Building-integrated agriculture’s role in supporting urban food cycle

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Abstract. Current urban food systems are categorized as unsustainable, for the well-being of urban consumers and the environment. Furthermore, health risks are higher in urban areas compared to rural areas. This is caused by soaring prices and difficulty of accessing nutritious food. Most of the raw produce sold in markets, lost half of their nutrients due to logistics from out of town, which results in high carbon footprint. On the other hand, the COVID-19 pandemic has created a shift within consumer behaviour that impacts health and waste. This phenomenon encouraged the authors to analyze effective food systems, in the design of building-integrated agriculture. The overall study questions criteria for sustainable processing, agriculture design strategies, and implementation of agriculture systems in urban space design. Research methods used are theoretical reviews, precedent study of Sunqiao Urban Agriculture District located in Shanghai, China and survey analysis conducted through online questionnaire. The results cover a set of conceptual strategies which include site design, mass compositions, spatial programming, lighting and ventilation, spatial forms, façade, and energy patterns which are then applied to create a building-integrated agriculture that plays a role in pandemic mitigation, community resilience, and promotes sustainable development within the food sector.

1. Introduction

In the next 30 years, 65 percent of the total world population is expected to live in urban areas. The predicted number stands at 6.3 billion by 2050 [1]. The reality is that problems related to inequality, malnutrition, and environmental degradation is in direct proportion to the increase of population density. Children living in low-income housing are often malnourished due to economic difficulties which force them to lower their consumption rate and quality. Statistics show that the number is much higher in urban populations compared to rural areas [2].

In a report reviewed by the Ministry of National Development Planning, estimated level of Indonesia's population falls below 70 percent of the standard Energy Adequacy Ratio (EAR), currently at 45.7 percent. The main cause of this problem stems from the difficulty of economic access to food, which is not proportional to the availability of existing food. As a result, spending on processed food and beverages has quadrupled, while excess food that aren’t consumed are linked to food and energy waste problems, both contributing to environment and food insecurity [3].
Current urban food cycles follow the traditional open field farming which are currently outdated. Produce are delivered from countryside into urban areas – raw produce sold in urban markets, are deemed to have lost half of their nutritional contents [4]. Other than that, with conventional farming systems, excessive use of agrochemicals and pesticides increases health risks and environmental pollution, while fossil fuels used in the delivery of crops further contribute to global warming [5]. As a response to those problems, building-integrated agriculture emerged from the development of agricultural technology, to increase food accessibility and prevent environmental degradation. This building typology holds an important role in creating a source of food supply that is easily accessible by the public, within the urban interior. In order to close the gap – especially during the COVID-19 pandemic, the strategy that needs to be applied is to create decentralized building-integrated agricultures, spread out in various urban areas, to allow people from a range of demographic backgrounds to obtain nutritious and fresh produce they all need.

Agriculture systems has always been the number one importance in building socio-economic strength. Food security is included in the United Nation’s Sustainable Development Goal (SDG) targeted for 2050. The Food and Agriculture Organization of the United Nations (FAO) projects that 80 percent of the additional food required to meet demand in 2050, will need to come from land already under cultivation. One of the solutions to implement is through the creation of food spaces within high-density urban areas [6].

Throughout history, food markets play a huge role in keeping the livelihood in urban spaces strong. In ancient Greece, the Agora acts as a centralized space not only for food markets, but also for debate, expression, and friendship among urban communities – creating a sense of belonging, attachment, and character in people's lives [7]. Yet since the pandemic hit, human touch has been at its farthest. The limitation from going outside into nature, barred from freedom and human interaction is creating a new problem for the mental health of urban dwellers.

