Urban community planning and spatial model construction supporting sustainable consumption and production

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Abstract. Introduction: Three main contradictions that accompany the urbanization process: population explosion and food demand, urban expansion and production space, production mode and energy consumption. The pressure of urbanization has caused a huge mismatch between production and consumption in space and mode. Analysing the status and trends of urban food system planning show that sustainable consumption and production are closely related to their spatial layout. Method: Take a simulated urban community sustainable food system as an example. Based on local production and consumption, distributed layout and resource recycling system. The model formulates a reasonable spatial planning strategy based on urban agriculture of different scales, technologies and efficiencies, quantifies the indicators of the productive community to suit different scales, and uses a python algorithm to simulate a spatial model with adjustable parameters. Results: Through the comparison and optimization of multi-plan spatial patterns, a sustainable consumption and production-oriented planning decision was formed, which was finally used to guide the productive community spatial planning project. Discussion: This model is only a preliminary attempt at food system planning, but ‘theory-simulation-design’ has proved the feasibility of productive community spatial planning and explored the path of sustainable urban communities that support sustainable consumption and production.

1. Introduction

1.1. Potential relationship between urbanization and the food crisis
According to the current progress, the Asia-Pacific region will not be able to achieve any of the 17 sustainable goals by 2030, especially SDG12-Responsible consumption and production has taken a step backwards[1]. (1) Population increase and food demand. Cities already have more than half of the world’s population, they consume 67-76% of the world’s energy, and emit 71-76% of greenhouse gases. Urban problems have become a major factor in the global survival crisis. By 2050, the urban population will reach 68% of the world’s, and the amount of agricultural products will still need to increase by 70% after deducting part of it for biofuels[2]. (2) Urban expansion and agricultural land. Over the past 50 years, more than 20% of the world's natural vegetation has been converted into cultivated land, and the urban area is expanding at a rate of 3% -7% per year. Even if crop yields are increased, there will still be a net expansion of 70 million hectares of arable land by 2050[3]. (3) Urban layout and food transportation. The long food mileage in today's cities has caused serious pollution and environmental damage. Food production accounts for only one-fifth of the total energy consumed by urban food systems, while processing and transportation account for four-fifths.
1.2. Data reveals hidden dangers

(1) The crisis is not only hunger but also obesity. If the food crisis is said to be inefficient, then ‘high efficiency’ has the problem of ‘all forms of malnutrition’[4]. (2) Efficiency brings yield but also ecology. The incidence of undernourishment and skyrocketing prices are important factors of social unrest, but the transitional development of land for agriculture has also caused an ecological crisis. (3) In addition to the economic costs of obtaining food, there are environmental costs. The current food production and distribution model relies heavily on cheap labor, fossil fuels, and large-scale efficiency, but has paid a huge ecological footprint and food mileage.[5] The drivers behind these trends of food insecurity and malnutrition are different. Exploring better spatial relationships in the planning of food systems in productive communities will help alleviate crises, replenish arable land, and respond to shortages; shorten the supply chain and strengthen food supply specialization and diversity.

1.3. Status and Trends of Urban Food System Planning

Urban food systems are less visible than other urban systems such as transportation, housing, employment, and even the environment, and have been ignored by planners[6]. The reason for this imperceptibility is the long-term disagreement between urban development and food issues[7]. The 5th AESOP Sustainable Food Planning Group Annual Meeting held in Montpellier, France, in 2013. The conference adopted methods such as ‘food justice’[8] in the United States or ‘food planning’[9] in Europe and focused on discussing how to update the role of agriculture in sustainable urban development. The research work on urban food systems is summarized as three trends: First, analyze the organization, flow and spatial dynamics between urban development and food, especially food procurement logistics or urban metabolism logistics. ‘Food sheds’, ‘foodscapes’, and ‘food deserts’ are the key concepts of these methods[10]. Second, analyze the local food system, focusing on the causal relationship between local food production and urban sustainability. More and more residents and governments are participating in alternative food networks through urban horticulture, shortening the food chain, direct selling by producers, and food education. Third, analyze food planning and public policies that integrate agriculture and food into urban planning and design [11]. In 2016, Urban Food Planning has comprehensively and systematically reviewed the trend of thought, theory and practice in the field of urban food planning in North America and Europe over the past 20 years[12].

