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A Study on Community Unit Scale Construction in China Under the Orientation of Green Production

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Abstract: Based on the principle of distributed layout, the community is chosen as the basic unit of the city, and an appropriate community scale is redefined based on the attributes and characteristics of green production. This article first summarizes the existing research models at the community level using bibliometric methods, and on this basis the process of researching the green productive community unit scale is constructed. Subsequently, the data on the scales of agriculture, energy, transport, and commercial facilities from the relevant Chinese national city standards are summarized, classified, and generalized. This is followed by the derivation of appropriate grid scales for green productive community units. Ultimately, a quadratic optimization scale was devised for community units at varying levels based on fractal and management unit theory. This paper presents a new community unit scale constructed for use in large- and medium-sized areas in China, which serves as an illustrative example. The newly developed community scale has the potential to improve the efficiency of resource allocation and support the transition from functional adjustment to structural adjustment in urban areas. Furthermore, the scale definition method and principle can be extended and applied to other large- and medium-sized urban areas globally.

Keywords: green production; large- and medium-sized cities in China; community units; scale construction; distributed layout

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1. Introduction

Current urban and transport planning practices have significant negative health, environmental, social, and economic impacts in most cities [1]. It is thus evident that a novel model of sustainable urban development is required to mitigate the adverse consequences of prevailing planning practices. The term "productive city" is used to describe a multi-level urban system that organically integrates various elements within the city, including agricultural production, energy production, social culture, public services, and others. The aim of this integration is to improve the city's resource and energy productivity, minimize energy consumption and waste generation, and make resources available for the highest-value uses [2]. The advancement of productive city research is of great significance in the construction of a low-carbon sustainable and resource-saving urban system that can achieve a virtuous cycle of producing and consuming resources and energy, developing multiple resources in a coordinated way. The purpose of this paper is, beginning with the scale aspect and being guided by the concept of a productive city, to construct a reasonable scale for the production unit with the goal of green production, realizing the self-sufficiency for each production factor within the unit and even generating outputs.

The concept of productive cities was first introduced by Wolfgang Teubner and de Zeeuw in 2002 [3]. Later, André Veyoun from the Department of Architecture at the University of Brighton, UK, pointed out that appropriate urban development patterns should be determined based on the characteristics of different cities [4]. In 2009, Nels Nelson stated that sustainable cities should shift the paradigm and transform into sources of production rather than consumption [5]. This transformation would enable nature to flourish beyond their borders while increasing efficiency in the use of energy and material utilization. Jeb Brugmann, in 2012's Agenda 21, suggested how to reinvent cities as places that produce resources rather than consume them, and demonstrated the viability of productive cities through studies [6]. In 2013, Kathrin Specht et al. analyzed the development potential of green urban buildings for future urban food production using a sustainability framework [7]. In recent years, research related to urban green production has increasingly tended to be quantified and implemented. In 2016, Chinese scholar Professor Zhang Yukun analyzed the problems of cities and buildings in the new era of change, and proposed that cities and buildings should be transformed in the direction of productivity, localization, distribution, and integration so as to ultimately realize the transformation of the consumer cities into productive cities [8].

In subsequent studies, Prof. Zhang Yukun and his team conducted a series of research projects on community-scale agriculture, energy, and resource recovery systems, focusing on spatial planning and design [9], potential estimation [10], modeling [11], and a framework for evaluating the potential of rooftops [12]. In 2018, Susana Toboso-Chavero et al. analyzed the feasibility of energy and food production with the development of a rooftop mosaic approach that combines life cycles with a rooftop guide and verifies that this approach can help cities achieve self-sufficiency [13]. In 2021, I. V. Hume et al. demonstrated the potential for self-sufficiency of vegetables in urban residential areas by categorizing and measuring urban residential lawn spaces with the assistance of remote sensing technology using Adelaide, Australia, as a case study [14]. In 2023, Fedorczak-Cisak, M and his team designed a methodology for self-sufficient energy housing communities and confirmed it with the example of nZEB in Poland [15]. These productivity studies focus on conceptualization, energy renewal, urban agriculture, material recycling, potential calculation, etc., and explore the feasibility of productivity concepts primarily at the level of a typical community. Research on factors of production and the range of services provided by facilities is still lacking. While a reasonable definition of scale is essential for the development of green productive community units, the transformation of Barcelona's Poblenou neighborhood has not only disrupted residents' travel routes due to the lack of a proper connection between the interior and exterior of the site, but has also made the neighborhood's boundaries extremely confusing [16]. The promotion of green productive cities should aim to transition from localized functional adjustments in terms of energy, food, etc., to structural adjustments on a larger urban scale[1]. This shift will allow the concept to have a more significant impact on enhancing the resilience and sustainability of cities. Consequently, the current research on green productive cities must commence with an examination of green production, encompassing a comprehensive coordination of multiple elements, including agriculture, energy, and transport. This will then facilitate the investigation of the optimal scale for community units to achieve self-sufficiency and even the positive production of energy, food, and other resources. Finally, based on the principle of distributed layout (a unit can consist of multiple subunits that can synergize with one another), this approach can be extended to encompass a larger city scale. In this study, first the relationship between green productivity, community, and scale with the help of a bibliometric methodology was analyzed, and then the process of researching the green productive community unit scale was constructed. Next, the collection of service facility scale data and productive categorization was carried out, and the facility service grid was divided based on the scale data. Then, the scale of green productive units was preliminarily determined. Finally, the secondary optimization of green productive community units was carried out on a scale based on fractal theory and a management unit model.