Research has shown that throughout the pandemic, young adults are showing symptoms of anxiety and depressive disorders. Some research even shows concerns about substance abuse and suicidal ideation that has been increasing since the pandemic started [8]. On the other hand, society’s movements have been limited to an absolute minimum, pushing them to stay indoors and therefore decreasing ease of access for quality food, due to lack of options. According to this year’s edition of The State of Food Security and Nutrition in the World – a joint effort published by 5 of the biggest world organizations – states that overall, more than 2.3 billion people (or 30 percent of the global population) lacked year-round access to adequate food. Statistics leapt in one year compared to the preceding five years combined.

The “transformation pathways” proposed in this year’s edition includes: intervention along supply chains to lower the cost of nutritious foods – for example, by encouraging planting crops or making it easier for growers to access markets – and by strengthening food environments and changing consumer behavior by growing better raw produce, reducing salt and sugar content in the food supply and protecting children from negative impacts of food marketing [9]. There exists a real need for open spaces that are safe for visitors to experience a connection with nature, while also creating a readily available open source for food within urban areas which everyone can access. In addition to that, open spaces limit the possibilities of transmission, whereas confined and closed spaces with poor ventilation will more likely increase the spread of the virus [10].

This approach can provide vulnerable and marginalized populations greater access to productive resources, technology and innovation to empower them to become agents of change towards more equitable and sustainable food systems. The successful transformation of food systems toward greater affordability of healthy diets for all, sustainably produced and with improved resilience, calls for win-win solutions. Thus, this study questions the criteria and parameters of sustainable food supply cycle processing, open air agricultural building design strategies, and agricultural space design strategies with the application of sustainable processing and urban farming systems.
2. Theoretical review

2.1. Closed loop food supply cycle
The processing of the food supply cycle is a cycle that includes upstream processes, namely production, to downstream processes, namely food waste processing [11]. Closed loop food supply cycle is a sustainable system in the principle of a circular economy. This principle aims to define causal relationships and flows of a system based on economic activity and consumption of limited resources, by redesigning the flow of waste generated from the system and focusing on positive benefits for the whole society [12]. The role of the agricultural system in the food supply cycle does not stop at increasing the accessibility of harvested products, but also performs an agricultural function in the center of the urban area. Urban farming systems play an important role as a community food supplier that combines producers, sellers and consumers, and is responsible for waste management through anaerobic, aerobic, and water purification methods to restore processes to agricultural production [13].

2.2. Urban farming system
Urban farming systems reuse natural resources and urban waste, to obtain a variety of crops and livestock [14]. In urban agriculture there are two system typologies, namely vertical and horizontal systems. Horizontal farming systems use land in urban areas and focus more on communities [15]. Vertical farming systems are the practice of growing crops in vertically stacked layers to minimize land and water [16]. Horizontal farming systems with intercropping methods are generally placed outdoors because they require open land. Permaculture is a principle in this typology of systems, which considers site, social, energy, and abstract elements such as time, data, and ethics (in humans and nature). In implementing a permaculture system, the site needs to be divided into 5 zones: built area, small plants and animals’ area, orchards and ponds, land boundaries, and recreational area which is wilder and more unkempt [17]. Ultimately as a parameter, a 10x10m land with a growth cycle of 130 days can meet the food needs of one household for a year [18].

The crop production system has a specific flow of operations: starting from seedling, planting, harvesting, packaging, cooking, consuming, disposing, and recycling waste [19]. The whole process is carried out by 4 parties, namely: agricultural experts who oversee the production phase, sellers for food processing, the general public for consumption and disposal, and biotechnology experts who play a role in treating waste. The crop production system, when grouped together, forms 3 main programs, namely agriculture, commercial, and waste treatment. Each activity group consists of users as the main driver of a certain process. Based on the literature of Kozai and Despommier, the users and flow of process, activities, and program space requirements are summarized in Figure 1.

2.3. Building-integrated agriculture
Building-integrated agriculture is a branch of architectural practice which integrates agricultural systems into building functions [20]. This form of integration can be achieved through the application of productive vegetation on building facades or implementing plant cultivation as part of the spatial programming. In order to achieve a sustainable system: programs, passive energy, and agricultural buildings need to be stitched with overarching food supply cycle and agricultural systems, as shown in Figure 2.
Figure 1. Food processing system & users.