These studies, as described above, are aimed at promoting the sustainability of urban food systems. At present, the research on food systems has gradually developed from the relationship between cities and foods to the integration of urban planning and design. However, food systems still seem to hope for the support and recognition of urban systems with a relatively low profile. The food system model of the productive urban community is a rethinking of the above questions. How can the spatial planning of the urban community and the food system be more compatible and sustainable, what will the morphological model be at this time?

2. Methodology

The concept of a productive city simply summarizes that in addition to ‘passively’ reducing urban consumption, it is also necessary to ‘actively carry out green production’: materials, energy, space and other resources to maximize sustainable urban development[13]. The 2030 Agenda for Sustainable Development also proposes that sustainable agriculture and food systems are inextricably linked to sustainable cities and communities. ‘Productive community food systems’ is not only a concept, but also a way to view food issues as an important part of a sustainable urban lifestyle.

In order to achieve the 17 sustainable development goals proposed by the United Nations for the next 15 years, the world needs to address the complex issues of cities and food more collaboratively and comprehensively. The 2016 Global Food Policy Report proposes a food system that requires efficient, inclusive, sustainable, smart climate response, healthy nutrition-oriented, and a good business environment[14]. This report is exactly the requirements and challenges for the current urban community food system. The theoretical basis and spatial planning strategy will draw on the above recommendations, and quantify productive spatial indicators and formulate simulation rules.
2.1. Theoretical basis strategy
(1) Local production and consumption is not a ‘closed’, but its primary significance is ‘inclusiveness’: to accommodate more residents and provide income, employment opportunities and food, rather than being crowded out by industrialized food. At the same time, the local food production and consumption system directly benefits the local economy and provides a ‘good business environment.’ Its purpose is not to be self-sufficient in the full sense, but to make the food supply, food system and dietary structure sustainable so as to establish a ‘sustainable’ local food system. ‘Nutrition and health-oriented’ ensures that the nutritional value of foods is maintained or increased throughout the value chain and focuses on important links with other sectors of the food system.

(2) The community food system advocates a compact and distributed layout. The local high density and reasonable distribution network guarantee the efficient operation of the resource cycle. In the future, climate change will continue to seriously affect crop yields. It is necessary for urban communities to establish a ‘climate smart food system’ to ensure food security and resist climate change. First, through some appropriate technologies such as no-till, adaptable crop varieties and mixed agroforestry systems. Secondly, the community food system is a small distributed network, but it also belongs to a larger urban distributed network system to resist the impact of extreme conditions.

(3) The community food system must be a ‘efficient’ resource-saving system that can meet current and emerging food needs while protecting already scarce resources. Innovations that improve land, water, and energy productivity are critical to achieving efficient food systems. In addition, we must not only do a good job of recycling resources, but also be alert to the efficiency of food systems caused by food loss and waste.

2.2. Space planning strategy
(1) Scale. It can be roughly divided into several types from near to far through urban-rural relations: family gardens or backyards, allotments, community farms, urban farms, corporate farms, organic farms, brownfield farms, and suburban farms. The key elements of different types of classification are: area, location, ownership, and business model.

(2) Technology. The production technology can be divided into three categories according to its difficulty and expansion: 1. Ecological intensification, giving priority to urban environmental problems, and increasing the biodiversity of local cities. 2. Vertical intensification, which increases space utilization efficiency through the vertical use of a certain piece of land or building. 3. Horizontal intensification, which increases the efficiency of time utilization by providing opportunities for multiple activities or functions on a certain piece of land.

(3) Efficiency. To ensure the sustainable operation model and economic feasibility of the planning strategy, different food production requires a certain scale and the lowest returns, such as the smallest continuous scale to be profitable.

Three different types of community food system spatial planning strategies: space scale, technology intensiveness, and yield benefits are coupled into a more abundant three-dimensional matrix of food system space types. It can provide food system planning strategies under different conditions in new cities, it can also be used as a screening condition for improving food system planning in existing cities. (figure 1)
2.3. Quantifying productive community indicators

(1) Spatial characteristics of urban communities. The basic indicators of the productive community model include: population density (D), coverage (C), and floor area ratio (FAR). Open space ratio (OSR) more intuitively describes ‘the amount of ground non-building space per square meter of total area’, indicating the pressure on non-building space.