Based on the concept of a productive city, this paper explores, for the first time, the reasonable scales and boundaries of green productive units at small and medium scales from a macroscopic perspective related to the development of cities and communities, including their energy, transportation, and integrated services.

It is hoped that we can move beyond the previous misunderstanding of studying green productive community units in isolation and neglecting scale studies. By reshaping the urban production structure system at the smallest scale, we can thereby facilitate the development of urban community units in a more sustainable direction.

2. Materials and Methods

2.1. Exploration of the Relationship Between Green Production, Scale, and Community

The interrelationship between green production, scale, and community is complex, and no study to date has definitively articulated the relationship among these three factors. Here, the coupling relationship between the three elements is analyzed using bibliometrics to optimize the current scale research model and subsequently develop the process for researching the green productive community unit scale.

2.1.1. Bibliometric Analysis

Cite Space 2021 is a bibliometric-based data visualization software designed to illustrate trends and areas of significant research activity over time. Firstly, the core databases on Web of Science were searched over the past five years using the search term "productive city".

A total of 102 papers were retrieved after excluding research areas deemed irrelevant, such as medicine, psychology, and virology (Figure 1). The findings indicate that there is a lack of productive studies, with the majority of research focused on urban studies [17], regions [18], and social work [19]. In most cases, the scale of a typical community is considered the default scale for green productive community units. However, the appropriate scale for the development of green productive community units is not clearly defined. The relationship between scale and productivity is characterized by considerable ambiguity.

In order to further investigate the relationship between scale and productivity, we selected scale as the research focus and "scale" and "community scale" as the keywords, and used the last five years as the time limit to search the core databases on the Web of Science. A total of 2008 articles were initially screened, and the collected literature was subsequently de-weighted with the assistance of Cite Space. Clustering analysis was then carried out with a time slice of five years, aiming to extract keywords with a centrality of 0.08 or above and a scale correlation (Table 1). Scale studies can be found focusing on energy renewal [20], transportation [21], etc., but there is a lack of studies related to productivity.

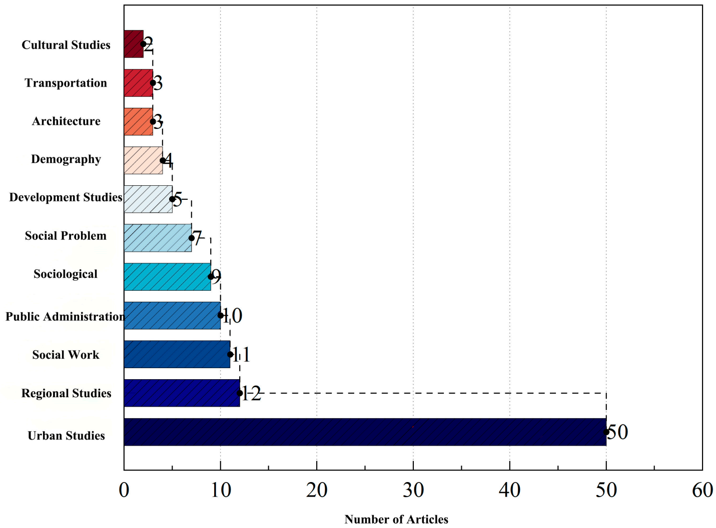

Figure 1. The number of articles related to productive urban research published in the last five years (data source: Web of Science Core Database).

Table 1. Scale keyword centrality analysis. Source: author.

Tab	Frequency	Centrality	Byword	Scope of the Study
1	31	0.13	City	Transportation, renewable energy
2	14	0.13	Simulation	Energy planning, energy modeling, transportation
3	39	0.12	System	Transportation, energy
4	18	0.12	Renewable energy	Distributed energy, energy storage, smart grid
5	14	0.12	Performance	Electricity, photovoltaic, and wind energy contribution to urban energy
6	24	0.11	Optimization	Home energy management, distributed energy, rooftop photovoltaics
7	7	0.1	Electricity	Electronic
8	30	0.09	Model	Energy, electricity consumption, renewable energy, energy efficiency
9	17	0.09	Impact	Projected electricity, land use
10	15	0.09	Management	Distributed energy, grid
11	18	0.08	Smart city	Cogeneration, Smart cities, energy efficiency, storage capacity

