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Research on Promoting Carbon Sequestration of Urban Green Space Distribution Characteristics and Planting Design Models in Xi'an

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Abstract: Urban green space is considered to have a strong ecological function to alleviate urban climate change by absorbing carbon dioxide. Therefore, promoting carbon sequestration efficiency within a limited urban green space has become a practical problem that must be solved in urban sustainable development. This study proposed three high carbon sequestration plant design models and a high carbon sequestration plant list for low-carbon green space construction. Based on the research on the distribution and change of carbon sequestration in urban green spaces, combined with field surveys and remote sensing images, this study analyzed the main factors affecting carbon sequestration. The study showed that the carbon sequestration in urban green space showed a decreasing trend year by year with the change of forest structure, and this difference was mainly related to the characteristic factors of urban green space plant community: plant carbon sequestration was significantly positively correlated with DBH (diameter at breast height) and community density, significantly positively correlated with hierarchical structure, and positively correlated with canopy closure. In addition, we put forward a list of plants with high carbon sequestration, including *Styphnolobium japonicum, Salix babylonica, Pittosporum tobira, Spiraea salicifolia, Iris pseudacorus* , and put forward three kinds of green space plant design patterns in different green spaces and habitats, solved the difficult problem of high carbon-fixing plants design in low-carbon gardens, established the community structure pattern of high carbon-fixing plants which can be directly applied to practical projects, and explored the sustainable design approach of ecological process in low-carbon cities.

Keywords: urban green space; landscape design; carbon sequestration; plant community models

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1. Introduction

At present, global warming has attracted widespread attention, and the main cause of its occurrence—CO_2 emission has gradually become the focus of the world's attention, and "carbon neutrality" research has also become a current hot issue. According to the comprehensive assessment report of the Intergovernmental Panel on Climate Change (IPCC), anthropogenic greenhouse gas emissions from the use of fossil fuels are one of the main causes of global warming. Thomas et al., Root et al. integrated various climate prediction models and predicted that the global temperature will rise by about 1.4~5.8°C in the next 100 years, and this trend of climate change will be further intensified[1, 2]. From the perspective of carbon emissions, cities are the areas where human activities have the greatest impact on the surface[3-5]. Studies have shown that cities are the main body of carbon emissions[6], and carbon emissions in cities account for 90% of China's total carbon emissions. Urban greenhouse gas sources in China mainly include four parts: production

(44.5%), construction (19.8%), transportation (17.5%) and forest reduction (18.2%)[7]. There are two ways to reduce greenhouse gases: reducing carbon emissions and increasing carbon sequestration. Urban green space plays an irreplaceable role in low-carbon cities. Through rational and scientific planning, urban green space can not only indirectly reduce carbon emissions, but also greatly increase carbon sequestration, and form a cold island within the site to cool the surrounding environment[8].

As an important part of the urban ecosystem, urban green space plays an indispensable role in the carbon sequestration and oxygen release and microclimate regulation of the urban built environment[9-11]. First, urban green space is the only natural carbon sequestration in urban areas, and planting plants is the only carbon sequestration method that does not consume energy[12]. Secondly, urban green space can indirectly reduce emissions—through the rational planning of the green space, the overall energy consumption of the city can be reduced, and the effect of emission reduction can be achieved[13-15]. The carbon sequestration function of urban green space mainly depends on the vegetation and soil in the green space to absorb and store CO_2, among which vegetation has a strong adsorption effect on CO_2, and the carbon sequestration capacity of different plants is very different[7, 16]. In addition to the great influence of plants on carbon sequestration, the spatial pattern of urban green space also has an impact on carbon sequestration. According to research, through rational layout and scientific planning of urban green space pattern, green space can absorb and store carbon dioxide ~~emissions~~ generated by nearby buildings and traffic, and reduce carbon emissions accordingly[14, 17, 18]; In addition, the rational layout of green space makes residents' lives more convenient, using less private vehicles and more use of public transportation or walking, which can also greatly reduce urban carbon emissions. The research on the carbon sequestration benefit of urban green space is still improving[19], and the indicators selected for research at different scales are not the same[20]. In order to further quantify and increase the benefits of green space carbon sequestration, quantitative analysis using software model technologies such as ArcGIS, Envi, and i-Tree has become a trend in the research field of related disciplines[21-25]. However, in the current urban built environment, most of the urban green space is distributed in small fragments, and the problems such as unreasonable vegetation structure make it unable to exert its original carbon sequestration value. Therefore, how to rationally distribute the spatial pattern of green space and improve the carbon sequestration efficiency and ecological value of green space within a limited urban area has become the focus and difficulty of current research.