Figure 2. Agricultura System diagram.

The site for the typology of agricultural buildings needs to pay attention to the surrounding environmental conditions. The location of the site is also an important point to consider, because the treatment system applied requires access to water, access to housing within the city to minimize the distance between staff and visitors, and the a complex pipeline system. The construction of agricultural buildings is recommended to be located close to natural water reservoirs such as lakes or rivers in order to reduce the amount of clean water that is used and wasted. The building itself will have more than 5 floors and about the size of one city block [21]. Several factors to consider the site of an agricultural area include flat land slope, sun exposure for 6-8 hours, minimal shadow projection, wind direction, fertile soil quality, and surrounding safety which needs to involve public and neighboring sites.

Programs are divided into agriculture, offices, commercial/tourism centers, and waste treatment. Each room needs to be physically separated, with a buffer area/airlock as an intermediary space. Circulation is divided into agricultural routes (semi-private, private), logistics routes (semi-public), and the general public in visitor routes (public). The overall design elements of agricultural buildings are summarized in Figure 3.
2.4. Application of Vertical Farming System in Buildings
The application of urban agriculture as a form of architectural practice application is no longer foreign. Building integrative efforts that use vegetation as a design element, have been applied previously. Several types of vertical farming applications based on the publication of the journal Taufani includes green roof, sloped green roof, green house, green living wall, and green façade [22].

2.4.1. Green roof
A green roof is the planting of landscape vegetation that consists of layers above the roof surface of a building. Installed in the form of a layered modular installation on the roof or by installing a pre-prepared receptacle, these layers have a specific role. The depth of the planting medium ranges from 50 mm to more than 1 m, depending on the weight capacity that the roof structure can withstand and its design objectives.

2.4.2. Sloped green roof
Since the roof typology used in tropical areas such as Indonesia is a sloping roof, one of the efforts to implement a green roof is to meet the conditions summarized in Figure 4. The slope of the roof is designed around 15 degrees so that the roof structure is safe to be stepped on, easing the maintenance. This type of construction uses a frame module as the placement of plant pots and is supported by fiber cement as roofing material. Several circulation paths are applied between plants to facilitate the harvesting process. The irrigation system on the roof uses automatic sprinklers.

The types of plants that can be grown on a sloping roof are limited. Given that the structure of the roof is not like a roof with a higher load-bearing ability, small vegetables such as Lettuce, Kale, Pak coy, etc., are more suitable for planting on sloping roof conditions. The distance between the vegetables is set to about 12.5 cm.

![Image 4: Farming installation on sloped roof.](image4)

![Image 5: Green house application.](image5)

2.4.3. Green House
Sloping roof farm in the design of the roof of the Greenhost Boutique Hotel – a hotel building in Jogjakarta (Figure 5), Indonesia – is designed to have a greenhouse on the roof of the building which accommodates small vegetable plant cultivation. Using a hydroponic system, vegetables get maximum sunlight and are in optimal room conditions for plant growth.

2.4.4 Green Living Wall
Green walls are the cultivation of plants on a vertical plane, placed on the wall of the building; attached to internal or external walls. Like a green roof system, this farming effort involves vegetation,
growing media, irrigation, and drainage integrated into the system. The irrigation system utilizes force of gravity, through the drip irrigation method.

2.4.5. Green facade
In the case of a balcony structure, the method of implementing a green façade system requires railings with an NFT (nutrient film technique) irrigation system. Size can be adjusted to the width-height of the building. Some of the plant typologies that can be planted are vines such as Lee Kwan Yew or Srikaya (useful as well as shading) and small vegetable crops such as lettuce, spinach, and others.

Pasona HQ by Kono Designs, a 9-storey building with a combination of office and commercial functions in Tokyo, integrates a vertical farming system in the facade of the building. This was
achieved by planting ornamental plants and citrus fruits on the double-skin façade. Plants are partially supported by the exterior climate of the building, creating a living green wall and unique identity for the building itself.

