systems can be a nexus that provides opportunities to achieve synergies between adaptation and GHG mitigation policies>> (Harper et al., 2022).

Despite all these policies and actions regarding food insecurity, there is still an urgent need for providing operational, innovative and holistic approach that can link urban spaces aligned with climate adaptation planning. In 2022, a project in Milan has made an effort in designing innovative modular urban farming structures named as Urban Vertical Farming (UVFs) where the food demand would be supplied by modular and IoT based vertical structures (Orsini, 2022). Other examples for vertical farming projects exist in Japan, Germany, United Arab Emirates, Hong Kong, Canada, U.S and Finland where guaranteed regular production of output and crop yields are boosted based on controlled environment including temperature, light, humidity, and artificial intelligence in urban spaces (Igini M., 2023). In parallel to these innovative design approaches, there is also a need in re-defining the building codes and standards, designing new infrastructure and regulations (Lovell A., 2022) at city scale. Yet, it is known that geographical, economical and social differences in different cities around the world determine the success or failure of such indoor and outdoor urban farming practices (Negrello, 2024).

Research problem

According to City of Toronto, almost one in four (24.1%) Torontonians live in food insecure households. The risk of food insecurity is higher for people with low income or receiving social assistance, racialized individuals, especially those who identify as Black or Indigenous, people who rent, as opposed to owning their home, and single parents. Therefore, a resilient urban food system that alleviates urban food insecurity through social and technological innovation is highly required. The main research problem of this paper is: "How to design a sustainable food system that increases food security and quality of life in urban communities in a holistic perspective?"

Objectives of the research

Based on the extensive literature review and the research question, the objective of this paper is to introduce a data-driven and sustainable urban food service and place design that extends beyond decarbonization: "City Harvest: A Resilient Urban Food System Design".

Design Strategy of City Harvest

The strategy of City Harvest focuses on three goals: urban farming, soil regeneration, and social connections. By promoting urban farming, the project aims to bring food production closer to communities, empowering them to take control of their food sources. Recognizing the urgency of soil degradation, City Harvest aims to close the loop on nutrient cycles, transforming the flow of nutrients into a circular system that supports sustainable agriculture (Fig. 1). On the other hand, the digital platform serves as a repository of multicultural food knowledge and geospatial data on food production growth. This provides an opportunity to foster social connections and helps people increase their knowledge about food, nutrients, and biodiversity, enabling them to make healthier dietary choices.

Product Ecosystem

City Harvest's product ecosystem will consist of 3 main pillars: i) Harvest Kits, ii) Harvest Hubs, iii) Food Connect (Fig. 2). Each pillar will work to address a different scale of the system, from the individual to the neighbourhood scale, then finally the city scale. Details of each pillar is explained in detail in the following sections.

Methodology

The 'City Harvest' is developed for the St. Lawrence neighborhood of Toronto which is recognized as the birthplace of the city with the first Food Market that brings people together around shared values and experiences of food, community, culture, and heritage. The methodology to design the system followed a qualitative approach of iterative and co-design processes of 32 participants' surveys in a workshop format, 2 design charrettes of more than 150 participants, and 2 in-depth interviews.

Results of Surveys, Interviews and Design Charrettes

A combination of qualitative approaches including surveys, interviews, and design charrettes were applied between 2023 – 2024 at Brookfield Sustainability Institute (BSI) of George Brown College in Toronto. In Fall 2023, the research team designed survey questions to be applied during a workshop with 32 volunteers' participation. The survey explored participants' experiences and interest in urban agriculture within the city of Toronto. According to the results, it is found that, in Toronto, most of the participants (69%) did not have recent experience growing their own fruits and vegetables. Yet despite the lack of urban agriculture experience, most participants (75%) would grow their own food if presented the opportunity. It is also discovered that the largest obstacle in residential urban agriculture was 'space' (Fig. 3).

In the fall of 2023, a series of interviews focused on the issue of food insecurity and they provided significant insights. The results highlighted the understanding that food insecurity within the current economic framework is predominantly an economic issue and cannot be addressed solely by increasing food production; instead, it requires comprehensive strategies that directly tackle the economic dimensions of affordability, including access to income and the broader costs impacting households.