In the urban environment, plant carbon sequestration are the main source of carbon sequestration in urban green space, and also the main component of urban carbon sequestration. Urban green space plants can absorb a large amount of CO_2 through photosynthesis. Therefore, studying carbon sequestration by urban plants is an important means to alleviate the urban heat island effect[26]. Studies have shown that Beijing's forests and garden plants can absorb 71.308 million tons of carbon dioxide every year, accounting for 53.2% of Beijing's total carbon dioxide emissions[27]; Urban plant carbon sequestration accounts for 1.2% to 11.9% of Finland's total CO_2 emissions[28]; Hangzhou's urban forests offset 18.57% of the carbon emissions of industrial enterprises annually through sequestration[29]; Street trees on the boulevard can offset the CO_2 emissions of about 14 residents from traffic-related activities[13]. In addition, plant communities with different structures also have an important impact on carbon sequestration, and the study of plant communities with high carbon sequestration can fill the gaps in current research[30]. Based on the previous research on plant carbon sequestration, how to transform high carbon sequestration plant community research into design language through scientific planning and design, use plant planting design to improve and regulate urban microclimate and provide scientific basis for low-carbon urban green space planting design has become a practical problem to be solved urgently.

In Xi 'an, China, there was a lack of low-carbon awareness in the early urban planning process, and enough green space was not reserved, which led to a serious shortage of urban green space area and quality. With the rapid progress of urbanization in Xi'an, problems such as urban ecological imbalance and heat island effect have become prominent. However, promoting the carbon sequestration of urban green space and applying low-maintenance and sustainable planting strategies in actual project practice are still unsolved practical problems. Therefore, this study takes Xi'an as an example, through the method of field measurement and remote sensing simulation, to understand the distribution of carbon sequestration in Xi'an in recent years, and to propose the allocation strategies of low-carbon plants in different green spaces. It mainly includes: (1) Estimating and mapping the temporal and spatial distribution of carbon sequestration in Xi'an in recent 20 years and analyzing the reasons for its changes; (2) Quantitatively study the carbon sequestration benefits of plant communities in green spaces, and analyze the relationship between plant community structure and carbon sequestration; (3) Optimizing the high-carbon sequestration configuration of the plant community in the existing green space, and proposing the design mode and strategy of plant planting to effectively improve the carbon sequestration capacity of the green space. This study was carried out in different urban green spaces in Xi'an, and the results will be instructive for other green spaces planned in the future. It will provide theoretical support and technical guidance for urban green space planning and design and ecological construction in Xi'an, and also provide new ideas for promoting the construction of low-carbon gardens in Xi'an and alleviating the heat island effect.

2. Materials and Methods

2.1. Study sites.

Xi 'an is an important city in northwest China. The coordinate range is 107°40′-109°49′E, and the north latitude is 33°39′-34°45′N. It is located in the middle of Guanzhong Plain area, with temperate semi-humid continental monsoon climate and four distinct seasons. The average annual frost-free period is 226 days. The average temperature in January is 0.4℃, that in July is 26.6℃, and the annual average temperature is 13.3℃. The annual average precipitation is 613.7 mm and the annual average humidity is 6.96%. The altitude is 410-420m. By December 2021, the administrative area of Xi 'an is about 10,752 square kilometers, and the built-up area is 700.69 square kilometers.

2.2. Remote sensing data.

According to the geographic strip number of Xi 'an, the remote sensing images with a resolution of 30m were obtained from China Geospatial Data Cloud (http://www.gscloud.cn/), and the radiometric calibration, atmospheric correction, image mosaic and clipping and unsupervised classification were carried out, and finally four land use type maps of Xi 'an in recent ~~20 years~~ were obtained. (Figure 1).