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OSR = \frac{(1 - C)}{FAR}
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(2) Per capita housing and production area. Controlled-scale fruits and vegetables are suitable for introduction into the city. In order to establish a productive community model, it is necessary to determine the standard amount of per capita residential area and per capita vegetable and fruit planting area. (Table 1) To simplify the simulation, the calculated standard quantity is approximated as a standard unit. Furthermore, in order to make the residential area more flexible and diverse, a residential unit is divided into 3-4 room units, that is, subdivided into individuals rather than families. The community food system space planning simulation will adopt the following configuration: each person (P) needs a standard cell (C) for living: 6m * 6m = 36m², and 3 (C) = 108m² for vegetable and fruit cultivation. (Figure 2)

Table 1. The standard quantities were calculated according to 2016 Chinese Residents' Dietary Guide, 2016 Chinese Family Development Report, and 2017 China Rural Statistical Yearbook.

| Basic parameters                     | Formula               | Calculate standard quantity |
|--------------------------------------|-----------------------|----------------------------|
| Resident per capita living area (Sr) | Sz = A * Sr           | Sz = (108.70 - 136.03) m² |
| Residential unit area (Sz)           |                       | Sz =121.18 m² (Average area) |
| Average household size (A)           |                       |                            |
| Daily per capita vegetable intake (Mr₁) | S₁ = (A * Mr₁ * 365) / a₁ | S₁ = (91.09 - 151.83) m² |
| Daily per capita fruit intake (Mr₂)  |                       |                            |
| Vegetable unit area yield (a₁)       |                       |                            |
| Fruit unit area yield (a₂)           |                       |                            |
| Annual vegetable production area (S₁)| S₂ = (A * Mr₂ * 365) / a₂ | S₂ = (154.86 - 2 71.01) m² |
| Annual fruit production area (S₂)    |                       |                            |

Figure 2. An average productive surface of at least 245.95 m² (left).

Standard unit simulates living space and planting area (right).

(3) Production intensity per unit area. Increasing productivity per unit of land area can be achieved in a variety of ways. Although the actual productivity gradient is non-linear, the planting area in the model will ideally use a productivity gradient (PI) on the 1-10 level, and roof planting is limited by technology (PI = 3 ). PI = 1 is equivalent to a 36m² annual supply of fruits and vegetables, and PI = 3 means that one person's vegetable supply per year is provided on this 36m² unit. (Figure 3)

Figure 3. Different types of productivity gradients.
2.4. Simulation rules and algorithm steps.

The community food system spatial planning simulation is similar to the cellular automata algorithm, and its generation logic mainly has three rules: Step 1. Each residential unit is equipped with three planting units, and each placement is determined by the degree of friendship (F) to be adjacent or far away; (Figure 4) Step 2. When all 8 units around a residential unit are occupied, the height of the residential unit is increased; (Figure 5) Step 3. When the target population density (D) has not been met, increase the (PI) of the planting unit or roof planting.[15]

![Figure 4. Simulation steps for community food system planning.](image1)

![Figure 5. The left side meets the vertical growth conditions, and the right side does not.](image2)

3. Result

3.1. Sample test

Affected by the effects of production intensity (PI), population density (D), and friendship (F), the area and distribution needs of the community food system are reflected in the spatial form: ‘partially compact or evenly dispersed’ in the horizontal direction and ‘high and low fluctuation’ in the vertical direction. The sample test will use three friendship degrees: F = 0.45, F = 0.85, F = 0.95, four population density targets: D = 140, D = 200, D = 220, D = 280, and generate 12 results. Spatial morphology texture maps and productivity gradients and distribution maps are obtained after statistics, which helps to understand a population density threshold that is more conducive to community agriculture and distributed production and sales, and improves the community food system model.

Observing the spatial morphology and texture of the 12 groups of simulation results found that: (1) The community food system can simulate a variety of situations in which population density and production intensity are within a reasonable range, but the differences are still obvious. (2) The current simulation factor only considers housing and planting matching, and the relationship is too single. (3) The state of ‘chaos’ is due to the temporary lack of the ‘transportation’ tandem part of the community food system. (4) The scattered lower limit and concentrated upper limit of the residential unit cannot be controlled, such as the interval between daylighting and fire safety distance, etc. (Figure 6)