In the Fall of 2023, the research team conducted a Design Charrette, where preliminary findings and various concepts with strategic approaches for the design process had been explored and presented. Subsequently, in the winter of 2024, an international student Design Charrette with a primary focus on design development was conducted. Through collaboration with participants across interdisciplinary perspectives, the research team concentrated on advancing the design of the digital platform, harvest hubs, and harvest kits. Both Charrette results culminated in the development of refined designs, visuals, prototypes, and associated business model drafts, demonstrating a cohesive integration of research insights and design innovation. With the help of collaborative design, the system proposal incorporated a data-driven participatory digital platform that can collect and manage urban food data produced by both the modular vertical structures attached to the facades of the buildings and the housing kits. In addition, co-production and training activities are considered as the main mechanisms where networked community connections are built both in digital and physical space design.

Pillar #1: Food Connect

City Harvest's digital platform, Food Connect, is poised to revolutionize the way people engage with food through co-production activities that occur both in digital and physical urban spaces. By providing a comprehensive online space, it aims to address multiple pressing issues surrounding food, starting with the reduction of food waste. Through Food Connect, individuals and businesses can easily share surplus food, thus diverting it from landfills and contributing to a more sustainable food system. Moreover, Food Connect seeks to foster a sense of community around food cultivation and culinary practices. By facilitating knowledge sharing and skill development, the platform encourages people to explore various aspects of food production and preparation. Through virtual workshops and forums, users can exchange expertise and experiences, ultimately empowering individuals to become more self-sufficient and connected to their food sources.

Design Principles

Food Connect is envisioned as a powerful analytics tool, leveraging data from urban agriculture community to generate valuable insights. By analyzing trends and patterns, the platform can inform decision-making processes related to food resilience, distribution efficiency, and production optimization. This data-driven approach not only enhances the effectiveness of food-related initiatives but also contributes to the long-term sustainability and resilience of urban food systems.
Food Connect operates with 3 major functions (see the Figma prototype in Fig. 4): Community, Marketplace, and Analytics. 'Community' is focused on providing a food focused digital social media space, complete with profiles, posting abilities and feedback mechanisms. A 'Marketplace' is provided digitally for any person or business to sign up. This allows for people to distribute vegetables they have grown themselves, or for restaurants and grocery stores to distribute soon-to-expire food at discount prices. This aims to simultaneously reduce food waste and lower food insecurity. Food Connect's 'Analytics' will be a real time, geo-spatial statistics platform that utilizes new and existing data, in conjunction with predictive technologies of AI.

Analytics and Data Sets
Food Connect Analytics would capitalize on existing data, as well as new data generated through City Harvest's interconnected smart system. With the inclusion of City Harvest data, Food Connect Analytics users would be able to forecast food price changes, optimize food distribution, and build food sovereignty and resilience. The Analytics will be able to provide city shaping insights through different data sets collected (Fig. 5). Food Connect Analytics will be able to provide city shaping insights through different data sets collected. All of the data sets used are open source, which will allow for transparency in food production data as well as collaborative process.

Artificial Intelligence (AI) Integration: Olive
Within Food Connect Analytics, AI integration would take shape in the form of a predictive AI model that can serve as a buddy named 'Olive' for the users. Olive will serve three main objectives:

i) *Predictive Modeling for Food Security and Distribution:*
Olive can analyze historical and real-time data from Food Connect to forecast future food production and consumption trends. By understanding seasonal patterns and urban agricultural output, Olive will optimize food distribution across the city, ensuring that supply meets demand while minimizing waste. This helps in creating efficient delivery routes, reducing emissions, and improving overall food security.

ii) *Personalized Recommendations for Urban Gardeners:*
Olive leverages data from Harvest Kits and Harvest Hubs to provide users with tailored gardening advice. By analyzing local conditions like temperature, humidity, and soil quality, Olive will suggest optimal planting times, watering schedules, and nutrient needs. This personalized guidance enhances crop yields and makes urban farming more accessible and effective.

iii) *Real-Time Monitoring and Anomaly Detection:*
Olive continuously monitors data from sensors across the Food Connect network, using machine learning to detect anomalies such as sudden changes in soil moisture or plant growth. When irregularities are found, the system can alert users or automatically adjust conditions, ensuring the sustainability and resilience of urban food production.