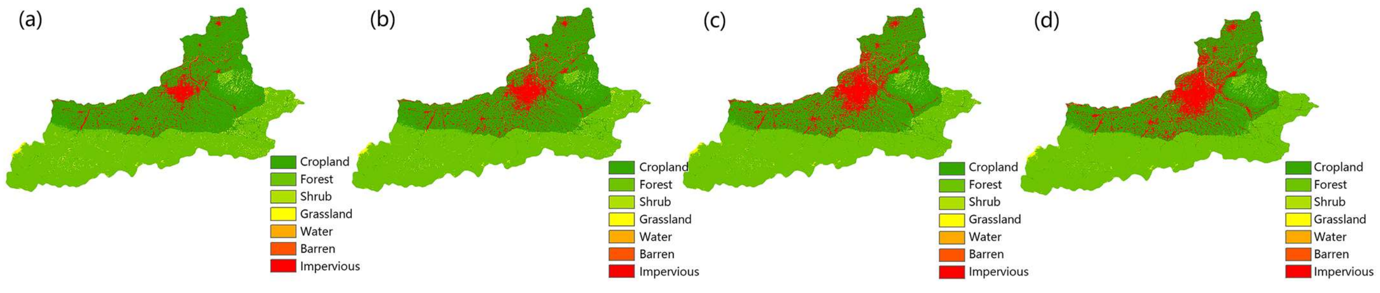


Figure 1. Map of land use types in Xi 'an in (**a**) 2000, (**b**) 2007, (**c**) 2014 and (**d**) 2019.

2.3. Quadrat selection and data estimation.

The study selected Xingqing Park (Site A) in Xi'an City and Kangding Garden (Site B) in Fengxi New City as sample plots, which are located in the old and new urban areas of Xi'an City respectively. In this study, in site A and site B, 20×20m arbor, shrub and grass quadrats and 1×1m ground cover plants quadrats were selected for recording (Figure 2). On the basis of systematic investigation, this study monitored 64 representative plant individuals of different types in Xi 'an urban green space. Using portable leaf area meter (CI-203), photosynthesis meter (LI-6400), DBH tape measure, infrared altimeter and tape measure, the following information of each plant in the sample plot was measured and recorded: leaf area index, net photosynthetic rate and DBH (diameter at breast height). The monitoring was carried out from September 2020 to September 2021 on sunny, windless, natural light days, from 8:00 am to 6:00 pm, performed every 2 hours to ensure that near maximum heliostat rate is measured[31].

(**a**)

(**b**)

Figure 2. Location of survey plot and selection of quadrat. (**a**) The location of quadrats in site A; (b) The location of quadrats in site B.

The daily net assimilation, daily average photosynthetic rate and daily carbon sequestration and oxygen release of the tested plants were calculated by the following formulas.

$$P = \sum_{i=1}^{i} [(p_{i+1} + p_i)/2 \times (t_{i+1} + t_i) \times 3600/1000] \quad (1)$$

In the formula (1), P is the daily assimilation amount per unit area (mmol/m²); Pi is the instantaneous photosynthetic rate of the initial measurement point (m²), Pi+1 is the instantaneous photosynthetic rate of the next measurement point (μmol/m²/s); ti is the time of the initial measurement point(h), ti+1 is the time of the next measurement point (h).

$$w_{co2} = P \times 44/1000 \quad (2)$$

In the formula (2), 44 is the molar mass of CO_2; w_{CO2} is the fixed mass of CO_2 per unit area of the blade (g·m-2·d-1). According to the reaction equation of photosynthesis:

$$CO_2 + 4H_2O \rightarrow CH_2O + 3H_2O + O_2 \quad (3)$$

The mass of oxygen released by the plant on the measurement day can be calculated as:

$$w_{o2} = P \times 32/1000 \quad (4)$$

The formula for calculating the carbon fixation and oxygen release of the whole plant is:

$$W_{co2} = w_{co2} \times LAI \times C \quad (5)$$

$$W_{o2} = w_{o2} \times LAI \times C \quad (6)$$

In the formula, w_{CO2} and w_{O2} are the daily carbon fixation and oxygen release per unit area, respectively; W_{CO2} and W_{O2} are the daily carbon fixation and oxygen release of the whole plant, respectively; LAI is the leaf area index; C is the crown area.