2.1.2. The Interrelationship Between Green Productivity, Community, and Scale

In terms of the focus of papers related to Eastern and Western scale research, research conducted in Western countries has primarily focused on distributed energy sources (DEG), microgrids, integrated energy communities, and solar photovoltaics (PVs). The objective is to facilitate the transition to community energy, and the approach is more practically oriented. Examples of such projects include those in Germany, Belgium, and the United Kingdom [22]. The optimal methodology for sizing Renewable Energy Communities (RECs) has been proposed by G. Coletta et al. from the University of Bologna in Italy [23]; the optimization of centralized and distributed schemes for REC PVs and energy storage technologies was studied by Emanuele Cutore et al. [24]; Nikita Tomin et al. improved power availability in settlements through new modeling [25]; Vladimir Z. Gjorgievski et al. assessed economic, environmental, technological, and social impacts by reviewing the recent literature on energy communities [26]; and Alexis S. Pascaris et al. demonstrated the value-added effect of agricultural photovoltaic power generation in increasing the value of the solar industry through their study [27]. In contrast, studies conducted in Asian countries, with China as a case in point, have focused on factors such as transportation accessibility, population size, community configuration, and sociology, with a particular emphasis on sociological perspectives in scaling studies. To illustrate, Wang [28] used a combination of population, land area, and administrative boundaries to define the boundaries of the living area within the core of the capital. Sun et al. [29] utilized data sources such as GPS data and activity logs to quantify the daily behavioral life cycle from the perspective of residents' daily activities. Xiao et al. [30] developed an innovative approach for measuring and evaluating community living areas based on point-of-interest data and the decision tree principle. Suo et al. [31] analyzed the travel characteristics of residents using public bicycle swipe card data, which they then used as the basis for measuring the boundaries of the community living circles. In their study, Peng et al. [32] examined the daily activity range and material information in the surrounding area of the community. They carried this out by analyzing the cell phone signaling and map POI data of the residents. Based on this analysis, they were able to identify and measure the scale of the living circle based on the travel paths of the residents. Chen [33] analyzed the boundary of the living area from the perspective of land use planning by using the combination of "land use scale, willingness to travel". Finally, Tian et al. [34] proposed a form of urban unit management from the perspective of urban morphology, which transformed the city into a "city on a unit". A bibliometric analysis, scale centrality analysis, and a comparative analysis of the East–West scale research focus revealed a deficiency in productive research on scale and a lack of research on scale links in productive research. All of these approaches consider the community as the object of research and progress linearly in their respective fields.

The relationship between productivity, scale, and community is illustrated in Figure 2B. In order to achieve this, it is necessary to re-establish the linkage between productive and scale research. This will ensure that community, scale, and productive research are interconnected, and that the construction of green productive community units can be advanced in a multifaceted and integrated manner. The unit building process is depicted in Figure 2A.

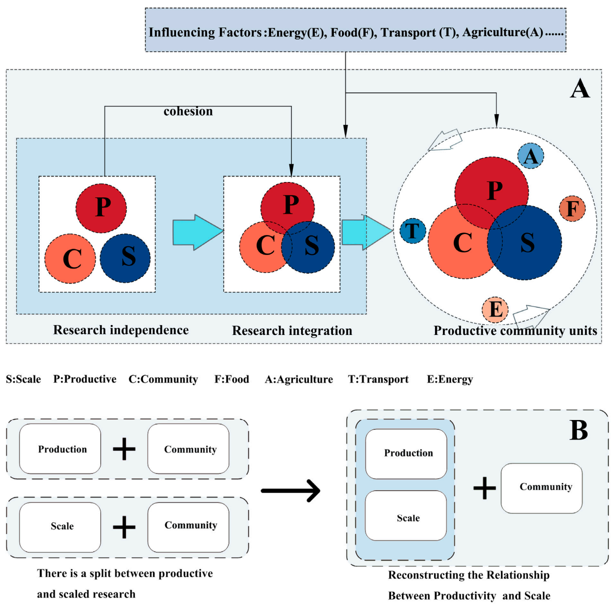

Figure 2. The relationship between productivity, scale (**A**), and community research in the process of constructing green productive community units (**B**). Source: author. Note: factors such as energy, transportation, and agriculture are interconnected and function collaboratively at the community and productive scales. Additionally, these factors may also be factors of other variables such as economics, politics, culture, climate, etc.

The complete green productive community unit should be a complex system that encompasses the integration of productive, scale, and community studies. In this state, it is constrained by energy, transportation, commercial, and agricultural factors. The constraints arise from two aspects, one of which pertains to the concept of productive cities. In 2018, Zhang et al. [9] proposed that productive cities must organically integrate factors such as energy production and agricultural production. The second aspect is that many studies of cities and neighborhoods combine factors such as commerce (including small residential services) and transportation [35,36]. Therefore, this paper integrates these four aspects.

2.1.3. Building a Green Productive Scale Research Process

The majority of contemporary research models on community unit scale are relatively homogeneous, with most studies focusing on optimizing community unit facility configurations. According to related scaling research papers [29–33], it can be summarized as the n + X model. Examples of such combinations include (A + X, T + X, E + X, R + X, etc.), where A/T/E/R represent various sectors of community development, including agriculture, transportation, energy, waste utilization, and other related fields. Here, X stands for public service facilities. Some studies have proposed an optimization system for public service facilities based on community self-sufficiency [37], which to some extent involves the concept of green productivity. However, it is essentially the optimization of the functional system of community facility allocation from a sociological perspective and does not prioritize scale as the focus of its research. This paper takes the scale based on the concept of green productivity as its starting point. It integrates energy, transportation, agriculture, and other elements to construct the green production community unit. Its overall research formula is as follows:

$$\text{T (Transportation)} + \text{E (Energy)} + \text{A (Agriculture)} + \text{R (Waste reuse)} + \ldots + \hat{x}.$$

where $\hat{x}$ stands for green productive service facilities.