Pillar #2: Harvest Kits

The Harvest Kit is a residential indoor soil-based growing kit that integrates a food waste dehydrator and eco-enzyme chamber. By empowering residents to grow food locally and manage organic waste effectively, it contributes to building resilient and sustainable communities. This can transform urban agriculture and foster a more equitable and environmentally conscious food system.

Design Principles

The Harvest Kit utilizes IoT technology, modularity, and circular design principles for various residential needs (Figure 6). It includes a modular soil tray that is easy to handle and can be returned to the high-nutrient composting facility to be replaced by a new one with nutrient rich soil and seeds, or replaced with soil trays containing plants from the harvest hubs connecting all the components of the City Harvest's product ecosystem.

The eco-enzyme chamber uses organic waste and produces natural pesticides and fertilizers, reducing the need for harmful chemicals to grow vegetables at home. This eco-enzyme can also be used as a household cleaning agent which is sustainable and harmless to the environment. By decentralizing food production and nutrient recycling, the kit contributes to reducing carbon emissions and promoting food resilience in urban areas. Moreover, its self-watering system and low maintenance requirements provide convenience and accessibility to users. Recycled steel, recycled aluminium, bio-waste recycled panels, and bio-based waterproof composite are some of the main materials used. The product has an inlet and outlet for the water and a connection for the electrical line. The distribution of organic fertilizer, i.e., the eco enzymes occurs through the plumbing system connected to the water wicking watering system.

Product Range

The smallest product in the range serves a crucial role in organic waste management and sustainable household practices. Specifically designed for eco-enzyme production and organic waste processing, this compact unit helps deal with most of the organic waste produced at household level. By transforming organic waste into eco-enzymes, users can contribute to a healthier environment and reduce their dependency on chemical-based fertilizers and pesticides for their indoor grown vegetables.
The single door model, which encompasses all the functionalities of the smallest unit, as well as additional soil-based growing kits, further enhances its utility. Equipped with various IoT sensors, the single door model enables precise monitoring of environmental conditions, ensuring optimal plant growth. The inclusion of soil trays capable of accommodating six plant pods are important units that play a part in City Harvest's overall system.
The double door model is a higher capacity version of the single shelf model. It can grow twice the amount of plants and has the capacity to store the dehydrated organic food waste in a larger compartment for up to a month before it can be collected and taken to the high nutrient composting facility.

The plants are supported by growth lights; a passive form of watering system through water wicks that also delivers nutrients to the plants as required from the eco-enzyme storage chamber below; a modular soil tray; and an exhaust fan to circulate air. Sensors are provided to measure light, pH level, salinity, temperature and humidity. IoT farming support through AI buddy “Olive” is provided using data collected by sensors and general insights from the digital platform. For ease of usage, an interface panel to operate the kit is provided with smart tint glass to contain the bright grow light and button-operated organic waste receptacles. Most of the operations are automated and can be controlled through the app on the user's phone.

Pillar #3: Harvest Hubs

Harvest hubs represent a forward-thinking approach to urban agriculture, capitalizing on the untapped potential of building facades and street spaces.

Design Principles

The hubs are designed with the primary goal of maximizing food production in areas that would otherwise go unused. The vision includes the implementation of automated urban farming modules, strategically placed on both buildings and streets, to efficiently utilize available space and contribute to local food production. This flexibility not only provides solution for food scarcity but also promotes sustainability and community resilience in different types of underutilized urban environments (Fig. 7).

Modularity

Module 1 is dedicated to enhancing the street scape by harnessing available opportunities. Positioned directly on the street, it serves as an automated, soil-based urban farming module capable of year-round food production. Utilizing a wick irrigation system, this module efficiently nourishes various vegetables, including tomatoes, carrots, and more. Its presence not only adds greenery to urban environments, but also contributes to local food security by making fresh produce accessible throughout the year.

Module 2 is designed to specifically target building facades, leveraging their vertical space for urban farming. This automated, soil-based conveyer belt module operates year-round, offering a consistent supply of fresh produce. Employing a sprinkler irrigation system, it efficiently nurtures a variety of leafy greens, including spinach, lettuce, kale, and more. By integrating seamlessly into the architecture of buildings, Module 2 not only enhances aesthetic appeal but also promotes sustainability and food self-sufficiency within urban communities. Module 2 also features a sophisticated tray design comprising 38 aluminum trays, each meticulously crafted with perforations to optimize airflow and drainage.