2.4. Simulation method of carbon sequestration data.

After the remote sensing images were preprocessed, InVEST was used to further simulate the temporal and spatial changes and trend analysis of carbon sequestration in Xi'an in 2000, 2007, 2014 and 2019. By simulating plant carbon sequestration and soil carbon sequestration in different years, the temporal and spatial trend of carbon sequestration in Xi'an and its main influencing factors were analyzed. The total terrestrial carbon sequestration includes plant carbon sequestration and soil carbon sequestration. Plant carbon sequestration is further divided into plant aboveground carbon sequestration, underground carbon sequestration and dead organic carbon sequestration.

3. Results

3.1. Analysis of carbon sequestration changes in Xi'an area in the past two decades

The results show that urban carbon sequestration is mainly composed of plant carbon sequestration and soil carbon sequestration. Plant carbon sequestration includes aboveground carbon sequestration, underground carbon sequestration and dead organic carbon sequestration. Plant aboveground carbon stock is the amount of carbon in aboveground biomass, including the carbon stock of all living plants above the soil, and it determines the productivity level of an ecosystem. Underground carbon sequestration is the amount of carbon in underground biomass, which is the carbon sequestration in plant roots corresponding to aboveground biomass, and it can reflect the change trend of aboveground carbon sequestration. Dead organic carbon sequestration is the amount of carbon stored in dead microorganisms, such as carbon dioxide stored in dead branches and leaves, rotten wood, etc. Soil carbon sequestration is the carbon dioxide distributed in organic soil and mineral soil, which is the core part of carbon sequestration. Small changes of soil carbon sequestration will affect a large amount of carbon loss. As the core of urban total carbon sequestration, soil carbon sequestration directly affects the terrestrial carbon uptake and sequestration, and plays an important role in the circulation of carbon elements in the ecosystem.

The research shown in Figure 3 shows that: first, the plant carbon sequestration showed an overall upward trend from 2000 to 2019, but the carbon sequestration density decreased year by year. The plant carbon sequestration density reached the maximum value in 2000 and the minimum value in 2019. At the same time, the woodland area in these four years was 50.91ha, 50.20ha, 48.73ha, 47.36ha, respectively. Therefore, there was a significant correlation between plant carbon sequestration and forestland area, that is, plant carbon sequestration increased with the increase of woodland area. However, the extent of carbon growth along with the urban green space is small, from 2007 to 2019, urban green space area is expanding continuously, the explosive growth in 2014-2019, but carbon built in the city is not very big improvement. Second, according to the research results, the change trend of soil carbon sequestration is as follows: it increased rapidly from 2000 to 2007, and increased slowly from 2007 to 2019. By comparing soil carbon sequestration and land use types in four years, soil carbon sequestration is closely related to land use types. From 2014 to 2019, the area of construction land increased rapidly, and the corresponding area of forestland and farmland decreased exponentially, so the soil carbon sequestration efficiency decreased. Third, the change trend of total carbon sequestration is basically similar to that of soil carbon sequestration. The distribution of total carbon sequestration has changed greatly in the past 20 years. The carbon sequestration density in the main urban area of Xi 'an decreases with the increase of construction land, while the carbon sequestration of forest land in the south of the Qinling Mountains does not change much, which is still a good natural carbon pool in Xi 'an.

Chen's study estimated CO_2 emissions and carbon sequestration of land vegetation in 2,735 counties in China[32]. According to the research results (Figure 3), since 1997-2017, Chang'an District has the largest carbon emission in all districts and counties in Xi'an, which reached 8.28 million tons in 2014; followed by Weiyang District, which reached 7.19 million tons in 2013, Beilin District and Xincheng District have the smallest carbon emissions. The comparative analysis shows that the carbon sequestration and carbon emissions in the main urban area of the city are smaller than those in the suburban areas. This may be due to the dense construction and population in the main urban area of the city, and carbon emissions mainly come from transportation and building carbon emissions, while there are many factories in the suburbs of the city, which generate a large amount of carbon emissions. In addition, the suburbs of cities are adjacent to urban forests, which contribute significantly to carbon sequestration.