3. Research methods

3.1. Precedent study

The object of precedent study in this section is the Sunqiao Urban Agricultural District designed by Sasaki Associates, located in Shanghai, China. Data collection was carried out through literature sources and analysis was carried out through qualitative methods. The Sunqiao Urban Agricultural District is situated on land flanked by 4 roads and 2 river canals that run through the interior of the site, with a tread tertiary road separating the blocks in a grid organization. The tread has a permeable character, regulating pedestrian relationships between building spaces.

![Figure 9. Location Sunqiao Urban Agricultural District.](image)

Food supply cycle of Sunqiao uses a combination of horizontal and vertical farming systems to support Shanghai’s overall increasing food requirements. The urban food waste produced is then decomposed and processed back as input for vegetable substrates and turned into animal feed for fish, chicken, pigs, and cattle. Irrigation is sourced from rainwater, where the waste from the planting water is then channeled into fishponds. The entire upstream to downstream system produces fish and green vegetables which can be purchased and consumed on site. The program is a combination of agricultural programs, offices, commercial and educational centers, and waste management. Sunqiao’s space program has a variety of food spaces in the Agricultural Production Center area, to support the urban food supply cycle. Food space is not only defined as a dining room, but includes production, food processing, and eating spaces. The culinary school is integrated and placed near restaurants and productive garden. This is designed to minimize the amount of leftover food. The combined program creates an experience zone, providing a tactile experience for visitors.

3.2. Survey analysis

The object of study in this section aims to obtain information on food habits of Indonesia’s urban consumers and clarify a phenomenon by describing a number of variables related to the problem, studying the phenomenon in review, and connecting one variable to another to gain concrete evidence. The method of data collection was done by authors, through the distribution of an online survey to 80 respondents living in big cities across Indonesia. Survey analysis is done through a quantitative and qualitative approach to gain statistical evidence. Data obtained are then classified separately, categorized, and calculated. Calculations are then presented in graphical forms to make them easier to read and understand.
3.2.1. Survey respondents
Overall respondents of questionnaire are people who live in urban cities across Indonesia, who fall into 3 categories based on age seen in Table 2. Determination of research respondents was done using purposive sampling technique. The young adult category was deliberately chosen to be the larger sample group because they are the most impressionable group and most prone to change. By analyzing their food habits from an earlier stage, it is hoped that the research could be better suited to their needs and raise further awareness and become more perceptible to the younger generations. The profile of survey respondents categorized by age are as follow: 1) 58 Young Adults: 18-24 y.o, (72.5%). 2) 18 Adults: 25-49 y.o, (22 %), 3). 4 Elders: > 50 tahun, (5%).

3.2.2. Data collection method
Due to COVID-19 restrictions, the survey was distributed online via Google Forms. General discussions covered within survey consists of 5 sections and 35 questions regarding to respondents' backgrounds, sources of food purchases, food processing habits, food consumption, and food waste disposal.

3.2.3. Online survey results
This survey shows that many urban communities do not comply with the procedures for sorting and processing personal or household waste. Not only that, the local governing bodies, companies, and residents still lack discipline. Respondents prefer to eat and cook at home, so it can be concluded that urban communities still have a culture of buying raw materials to process their own food. Regarding the purchase of food, respondents answered that they prioritized the price and distance from the place of sale and purchase. Regarding food consumption, the element that is most concerned is the quality of food ingredients. In addition, seeing the whole waste management process can encourage them to comply more with the rules related to waste disposal and processing. Therefore, shows that urban consumers need transparency. Most of the respondents answered that they have an interest in a place of business that has a good waste management system. The summary results of data analysis can be seen in Table 1.