Structure and Material

The structural integrity of Module 2 is paramount, achieved through the utilization of extruded aluminum for its framework. This lightweight yet robust material ensures durability while facilitating ease of installation and maintenance. Following the principles of a curtain wall system, the structural design optimizes space utilization by transferring loads efficiently through the existing building structure, minimizing the need for additional support elements. The outer skin of Module 2 is composed of ETFE (ethylene tetrafluoroethylene) membrane, renowned for its transparency, durability, and thermal properties. This material acts as a protective cover for the structure, shielding it from external elements while allowing ample natural light to permeate through. By creating a controlled environment conducive to year-round growing, the ETFE membrane enables Module 2 to thrive in diverse weather conditions, ensuring consistent and optimal growing conditions for the cultivated plants. Furthermore, the modular design of Module 2 allows for scalability and adaptability to different urban environments. Its versatile structure can be tailored to fit various building facades, maximizing the utilization of available space and promoting urban greening initiatives (Fig. 8)

Conclusion

Experts estimate the current health of topsoil used for agriculture contains only enough nutrients left for approximately 60 harvests. With a global system that relies on agriculture to feed humans and livestock, ensuring the resiliency of soil health is critical to providing a sustainable food system for the future. By creating local, decentralized facilities to manage food waste, neighbourhoods can supply themselves with high-nutrient soil for food production while reducing GHGs from landfills and distribution. Sustainably managing food waste also provides unique opportunities for rural soil remediation, building urban mycorrhizal networks, and creating eco-enzyme-based products.
A transformation at the systems level needs a comprehensive and multifaceted approach. City Harvest therefore aims to tackle the issue through three essential interventions: Urban farming, Soil regeneration, and Social connections through digital and physical space integration. As an integrated hub in the neighborhood, City Harvest aims to supply 80% of St. Lawrence neighbourhood's annual vegetable production by 2035. Also, the platform design enables to measure local indicators and sub-targets of Sustainable Development Goal (SDG)#2 for Zero Hunger and SDG#11 for Sustainable Communities.

Notes

[1] https://www.toronto.ca/wp-content/uploads/2017/11/9787-TO_Prosperity_Final2015-reduced.pdf
[2] https://www.toronto.ca/legdocs/mmis/2018/hl/bgrd/backgroundfile-118057.pdf
[3] https://www.toronto.ca/legdocs/mmis/2021/ec/bgrd/backgroundfile-170565.pdf
[4]https://www.toronto.ca/city-government/accountability-operations-customer-service/long-term-vision-plans-and-strategies/reconciliation-action-plan/
[5] https://montreal.ca/en/articles/montreal-common-innovating-together-to-reimagine-city-15119