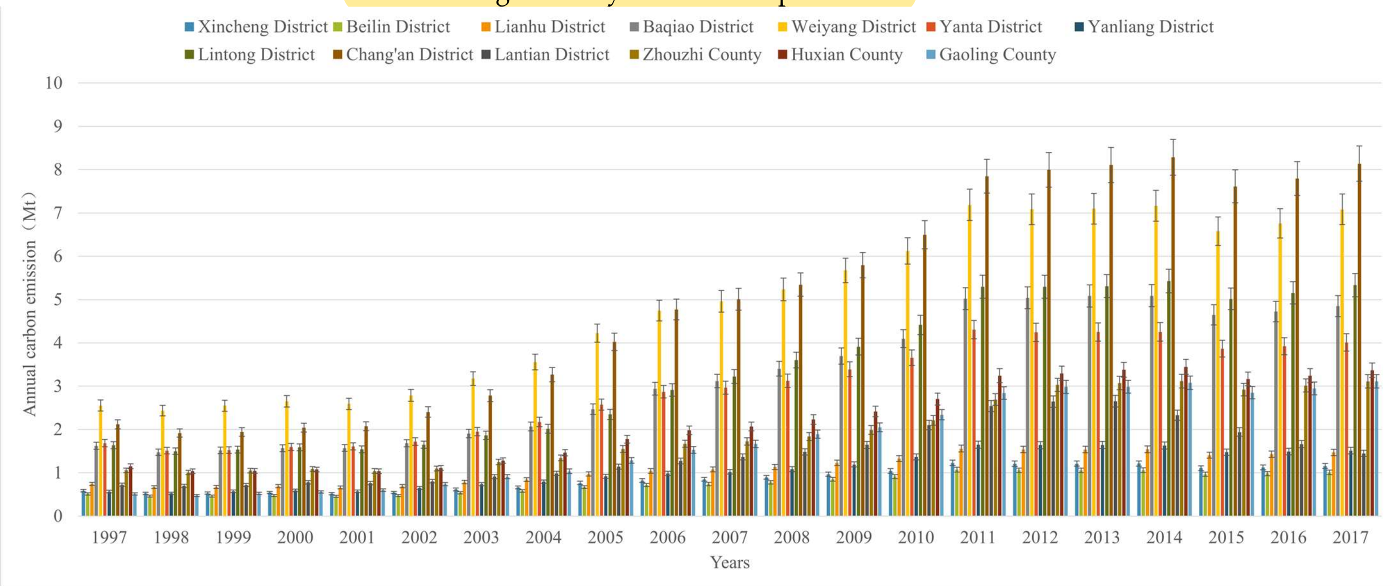


Figure 3. Carbon sequestration and carbon emission values of all districts and counties in Xi 'an.

3.2. Distribution and variation characteristics of carbon sequestration in urban green space in the study area

Overall, the total carbon sequestration of forest land, shrub and cropland is the highest, while the total carbon sequestration of water, construction land and bare land is lower (Figure 4). Combined with the change trend of land use types, it can be seen that the carbon sequestration within the urban built environment of Xi 'an has changed obviously (the construction land in the south of the city), while the carbon sequestration in the forest land and cropland has little change (most areas in the north of the city). The changes of aboveground carbon sequestration and underground carbon sequestration are similar, and the higher carbon sequestration of dead organic matter is mainly in forest land and cropland. The change of carbon sequestration changes with the change of forest land, that is, the most important plant carbon sequestration source in forest land, which has a direct impact on this part of carbon sequestration. In addition, it can be found that the carbon sequestration of plants was the highest in 2000 and the lowest in 2019. The overall carbon sequestration showed a decreasing trend, and the change of land use type had a direct impact on the change of carbon sequestration.