| Table 1. Results of urban consumer food habits survey. |
|-------------------------------------------------------|
| **Survey Answers** | **Survey Analysis** |
| 37.5% respondents answered No, when asked whether the waste management in the area where they live is already regular or not. A lot of waste is scattered on the road, people are not disciplined in disposing and separating waste, minimal trash cans, and types of waste mixed by transporters. | ![Image](image1.png) |
| **Locations that have not been discipline in managing waste** among them are: Manggarai, Bali, Ciputat, Pamulang, Depok, Mampang, Bandung, Manado, Pontianak. |
| 51.2% of the respondents answered that they trust supermarkets better, 36.3% choose to shop in local food markets, whereas the remaining 8.8% harvest their own produce. 58.8% of the respondents prioritize quality and 41.2% prioritizes price point. Most respondents out shopping groceries weekly (53.8%), for their immediate family with 2-6 family member (73.8%). Type of food that’s shopped most often is vegetable, followed by animal produce. Respondents chose pictures of food that are displayed under well-lit areas which emphasize bright colors and are organized based on categories. Food that are displayed must look clean and fresh. | ![Image](image2.png) |
Respondents chose pictures of food that are harvested, packed, and organized for them to choose and take themselves.

42.5% of respondents answered that they like to cook food at home, while 35% admit they often like to use food delivery services. 77.6% chose pictures of food being prepped or cooked, which becomes the process that they are interested in.

53.8% of respondents often eat out of the house. 95% of respondents said the main reason they go out to eat is for recreation with friends and family. In addition, 78.8% of respondents prefer to eat at home.

The atmosphere of dining location chosen by most respondents reflects a warm room and resembles a dining table at home with minimal yellow lights and is close to the outdoor area. The preferred way to serve food tends to be self-served or served by the chef with the opportunity to see them cook (the cooking process is watched like a show).

62.5% of respondents agree with the statement that they separate their wastes by type (at home or in public spaces), but 77.5% said they care about waste management but don't want to be bothered.

60% of all respondents said that they would be more disciplined if the waste they disposed of had a clear purpose and process, while 55% said that having a waste bank near their house would help.

65% said restaurants that reprocess food waste generated were attractive to visit, 66.25% said shopping for handpicked food and shopping directly from farmers were two of the most attractive features, and 71.25% restaurants with their own gardens were the most attractive.

77.5% of respondents chose beautiful and clean views to support recreational and tourist comfort with visually descriptive form of trash cans - types of waste are separated according to color with large texts.

Considering these reasons, the consumption program that needs to be implemented is the concentration of restaurants and cafes. For those who choose to eat at home, it is necessary to implement a shopping program. Due to the dominant number, the percentage of the program area for purchasing raw food needs to be larger than that of eating places.

This answer supports the need for a waste bank in public spaces. Even though the community has separated the waste according to the type at home, the processing needs to be done by other parties to ensure that the waste is processed.

It is necessary to implement several waste collection sites based on the following categories: organic, solid and liquid waste.

Agricultural programs need to be integrated inside and outside the building. Due to the great desire of respondents who choose to pick their own food, agricultural programs need to be combined with all existing programs - waste management programs, consumption and purchasing, recreation/tourism, and food processing.

3.2.4. Survey analysis

80 respondents prioritized price and distance from the place of sale and purchase. Both can be achieved through the decentralization of agricultural buildings in urban areas. In addition, seeing the real waste processing process can encourage them to comply more with regulations related to waste disposal and processing. Respondents have a great interest in the place of business with its own agricultural system and good waste management. Based on theoretical studies, precedent studies, and the results of previous questionnaire studies, a complete flow and program of urban agricultural buildings with the application of food spaces is formulated in Figure 7.
4. Result and Discussions