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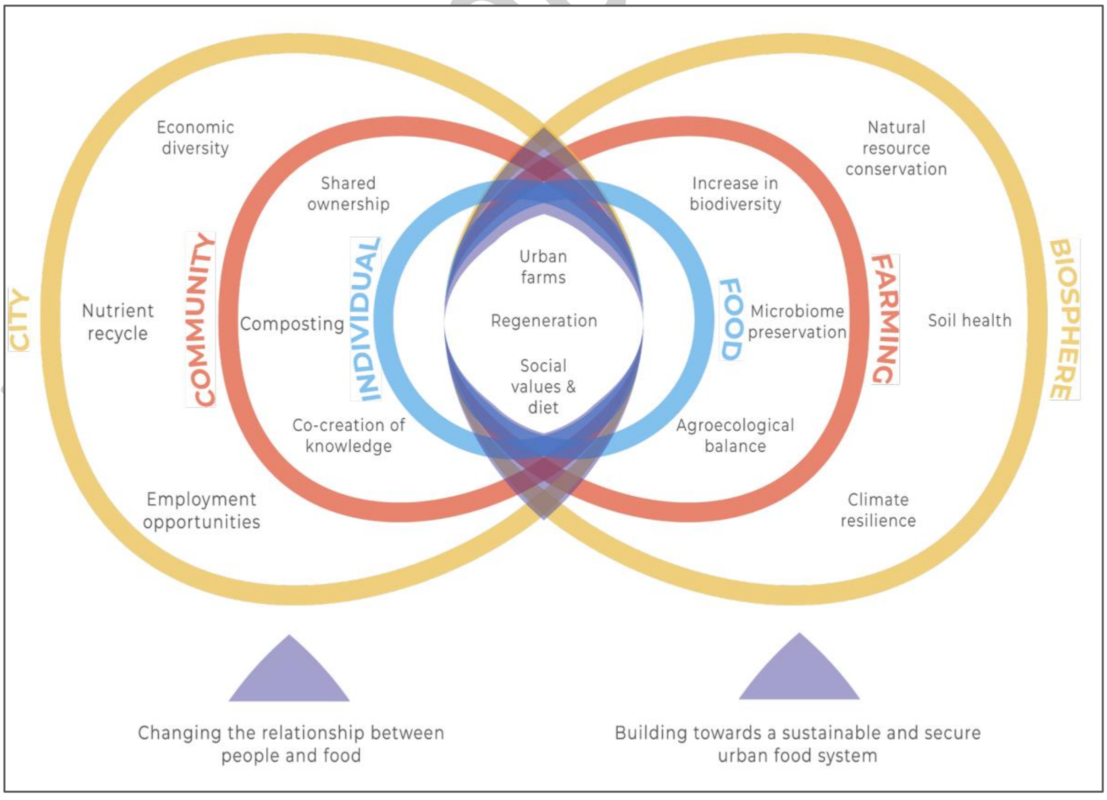