2.2. Green Productive Community Unit Scale Construction

In the construction of a green productive community unit scale with $\hat{x}$, the classification of related green productive facilities is not sufficiently clear. Therefore, this paper firstly reclassifies the related service facilities and then proceeds with the construction of a green productive community unit scale.

2.2.1. Basis for Classification of Facilities

Public service facilities refer to a variety of facilities that provide public service products to the community. Currently, these facilities are categorized in a diverse way [38–43], and the outcomes resulting from the classification based on different principles vary significantly. In this paper, we classify service facilities into three groups based on the principles of green productivity and distributed production: production, living, and auxiliary facilities.

2.2.2. Data Collection

In this section, data on the scale of facilities in the three fields of energy, transportation, and comprehensive services is collected and sorted. This is followed by the delineation of the grid of facility services and the construction of a reasonable scale of green productive community units based on the distribution law of facilities.

Principles of Collection

(1) Scale constraints: Given that this study is focused on the community unit level, the data collection was concentrated within a radius of 0–1.5 km [44]. The data collection

was limited to the three areas of energy, transport, and integrated services facilities, with a specific focus on the radius of facility services data.

(2) Classification by type: Statistical categorization is based on the guidelines provided by the National Bureau of Statistics of China in the "Statistical Classification of the Production Service Industry" [45] and "Statistical Classification of the Living Service Industry" [46] for distinguishing between production and living service sectors. Among them, decentralized wind power, distributed power generation facilities, public refueling and gas filling stations, biomass conversion stations, tram charging stations, cogeneration stations, farmers' markets, marketplaces, renewable resource recycling stations, cultural activity stations, community service stations, and water supply facilities are categorized as production facilities. Small shops, motorized and non-motorized car parking lots, gas regulating stations, fresh food supermarkets, urban low-voltage distribution stations, fitness activity grounds, and other facilities are categorized as living facilities. Furthermore, community management services, resource recycling facilities, and other facilities that are significantly impacted by traffic factors and are not directly linked to residents' lives are uniformly classified as auxiliary facilities. The specific classification results are presented in Table 2.

Table 2. Classification results. Source: author[2].

Facility Type	Energy/Transportation/Integrated Services	Name of Facility	Service Radius	Data Sources
Production facilities	Energy	Distributed Wind Power	>20 km	[47]
		Distributed Generation Facilities	Full coverage	[48]
		Cogeneration Stations	>1.5 km	[49]
		Biomass Conversion Stations	>1 km	[50]
		Recycling Stations	>1.5 km	[51]
	Transportation	Public Refueling Stations	<1.5 km	[52]
		Trolley Charging Stations	>1.5 km	[53]
	Integrated services	Farmers' Markets	<1 km	[54]
		Productive Goods Distribution Centers	3–4 km	[55]
		Marketplaces	<1.8 km	[56]
		Water Supply Facilities	<0.5 km	[57]
Living facilities	Energy	Urban Low-Voltage Distribution Stations	<0.3 km	[48]
		Liquefied Petroleum Storage and Distribution Stations	≤0.5 km	[55]
		Gas Regulating Stations	0.5 km	[58]
	Transportation	Motor Vehicle Parking Lots	<0.15 km	[59]
		Railway Stations	0.8 km	[52]
		Public Transportation Stations	0.5 km	[52]
		Trolley Charging Stations	≤0.5 km	[60]
		Bicycle Parking Lots	<0.1 km	[59]
	Integrated services	Small Shops	<0.3 km	[55]
		Fresh Food Supermarkets	300 m	[58]
		Living Goods Distribution Centers	2–3 km	[55]
		Public Restrooms	<0.15 km	[61]
		Outdoor Fitness Activity Grounds	≤0.3 km	[58]

Table 2. *Cont.*

Facility Type	Energy/Transportation/Integrated Services	Name of Facility	Service Radius	Data Sources
Auxiliary facilities	Energy	--	--	--
	Transportation	Garbage Collection By Motorized Vehicles	<2 km	[58]
		Garbage Collection by Human Power	0.4 km	[58]
		Domestic Garbage Transfer Stations	>10 km	[62]
		Domestic Garbage Collection Points	<0.1 km	[63]
	Integrated services	Cultural Activity Stations	<0.5 km	[64]
		Community Service Stations	<0.3 km	[58]
		Community Service Stations (Street Level)	$\leq$1.0 km	[58]

Classification Results

The specific categorization results of public service facilities following the categorization of production, living, and support facilities (Table 2).

A Special Note Is Required

(1) Facilities such as farmers' markets and marketplaces that are directly related to the trading and circulation of green factors of production, such as urban agriculture, are categorized here as integrated community service facilities. This classification is due to their inseparable connection to integrated community services.
(2) The decentralized deployment of wind power, distributed across communities and peri-urban areas, is more closely aligned with the needs of the population and is better suited to the sustainable development of green and productive community units. There are already mature applications such as the Butendieks Community Wind Farm and the Community Wind Farm in Hilchenbach, Bonn [65]. Consequently, these factors are incorporated into the data collection process.

2.2.3. Facility Gridding

In order to facilitate the visualization of the clustering of facility-scale data and to inform the subsequent construction of green productive community unit scales, after categorizing facilities in the areas of energy, transport, and integrated services into production, living, and auxiliary facilities, three grids for production, living, and auxiliary were created with the community service station (a working platform for the extension of the government's public services to the community) as the central point.