Observing the productivity intensity and distribution map of the 12 groups of simulation results, it was found that: (1) The more even the site distribution, the more even the production intensity distribution, and the production intensity increases slowly with the land tension (first column). (2) The site distribution is moderate, and the increase in population density has caused some low-intensity ground plantings to be converted into high-intensity roof greenhouses (second column). (3) The distribution of the site is concentrated, and the ‘obstacles to roof planting’ become more obvious, but it eases as the population density increases (third column). (4) At the same population density, the more uneven the distribution of the site, the greater difference between productivity gradients (each row). (5) From the overall observation, it is found that there is a clear ‘normal’ and ‘abnormal’ diagonal dividing line from the upper right to the lower left. In contrast, the two sets of comparisons from the upper left to the lower right can form a similar land occupation rate (ground planting production intensity is similar) when the distribution of community forms is very different (the roof planting production intensity also changes). By designing some relatively large and complex ‘big’ buildings, they can accommodate more residents and food supplies in the same or even less footprint as other ‘small’ buildings. (Figure 7)
3.2. Community model

Three groups of 600m * 600m community models correspond to Stoke Newington in London, Brooklyn Hight in New York, and Gracia in Barcelona. It has been shown initially that by limiting the distance that communities are allowed to relocate agriculture, there is an opportunity to construct a possible distribution of housing and planting in urban organizations. Aiming at the actual population density requires the community to develop vertically and increase agricultural productivity. Although the community model has not yet reached the level of a complete food system, it also points out the direction of subsequent research:

1. The current community model is only a small part of the theoretical model. It should be more detailed logic rules based on the actual urban agricultural activities. For example, the planting intensity should be tied to spatial factors such as area and location, and the constraints of spatial form are insufficient.

2. Screening and connection of food supply and distribution nodes need to be applied to the food transportation network topology. To maximize the value of local production and consumption, community public buildings, energy, water resources, social networks, etc. must be unified to form a true community food system model.

3. The algorithm is likely to cause misjudgment of the cause of the result. Other methods are needed to quantitatively evaluate the result and ensure accurate index analysis in urban space. Although the simulation model is not completely consistent with the real city, its functions include testing the rigor of the theoretical model, providing scale predictions for the design, and even just exploring other possibilities.

4. As a simulation of the community food system, although the colored matrix plaque can show the basic form, it lacks a fine 3D rendering to show more
details. The self-organizing feedback mechanism of the system dynamics proposed by the theoretical model is insufficient, the feedback between parameters is still processed manually. (Figure 8)

![Figure 8. Community simulation model isometric, aerial view and texture map.](image)

3.3. Design competition

‘Second Nature: Ecological Reconstruction of Terraced Forest Cities’ is a planning and design for the food system of future forest city. Organically integrate food production (terraces and forests), food transportation (roads), and food consumption (buildings), reproduce the city’s metabolism, and explore a new concept of a productive city suitable for sustainable development. Transformation from globalization to localization, from centralized to distributed, and from unity to integration. (Figure 9)

The main strategies and characteristics of food system spatial planning:

1. The second nature covered by food production. All motor vehicle roads are covered by buildings. The city can use surfaces (roofs, terraces, courtyards, etc.) to plant fruit trees and vegetables, and light-transmitting photovoltaic canopies can be set up in parts with good sunlight. The ‘full food production coverage’ site is integrated with the external natural environment to meet the demand for food production land. (Figure 10)

2. Ecological buildings for green production. The terraced residential layout provides a ‘front yard’ for every household, which is suitable for the growth, cultivation and management of fruits and vegetables. While earning economic benefits, it can also provide employment opportunities for residents and shape ‘community farmers’ in the food system. (Figure 11)

3. Three-dimensionally integrated urban form. Through the integration of terraces, transportation, and architecture, a ‘zero-distance’ food mileage is created, breaking the flat urban form and isolated single buildings. The road covered by the building is both land-saving and shading; the terraced agricultural landscape of the opening courtyard extends the leisure space to residents on all floors, and provides a ‘second escape route’ that is not available in ordinary high-rises. (Figure 12)

![Figure 9. Urban food system spatial planning simulation.](image)

![Figure 10. Aerial view of terraced forest city.](image)
4. Discussion
The contradiction between sustainable urban development and the consumption of overloaded resources urgently requires a brand new sustainable food system. The research on food systems has increased significantly in the past decade, but mostly limited to strategic, policy, and theoretical planning. The research on sustainable food system models in urban transformation is relatively lacking.

Productive cities have innovatively experimented with community food systems directly reflected in spatial planning, from planning strategies to shape prediction to spatial design. Pave the way for overall productive city research and provide a reference for building urban communities that support sustainable consumption and production. The spatial planning of the community food system is only the food production of the agricultural part of the future city.

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