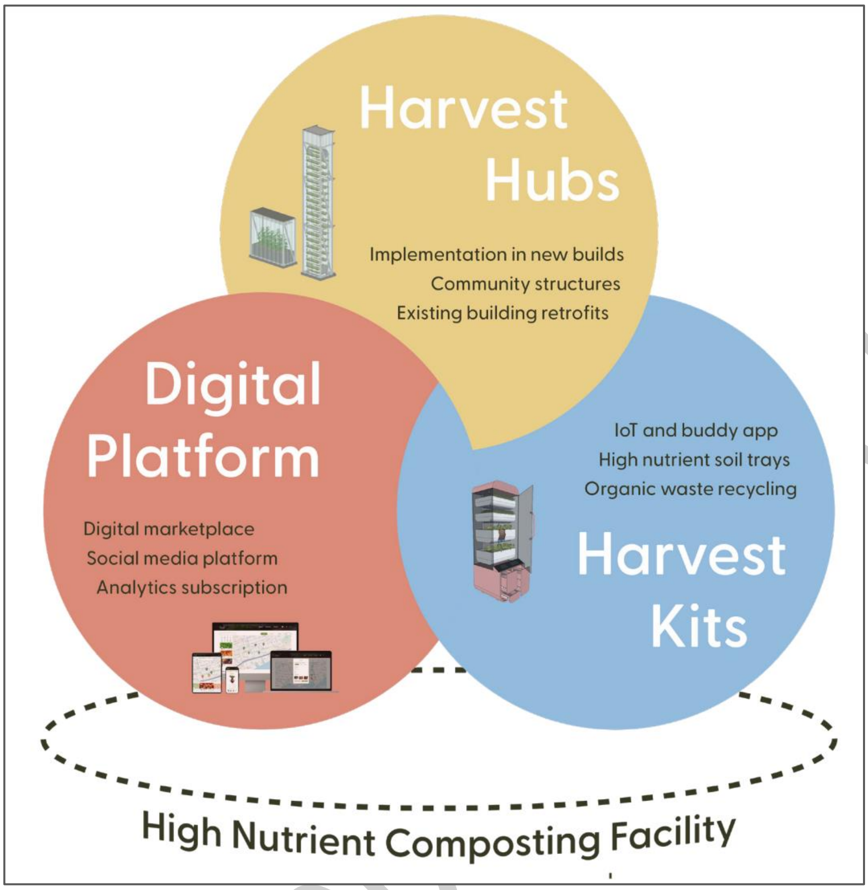
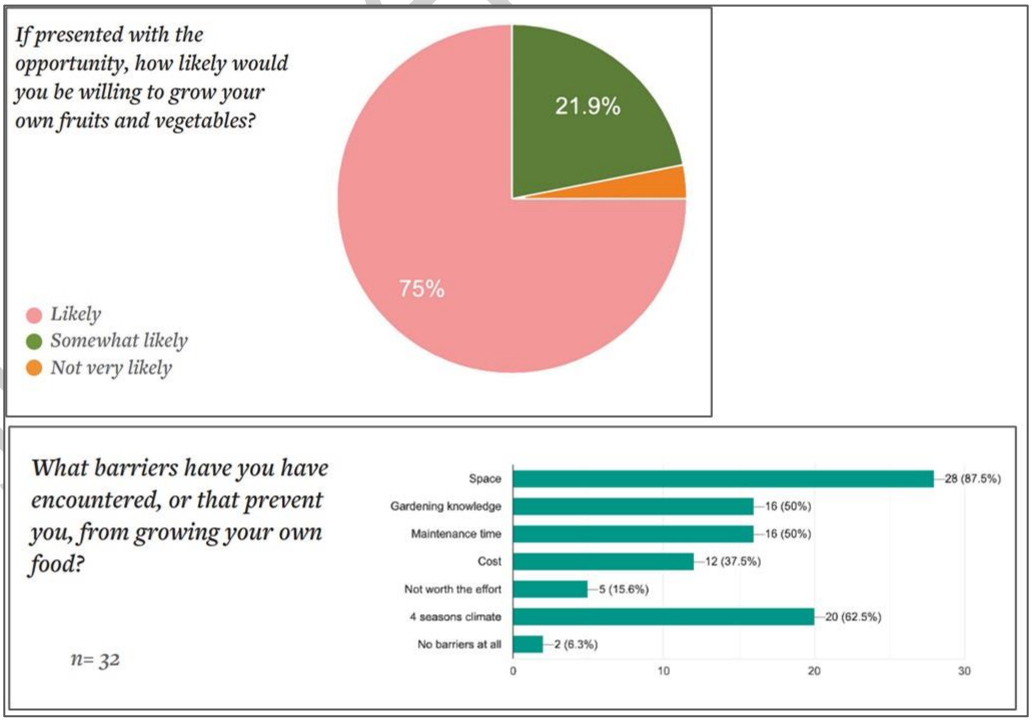
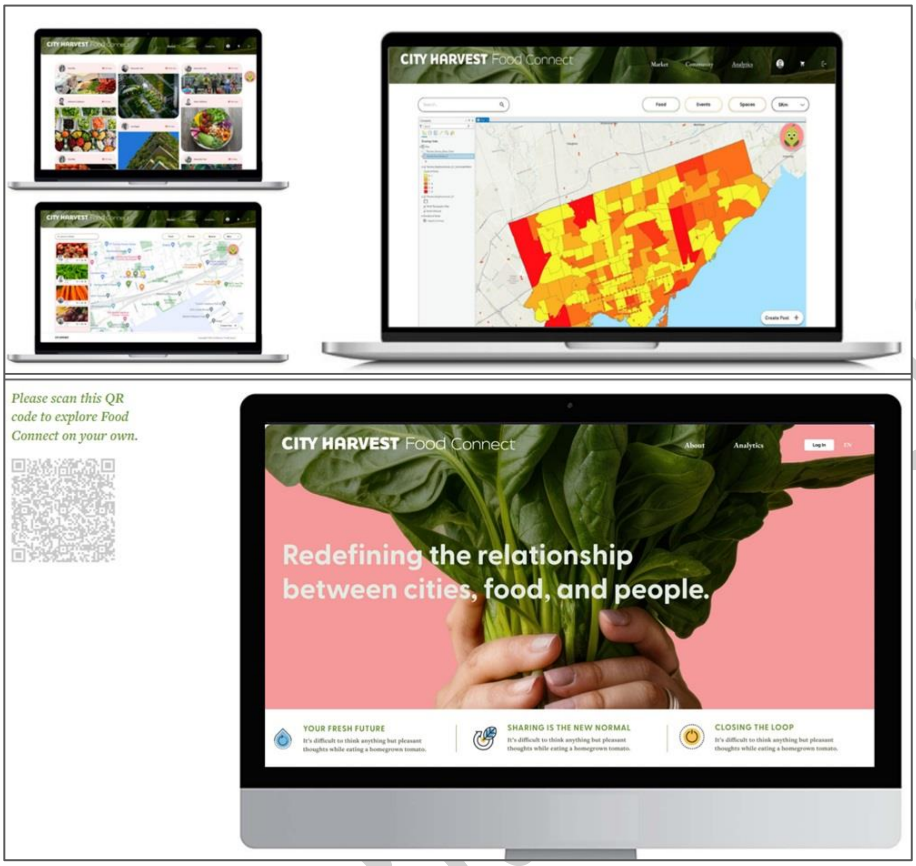
Images