4.1 Building-integrated Agriculture Space Programming

An agricultural building with food supply cycle processing requires a combination of 4 program categories namely agriculture, office, commercial/tourism center, and waste treatment to achieve a closed cycle from production to disposal (upstream to downstream) [16]. Circulation needs to meet the needs of 4 actors: agriculturists & biotechnologists in the agricultural route (semi-private, private), sellers in the logistics route (semi-public), and the general public in the visitor route (public). According to books and articles summarized from Despommier; Zeidler, Schubert & Vrakking, and Kozai, design and programming required in the spatial design of building-integrated agriculture includes: farm production, administration, food processing, commercial area, recreation area, and waste management as shown in Table 2 [23].

| Program                  | Zoning      | Space                  | Function                                                                 | Information                                                                                     |
|--------------------------|-------------|------------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Farm Production          | Indoor      | Seeding                | Space for seed selection and germination                                 | • Room quality (gas level, air pressure, temperature, etc.) needs to be controlled.          |
|                          |             | Cultivation Room       | Plant cultivation area ➔ harvesting                                      | • Using passive energy from natural sources (solar, wind, water).                             |
|                          |             | Laboratories            | Monitor the safety and health of plants, crops and food products          | • Vertical farming systems (hydroponics, aeroponics, aquaponics).                             |
| Airlock/ Changing Room   |             | Place for staff and visitors to the planting room to change clothes | Needed to ensure the planting space remains sterile and clean from potential external disturbances | • Lighting from sunlight or artificial                                                       |
### Control Center
Monitor the overall running of the facility
Monitor and security room

### Outdoor Facade
Living green wall
Balcony, full sun, rain/clean water irrigation

### Garden
Using a horizontal farming system for landscape needs and can produce more food
Full sun, planted in the ground, and using rainwater/clean irrigation
Can be applied to vertical farming systems (hydroponics, aquaponics)

### Administration
Indoor Office
Management staff workplace, accommodates staff amenities
- Office & meeting room
- Pantry
- Restroom

### Staff Amenities
Section of the building specifically for vertical agricultural workers, accommodating staff amenities
- Break room
- Pantry
- Praying room
- Restroom

### Food Processing
Indoor Kitchen
Room where food is processed and cooked for consumption preparation
- Cooking area
- Food storage
- Refrigerator & Dishes area

### Cleaning
Cleaning and packaging of food for sale
Segregation by type, cleaning and packaging of the harvest

### Commercial Area
Indoor/Outdoor Marketplace
Center for buying and selling transactions between producers and consumers
- A program that is useful as an economic support for food sales
  - Dining space
  - Restroom

### Recreation Area
Indoor/Outdoor Eco-education
Bringing more varied activities for visitors and building awareness through educational programs
- Receptionist
- Lobby
- Restroom
- Gallery, museum, etc.

### Waste Management
Indoor Garbage Sorting
A place where solid waste is sorted according to type for further treatment
Contains trash containers that have been separated
- Digester
- Water purification

### Outdoor Compost Area
Space for compost production
Composters

### 5. Conclusions
Through theoretical study research, it is known that the criteria and parameters for building an effective treatment cycle consist of processes that involve production to waste treatment. The principle of permaculture responds to the surrounding ecology, through the application of vertical and horizontal systems. Both food systems are integrated with program design, in order to encourage interaction between users and agricultural activities. Primary programs include agricultural programs,
while secondary programs include commercial, tourism, and office/residential programs. The program concept is used to create a public interior space that integrates food space into urban life.

Precedent analysis studies and questionnaires concluded that spatial program design, zoning arrangements, access, circulation, and connectivity between rooms are a set of strategies that create dynamics of public negotiation space. On the other hand, scale, proportion, lighting, ventilation, and the play of material combinations regulate sensory perception and the level of privacy between rooms. The element of interactivity makes the public a participator of the whole process.

It is hoped that the results of research and design will encourage the application of agricultural systems in urban contexts and contribute to architectural science by providing a set of concepts and design results as a model for developing agricultural spaces. It is recommended for the continuation of the research process in the future, to further research the theoretical aspects of technical studies rather than other agricultural systems and waste treatment methods, as well as further develop the application of materials and structures that are lower in energy.

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