Production Grid

With regard to the production grid, once the various scales of productive facilities have been coordinated and sorted, the distribution pattern of energy, transport, and integrated services can be expressed as follows (Figure 3A):

(1) Area $\leq$ 0.3 km: The distributed generation facility represents the core of the system.
(2) Area $\leq$ 0.5 km: Water supply facilities serve as the core infrastructure, enabling the efficient deployment of distributed generation facilities.
(3) Area > 0.5 km: Within this area, farmers' markets, marketplaces, public petrol and gas filling stations, tram charging stations, cogeneration stations, recycling stations, and biomass conversion stations are the core facilities. Additionally, distributed power generation and water supply facilities can be optimized.

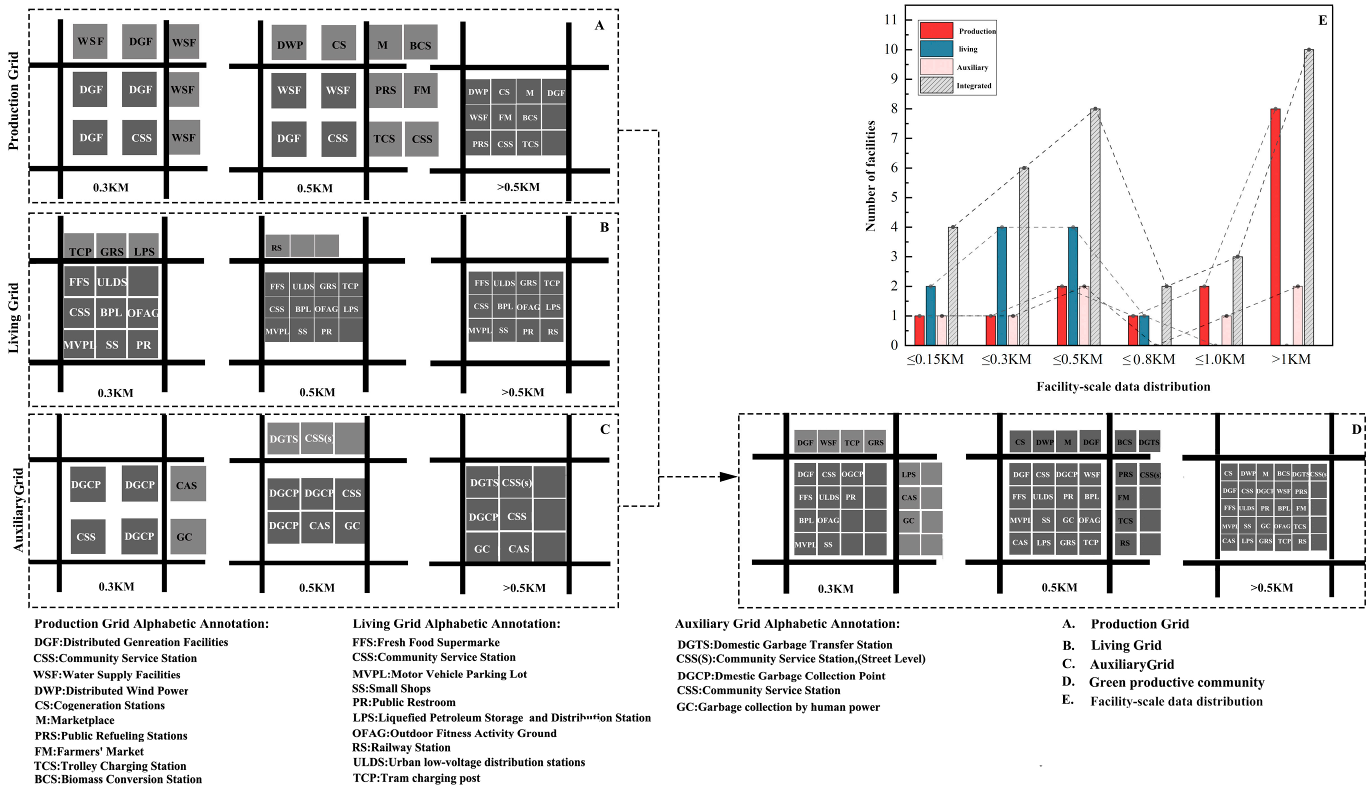

Figure 3. Facility gridding. Source: author. Note: The letters within the grid in the figure represent different types of facilities. The number of facilities within the cells will be quantified in subsequent studies using Geographic Information Systems (GIS) and other technologies.

The core grid size of the production grid was determined to be 0.5 km, based on the degree of clustering of their facilities, as illustrated in Figure 3E.

Living Grids

Utilizing the identical production grid division methodology, the classification of energy, transport, and comprehensive service facilities into the living category was carried out as follows (depicted in Figure 3B):

(1) Area ≤ 0.3 km: The main core facilities within this area include low-voltage power distribution, a small shop, an outdoor fitness activity area, motorized and non-motorized car parking lots, and public toilets.
(2) Area ≤ 0.5 km: The primary facilities in this area include gas pressure regulation stations, oil storage and distribution stations, public transport stops, tram charging stations, and more. Additionally, it is feasible to allocate amenities such as low-voltage distribution stations, small shops, public toilets, outdoor fitness areas, motorized/non-motorized parking lots, and other facilities within this area.
(3) Area > 0.5 km: The core facilities in this area are mainly rail-based, while the 0.3 km and 0.5 km areas can also be realized with a reasonable distribution of facilities.