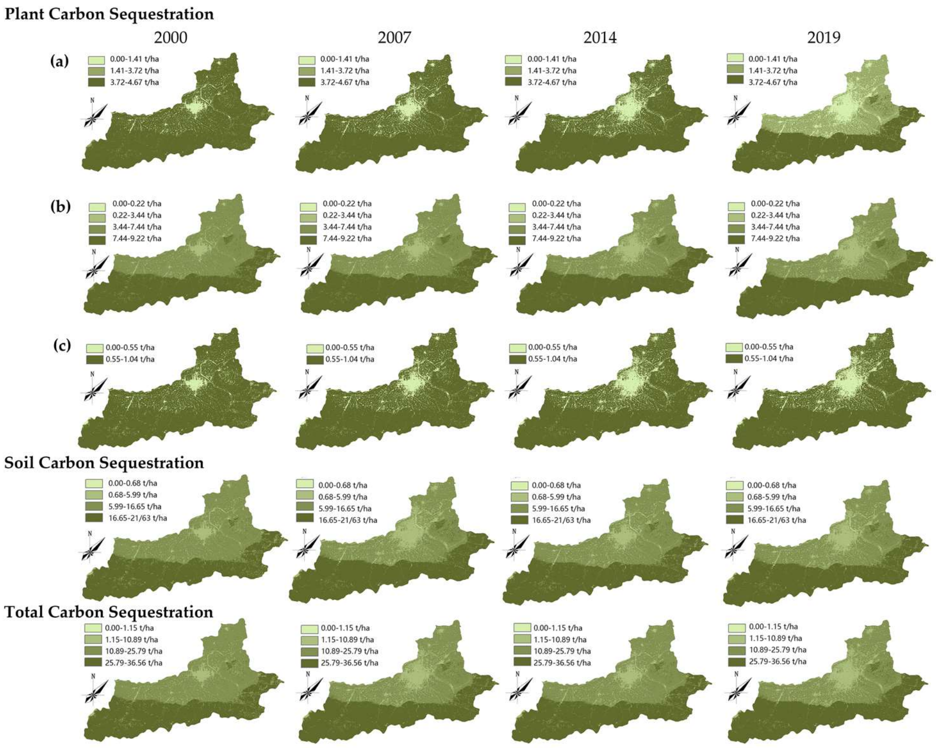


Figure 4. Carbon sequestration and carbon emission values of all districts and counties in Xi 'an. (a) Aboveground carbon sequestration of plants; (b) underground carbon sequestration of plants; (c) dead organics' carbon sequestration.

3.3. Heterogeneity of plants and habitats in the study area

Based on the previous research on urban macro-meso scale carbon sequestration, four types of green spaces were selected in the study area: dense woods (arbor-grass plant community), open woods (arbor-shrub-grass plant community), open green space (shrub-grass plant community) and square green space (ground cover plant community). The sites were distributed in the main urban area and the new urban area (Site A is located in Beilin district, Site B is located in Xixian New District) to try to study the key factors affecting carbon sequestration.

3.3.1. Type and size of plants under investigation

The species and stems of 64 plants belonging to 58 genera in 36 families were investigated (Figure 5), including 14 species of deciduous trees, eight species of evergreen trees, 10 species of deciduous shrubs, 10 species of evergreen shrubs and 22 species of herbs. The dominant species of deciduous trees in the study area are *Styphnolobium japonicum, Koelreuteria paniculata, Ulmus pumila and Ginkgo biloba*; the evergreen dominant species are *Ligustrum lucidum, Pinus tabuliformis and Pinus bungeana*; the shrub dominant species are *Nandina domestica, Pittosporum tobira and Buxus megistophylla*; and the herb dominant species are *Ophiopogon japonicus, Oxalis corniculata and Iris tectorum*. The results show that the most common species in the study area are *Styphnolobium japonicum 'Pendula', Ulmus pumila, Paulownia fortunei* and *Styphnolobium japonicum*, and they are the dominant species. These are common afforestation tree species in Xi 'an, including native tree species and introduced tree species.