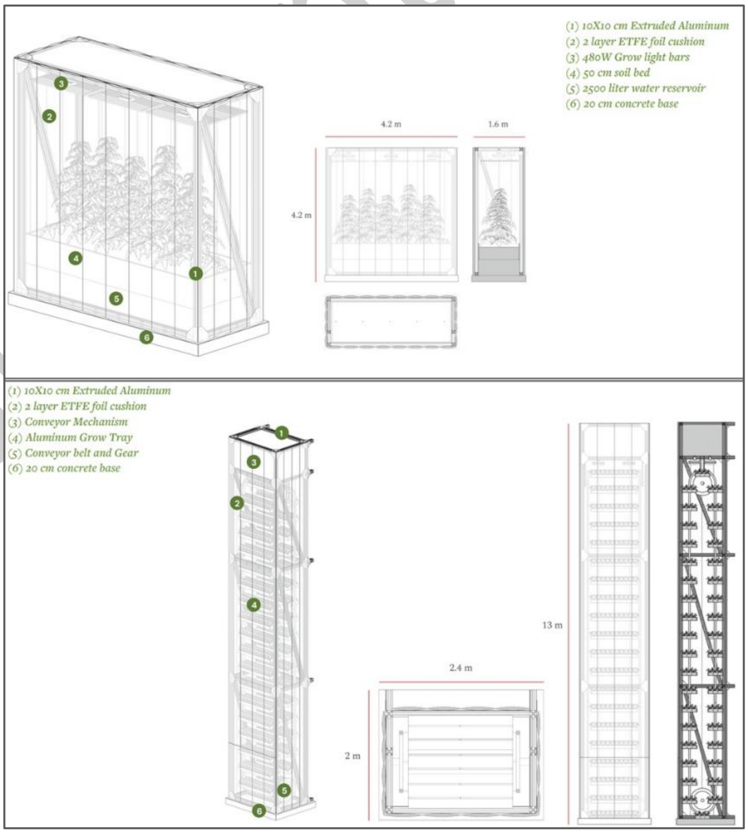

Harvest Hubs
Implementation in new builds
Community structures
Existing building retrofits
Digital Platform
Digital marketplace
Social media platform
Analytics subscription
IoT and buddy app
High nutrient soil trays
Organic waste recycling
Harvest Kits
High Nutrient Composting Facility