Following the coordination and sorting of the various amenity sizes, and considering the degree of amenity clustering shown in Figure 3E, the living core grid size is determined to be between 0.3 and 0.5 km.

Auxiliary Grids

By categorizing the auxiliary nature of energy, transport, and integrated service facilities, the distribution pattern of auxiliary facilities can be expressed as follows (shown in Figure 3C):

(1) Area ≤ 0.3 km: Community service stations and domestic refuse collection points are the core facilities in this area, which is a densely populated area where residents mainly travel by foot.
(2) Area ≤ 0.5 km: The cultural activities station and the manpower collection and transfer station represent the core facilities within this area. It is still possible to realize a reasonable arrangement of community service stations and domestic waste collection points within this area.
(3) Area > 0.5 km: The core facilities in this area include domestic waste transfer stations, recycling stations, and community service stations (street level), in addition to a reasonable distribution of ancillary facilities within 0.3 km and 0.5 km of the area.

Following the coordination and sorting of the various auxiliary facility sizes and the analysis of the degree of facility clustering (Figure 3E), the core size of the auxiliary grid was ultimately determined to be 0.5 km.

2.2.4. Green Productive Community Unit Construction

Once the facilities were divided into three distinct grids—production, living, and auxiliary—a green productive community unit was constructed by combining the three. The distribution pattern of facilities within the unit is illustrated in Figure 3D and can be defined as follows:

(1) Area ≤ 0.3 km: Within this area, it is possible to rationally arrange production, living, and auxiliary facilities such as distributed power generation stations, low-voltage power distribution stations, small shops, outdoor fitness activities, motorized and non-motorized car parking lots, public toilets, and domestic waste collection points.
(2) Area ≤ 0.5 km: Within this range, it is possible to rationally allocate production, living, and auxiliary facilities such as water supply facilities, cultural activity stations, manpower collection and transfer stations, gas regulation stations, oil storage and distribution stations, public transport stations, tram charging piles, etc., while also allowing for the rational allocation of facilities within a range of 0.3 km.
(3) Area > 0.5 km: Within this range, it is possible to achieve a rational distribution of production, living, and auxiliary facilities, including farmers' markets, marketplaces, public refueling and gas filling stations, tram charging stations, cogeneration stations, renewable resource recycling stations, biomass conversion stations, railways, domestic rubbish transfer stations, transport stations, community service stations (at the street level), etc. Additionally, a rational distribution of facilities within a range of 0.3 km and 0.5 km can also be achieved.

By comprehensively analyzing the distribution patterns of production, living, and auxiliary facilities, as well as the degree of agglomeration of various types of facilities within different areas (Figure 3E), it can be seen that the degree of agglomeration of facilities is higher within a 0.5 km radius centered on community services, and therefore the size of the green and productive community unit is initially defined as 0.5 km.

2.3. Secondary Optimization of Community Unit Scales

In order to enhance the development potential of the green productive community units and make them more feasible in various regions, a secondary optimization of the unit scale is carried out here to refine the dimensions of the green productive community units.

2.3.1. Scaling Quadratic Optimization Based on Fractal Theory

Fractal theory was first proposed by B. B. Mandelbrot, a prominent mathematician, in his early studies of cities [66]. In the contemporary era, it has become a crucial component of research on self-organizing cities within the field of urban planning [67]. The morphology and structure of cities may initially seem to lack discernible rules; however, upon closer examination, they reveal underlying self-similar principles. Batty et al. conceptualized the city as a fractal entity and investigated its form, structure, growth, and evolution through the lens of fractal theory [68]. The fractal theory suggests that urban development is characterized by fractal properties, which manifest in various aspects such as the built environment, architectural details, structural units, and the overall spatial configuration of the city. Since the rise of modernism in the 20th century, this complexity has started to be rejected, and the fractal structure of the city has been destroyed. Reinventing the fractal structure of cities is of great practical significance in promoting the sustainable development of community units and cities. This paper introduces fractal theory with the aim of restructuring the fractal structure of the "community-city" at the spatial level of the community unit. This will enable the green production unit to intervene in urban governance in a more reasonable way, thereby enhancing its sustainability and appeal.

A 500 m Fundamental Fractal Unit

As demonstrated in existing research on urban planning, the fundamental unit of a fractal should adhere to the principles of a small-scale and multi-level organization while enhancing the rationality of urban and community resource allocation.

From the perspective of urban development history, the scale of urban living units has undergone a transformation from small to large and then back to small, during which small-scale units were particularly prevalent [69]. For instance, the scale of the Barcelona Superblock is controlled at 110 m × 110 m, the Melbourne neighborhood is controlled at 100 m × 200 m, and the TOD model of New Urbanism in the US has the longest length of a single side controlled at 183 m. In cities with high vitality and livability, small-scale development patterns are common [70].

From a fractal perspective, it can serve as a diagnostic tool, aiding in the identification of functional regional spaces, including the scope of urban sprawl and access to facilities [71].