Figure 5. Photos of urban green space quadrats (quadrat A1-A6 from Site A, quadrat B1,-B2 from Site B)

3.3.2. Analysis of differences in carbon sequestration of investigated plants

The table 1 and table 2 shows the species and annual carbon sequestration (kg/hm²) of each measured plant, and the average values of different plant categories. It can be seen that different plants in the study area have different carbon sequestration capacity. The carbon sequestration of plants in the study area varies greatly, and the order of carbon sequestration capacity of urban green space plants in the study area is: deciduous trees > evergreen shrubs > deciduous shrubs > herbaceous plants. According to calculations, the annual average carbon sequestration of trees is about 60.29kg/hm², that of shrubs is about 8.43kg/hm², and that of herbaceous plants is 1.43kg/hm². The carbon sequestration of trees is much larger than that of shrubs and ground cover plants. In addition, there are differences in carbon sequestration between evergreen and deciduous plants due to differences in leaf area index and photosynthetic rate. Among the trees, *Platanus orientalis, Acer pictum subsp. mono, Acer buergerianum and Styphnolobium japonicum* have higher carbon sequestration capacity; among the shrubs, *Photinia×fraseri, Amorpha fruticosa, Pittosporum tobira, Nandina domestica* and *Ligustrum quihoui* have higher carbon sequestration capacity; among the ground cover plants, *Coreopsis basalis, Miscanthus sinensis 'Gracillimus', Oxalis corymbosa* and *Iris tectorum* have higher carbon sequestration capacity.

Table 1. Carbon sequestration of trees and shrubs in the study area

Plant species	**Annual carbon sequestration（kg/hm²）**	**Plant species**	**Annual carbon sequestration（kg/hm²）**
Deciduous plant		**Evergreens**	
Trees			
Platanus orientalis	178	*Photinia serratifolia*	125.19
Salix babylonica	141.07	*Magnolia grandiflora*	80.74
Koelreuteria paniculata	121.11	*Ligustrum lucidum*	64.86
Melia azedarach	114.76	*Juniperus chinensis 'Kaizuca'*	55.34
Ulmus pumila	100.7	*Pinus tabuliformis*	48.08
Celtis sinensis	96.16	*Osmanthus fragrans*	30.39
Styphnolobium japonicum	69.4	*Pinus bungeana*	19.50
Acer pictum subsp. mono	30.78	*Eriobotrya japonica*	7.59
Acer buergerianum	26.34		
Punica granatum	26.31		

Prunus cerasifera 'Atropurpurea'	11.34		
Acer palmatum 'Atropurpureum'	7.71		
Prunus davidiana	6.35		
Acer palmatum	2.60		
Mean value	**66.62**	**Mean value**	**53.96**
	Shrubs		
Lonicera maackii	16.73	*Rosa (Floribundas Group)*	23.49
Rosa xanthina	11.08	*Nandina domestica*	17.65
Kerria japonica	10.58	*Photinia × fraseri*	14.12
Spiraea salicifolia	10.29	*Pittosporum tobira*	10.85
Chimonanthus praecox	8.73	*Ligustrum quihoui*	10.05
Forsythia suspensa	7.33	*Buxus bodinieri*	9.72
Ligustrum sinense	6.26	*Buxus sinica var. parvifolia*	6.39
Jasminum nudiflorum	6.11	*Buxus megistophylla*	5.34
Amorpha fruticosa	1.18	*Juniperus procumbens*	0.30
Weigela florida	0.62	*Pyracantha fortuneana*	0.25
Mean value	**7.89**	**Mean value**	**8.97**

Table 2. Carbon sequestration of herbaceous plants in the study area.

Plant species	**Annual carbon sequestration（kg/hm²）**	**Plant species**	**Annual carbon sequestration（kg/hm²）**
Iris pseudacorus	10.13	*Miscanthus sinensis*	0.63
Physostegia virginiana	4.32	*Ophiopogon japonicus*	0.52
Carex giraldiana Kukenth	2.62	*Coreopsis basalis*	0.38
Zephyranthes candida	2.56	*Lolium perenne*	0.32
Stipa lessingiana	2.30	*Fatsia japonica*	0.27
Iris tectorum	1.37	*Dianthus plumarius*	0.25
Miscanthus sinensis 'Gracillimus'	1.23	*Ophiopogon bodinieri*	0.23
Pennisetum alopecuroides	1.12	*Pennisetum alopecuroides 'Little Bunny'*	0.20
Oxalis corymbosa	1.02	*Arundo donax 'Versicolor'*	0.11
Juncus effusus	0.91	*Cynodon dactylon*	0.09
Hedera nepalensis var. sinensis	0.86	*Poa annua*	0.04
	Mean value 1.43		