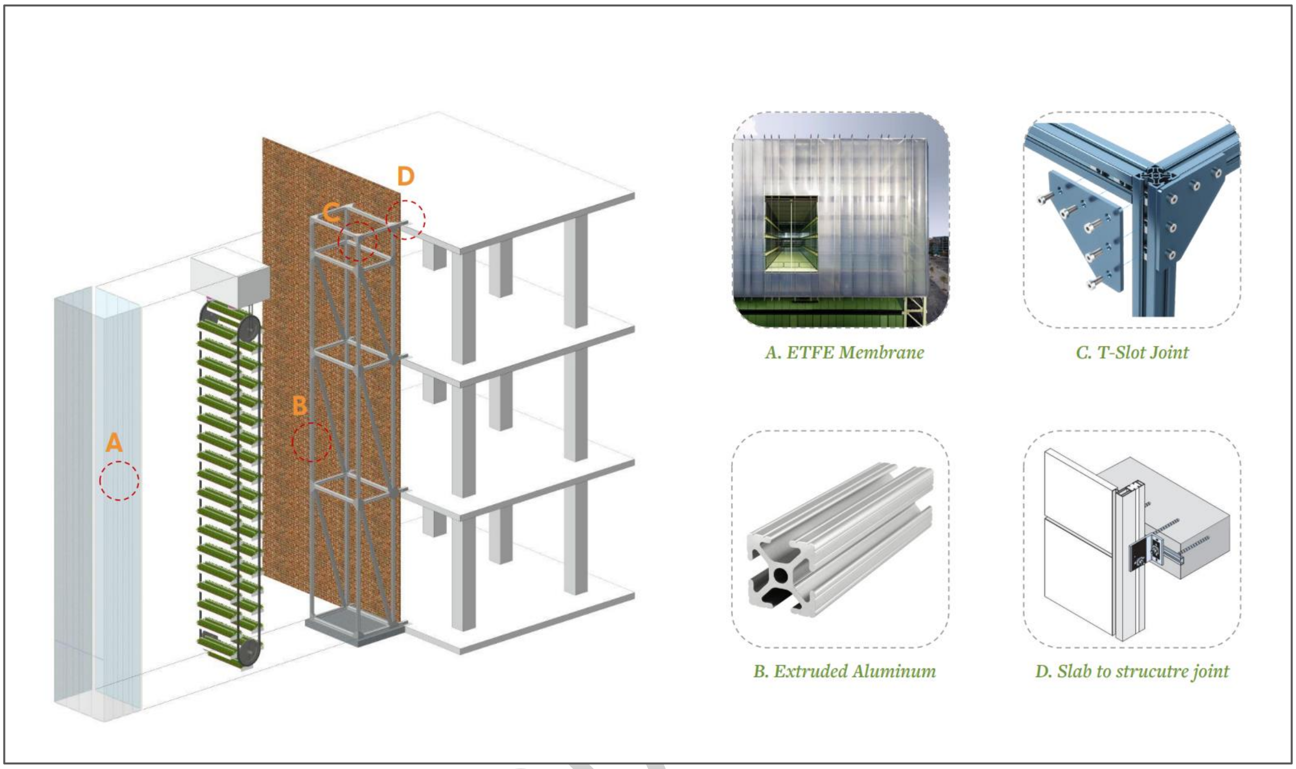

If presented with the opportunity, how likely would you be willing to grow your own fruits and vegetables?
21.9%
75%
Likely
Somewhat likely
Not very likely
What barriers have you have encountered, or that prevent you, from growing your own food?
n= 32
Space
Gardening knowledge
Maintenance time
Cost
Not worth the effort
4 seasons climate
No barriers at all
28 (87.5%)
16 (50%)
16 (50%)
12 (37.5%)
5 (15.6%)
20 (62.5%)
2 (6.3%)
0
10
20
30


CITY HARVEST Food Connect
Please scan this QR code to explore Food Connect on your own.
CITY HARVEST Food Connect
About
Analytics
Redefining the relationship between cities, food, and people.
YOUR FRESH FUTURE
SHARING IS THE NEW NORMAL
CLOSING THE LOOP


Ages
Food Typology
Groviture Food Production
Toronto Neighbourhoods
Spatial distribution of Groviture food production by age in Toronto
Spatial Query, example 1.
Toronto Neighbourhoods
Tomatoes Grown (lbs)
Food Connect Sales
Weather Patterns
Toronto Neighbourhood Tomato Consumption and Sales Analysis with Weather Pattern Correlation
Spatial Query, example 2.


BASIL PLANT
Exhaust fan for temperature regulation and aeration
Smart interactive LED panel
Sensors
Water & Nutrition tray with water wicking system
AI buddy app- Olive
LED Growth lights
Smart interactive LED panel
Organic waste dehydrator
Eco-enzyme chamber
Residue compartment


(1) 10X10 cm Extruded Aluminum
(2) 2 layer ETFE foil cushion
(3) 480W Grow light bars
(4) 50 cm soil bed
(5) 2500 liter water reservoir
(6) 20 cm concrete base
4.2 m
1.6 m
4.2 m
(1) 10X10 cm Extruded Aluminum
(2) 2 layer ETFE foil cushion
(3) Conveyor Mechanism
(4) Aluminum Grow Tray
(5) Conveyor belt and Gear
(6) 20 cm concrete base
13 m
2.4 m
2 m



Captions

Fig. 1 – City Harvest System Map
Fig. 2 – City Harvest Product Ecosystem
Fig. 3 – Survey results
Fig. 4 – Food Connect Platform Design
Fig. 5 – Food Connect Analytics
Fig. 6 – Design of Smart Harvest Kit
Fig. 7 – Design of Harvest Hub – Module 1 and 2
Fig. 8 – Structure and Material Design - Module 2