From the perspective of scales suitable for fractals, as demonstrated in the study by Liang et al., cells that incorporate multiple human-scale features and various levels in their layout are more suitable for applying fractals [72].

In this paper, by analyzing the degree of clustering of the facility-scale data (Figure 3E) it can be observed that the service area of the facility is primarily around 500 m. This scale aligns with the principle of a small scale that is necessary for fractals and is consistent with the scales commonly used in urban planning practices. Therefore, 0.5 km is chosen as the initial unit for fractal analysis. In order to enhance the green productive community unit, which can also be implemented at a micro scale, the 0.25 km unit is subdivided from the 0.5 km unit based on the size of the residential neighborhood[3].

Feasibility of Implementing Fractal Combinations at the Macro Level

The 500 m units can be combined with the fractal 250 m units to enhance the flexibility and feasibility of implementing the green productive units. These units can be combined in various ways depending on the area. The main combination methods include 250 m with 250 m, 250 m with 500 m, and 500 m with 500 m. Specific combination methods are illustrated in Figure 4.

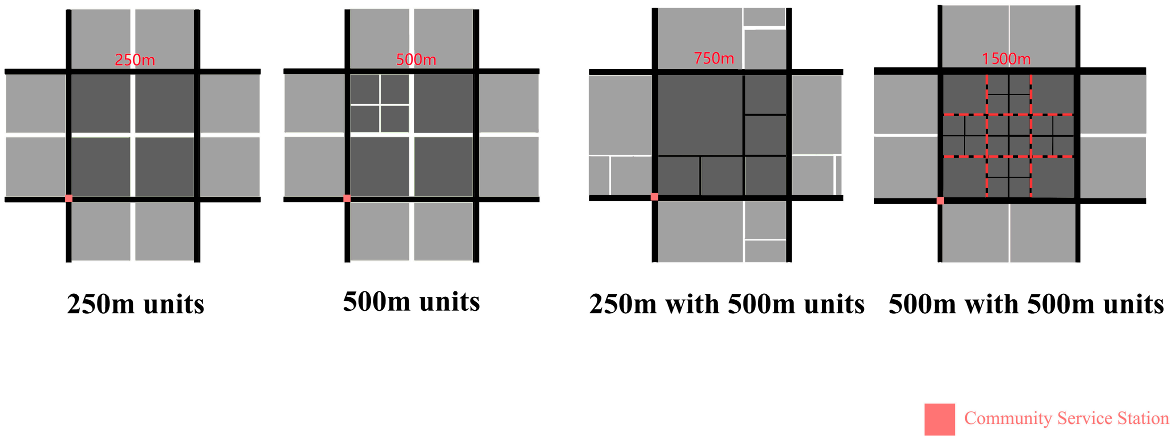

Figure 4. Fractal unit combination mode. Source: author.

2.3.2. Secondary Optimization Based on Community Management Units

The above fractal optimization primarily focuses on the spatial distribution of facilities. However, the efficient and smooth operation of a community is inextricably linked to rational management. Therefore, it remains to be determined whether this fractal structure can be equally applied at the management level in terms of community management. The current grass-roots community management in China consists of two main elements: spatial planning and administrative management. In terms of spatial planning, a three-tier spatial structure system is established based on the region's different scales, including streets, residential communities, and residential districts. Regarding social management, a three-tier system of management units is organized based on varying scopes of management, comprising street offices, community neighborhood committees, and residents' groups [44].

At present, the practice of fundamental management units in Shanghai has matured. The size of the management unit is specified in the "Shanghai Municipality on the promotion of the implementation of the views on the implementation of the fundamental management unit of the real" notice [74]. It adopts the 2 + 2 model, which means 20,000 people within an area of 2 square kilometers with clearly discernible regional boundaries. The service radius of the fundamental management unit is calculated to be approximately 750 m based on China's current per capita floor space of 36.15 square meters and a plot ratio not exceeding 2.5. This can be achieved by combining the 500 m unit with the 250 m unit derived from the fractals in Section 3.1. Consequently, the green productive community unit is also more flexible and feasible to manage.

Conclusion of the Optimization

In conclusion, the size of the green productive community unit is determined to be 0.5 km $\times$ 0.5 km, with an additional subunit of 0.25 km $\times$ 0.25 km.

3. Discussion

3.1. The Role of Green Productive Community Units for Urban and Community Development

The majority of existing studies typically start by identifying a specific factor that is thought to impact the growth of a community and a city, and then proceed to make adjustments to the current circumstances. In this paper, the green productive community units are constructed through the multi-factor integration of energy, transportation, and comprehensive supportive factors. This approach enhances the value of the renewal strategy at an integrated level in terms of urban development. Secondly, green productive community units and their auxiliary units can optimize the urban production structure system at the smallest level due to their small size, thus promoting urban transformation.

The development status of various cities varies, and their geographical characteristics differ as well. Consequently, the actual production units established may also vary, as multiple distinct production units may exist in a single city at the same time. Therefore, developing a model of production units that are suitable for local development, share certain commonalities, and can be replicated is an immediate concern that will enable rational interventions in the functionalities and structure of both the city and the community.

3.2. Advantages of Green Productive Community Units in Terms of Facility Configuration

Currently, facilities within existing community units in China are allocated based on a 1000-person target, which is less flexible and more influenced by average population growth or decline. In contrast, the facilities of green productive community units are designed based on self-sufficiency or the positive output of internal means of production. This allows the community units to be tailored to their own conditions, making them more balanced and sustainable.

3.3. Research Gaps and Future Plans

In this paper, we consider only a few aspects that affect the development of cities and neighborhoods. The final scale of green production units is presented as a desirable development model, excluding other external influences. The relationship between various production units and the quantitative allocation of resources within these units has not been thoroughly examined. Subsequent research will be conducted in two phases: a theoretical phase and technological phase. The theoretical phase will involve the development of green production unit models tailored to local conditions. These models will be customized for various regions, climatic zones, and countries to ensure they are suitable for local development. On the technical aspect, GIS technology (facility configuration), big data technology, and artificial intelligence (to develop a smart service platform) will be combined to explore the feasibility of green productive community units achieving self-sufficiency or even generating outputs through internal means of production. At present, GIS technology [75], smart platform [76] development technologies, and artificial intelligence [77,78] have established the foundation for the creation of adaptive, comprehensive, and intelligent production units.

4. Conclusions

The conclusions of this study on the community unit scale construction and configuration optimization oriented towards the concept of green productivity is summarized below.

4.1. Fundamental Formula for Community Unit Scale Construction

Firstly, an overview of existing scaling research methods is provided, leading to the conclusion that the current model of scaling research is the N + X model. Based on this, a methodological model for constructing the unit scale of a green productive community is proposed, namely (R + T + A/. . .) + X. This model reshapes the relationship between scale and productivity.

4.2. Scaling Data Distribution Patterns and Core Grid Delineation

After classifying the service facilities in the fields of energy, transport, and integrated services into production, living, and auxiliary categories, and after dividing the facilities into service grids, it has been concluded that there are differences in the clustering of service facilities at various scopes. For instance, production facilities show a greater aggregation within 0.3 km and beyond 1.0 km; living facilities demonstrate a greater aggregation within 0.3–0.5 km; and residential support facilities exhibit a greater aggregation within 0.3 km. The core scale of the various service grids is delineated based on the variability of the data aggregation. Following the integration of data on production, living, and support facilities, and the analysis of the clustering level of all facilities within various ranges (Figure 3E), it can be concluded that most facilities are clustered within a 0.5 km radius. Consequently, the initial scale of the green productive community unit is determined to be 0.5 km.

4.3. Fractal and Management Unit Optimization Results

At this juncture, the green productive unit scale represents the culmination of the data synthesis after classifying facilities. However, it is still uncertain whether this scale can be replicated at the micro or macro level. Therefore, a secondary optimization of the scale is required.

(1) Fractal optimization: In order to enhance the feasibility and flexibility of the green productive community unit, fractal theory is introduced in the optimization process, with 500 m used as the base to fractal downwards. To ensure the reasonableness of the fractal, according to the Chinese national standard GB/T 51328 [73], the 250 m unit (the maximum spacing between roads is 250 m) was implemented as a subunit of the 500 m unit fractal. The 250 m subunit can be used as a supplementary unit to the 500 m unit, and the combination of the two (as illustrated in Figure 4) allows for the application of the green community unit at different spatial levels.

(2) Management unit optimization: The fundamental management unit in Shanghai is taken as the standard, which has a population of 20,000 and covers an area of 2 square kilometers. Using the current average per capita building area of 36.15 square meters in China, and a plot ratio not exceeding 2.5, the service radius is estimated to be around 750 m. The aforementioned scale can be achieved through a combination of 500 m green productive community units and 250 m complementary units. It can be seen that the fractalized green productive community units have a greater potential for development at both the planning and management levels. Therefore, in this study, the fundamental scale of the green biogenic community unit was ultimately determined to be 0.5 km $\times$ 0.5 km, supplemented by a 0.25 km $\times$ 0.25 km unit.

The green production unit presented in this paper is an idealized model of a unit as previously described, focusing solely on community-level interventions within the city under current conditions. Subsequently, adaptive production units were developed based on the units constructed in this paper, considering the varying conditions of different regions (mountains and plains), distinct areas within cities (central and peripheral), and diverse climatic zones (arid and humid).Finally, these findings on green production units can be used to adjust the structure of cities at the macro level.

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Notes

[1] Functional to structural optimization refers to the transition from optimizing the local functional systems of existing cities and communities—such as the food system, energy system, and recycling processes—to rationalizing the internal functions of these areas by adjusting the overall production structure of the entire city or community. This includes the development of integrated systems, such as the food-energy-recycling system.

[2] The types of facilities are primarily classified according to the relevant standards set by the National Bureau of Statistics of China, except for community management services, resource recycling facilities, and other facilities significantly influenced by traffic factors and not directly related to residents' daily lives are uniformly categorized as auxiliary facilities. The scale data for the facilities are derived from Chinese national standards as well as various local standards. Some scale data may differ across these standards and are indicated here with symbols such as $>$ and $<$ and $\leq$ to ensure the accuracy of the idata.

[3] Residential neighborhoods are generally surrounded by roads, road spacing that is the length of residential neighborhoods, according to the national standard "urban integrated transport system planning standards" GB/T 51328 [73] requirements, the spacing between the road should be 150~250 m, in order to facilitate the fractal here to select the upper limit of 250 m as a modulus.

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