3.3.3. Analysis of differences in carbon sequestration of investigated plants communities

According to the field monitoring data, the highest carbon sequestration in the site is quadrat A1, and the annual carbon sequestration of plant communities in the quadrat is 499.25kg/hm², followed by A5, and the annual carbon sequestration of plant communities in the quadrat is 497.59kg/hm².The factors that lead to the large difference in carbon sequestration among plant communities mainly include plant species and plant hierarchical structure. For example, there are many plants with high carbon sequestration capacity in the A1 quadrature (*Salix babylonica, Acer pictum subsp. mono, Kerria japonica*), the community level is a multi-layer structure, and the three-dimensional green amount is high, so the annual carbon sequestration capacity of the A1 quadrature is high; although it is also a stratified structure. In contrast, although it is also a stratified structure, due to the small proportion of high carbon sequestration plants in the A2 plot, the community carbon sequestration is smaller. (Table 3).

Table 3. Carbon sequestration of green space plant communities in the study area.

Research site	Quadrat	Plant community	Annual carbon sequestration (kg/hm²)
Site A	A1	*Salix babylonica + Ligustrum lucidum + Acer pictum subsp. Mono + Cupressus funebris+Punica granatum + Prunus persica - Photinia × fraseri + Amorpha fruticosa + Ligustrum quihoui + Spiraea salicifolia + Lonicera maackii + Pyracantha fortuneana + Fatsia japonica + Kerria japonica*	499.25
	A2	*Salix babylonica + Acer buergerianum - Pittosporum tobira + Nandina domestica + Photinia × fraseri - Oxalis corymbosa + Iris tectorum + Ophiopogon bodinieri*	211.95
	A3	*Pinus bungeana + Ligustrum lucidum + Ulmus pumila + Styphnolobium japonicum 'Pendula' - Chimonanthus praecox + Pyracantha fortuneana + Spiraea salicifolia - Phyllostachys sulphurea var. viridis + Ophiopogon bodinieri*	225.93
	A4	*Pinus tabuliformis + Ligustrum lucidum - Lonicera maackii + Chimonanthus praecox + Ligustrum quihoui + Photinia × fraseri + Weigela florida + Pittosporum tobira - Ophiopogon bodinieri*	174.27
	A5	*Pinus bungeana + Celtis sinensis + Punica granatum + Photinia × fraseri + Ligustrum lucidum + Styphnolobium japonicum + Pinus tabuliformis - Spiraea salicifolia + Lonicera maackii + Buxus bodinieri + Rosa xanthina - Fatsia japonica*	497.59
	A6	*Salix babylonica + Punica granatum + Prunus cerasifera 'Atropurpurea' + Styphnolobium japonicum + Ligustrum lucidum - Pyracantha fortuneana + Juniperus chinensis 'Kaizuca'*	368.57
Site B	B1	*Styphnolobium japonicum - Ilex chinensis + Nandina domestica + Rosa (Floribundas Group) + Photinia × fraseri - Iris pseudacorus + Carex giraldiana Kukenth + Miscanthus sinensis + Physostegia virginiana + Iris tectorum + Pennisetum alopecuroides + Poa annua*	166.5
	B2	*Ilex chinensis + Nandina domestica + Pittosporum tobira + Photinia × fraseri - Coreopsis basalis + Miscanthus sinensis 'Gracillimus' + Stipa lessingiana + Lolium perenne*	63.08

3.4. Influence of plant community characteristic factors on carbon sequestration of urban green space

1. Hierarchical structure of plant community

In the field investigation of the quadrat, it was found that the hierarchical structure of the plant community in the quadrature mainly includes three types: tree-shrub-grass type, shrub-grass type and herb type. Among them, the tree-shrub-grass structure has the greatest impact on carbon sequestration. For example, the plant community in A1 and A5 plots are arbor-shrub-grass type, and the annual carbon sequestration is as high as 400kg/hm².

2. Canopy density of the plant community

The higher the canopy density, the greater the carbon sequestration of the plant community (Figure 6a). The average canopy density of the plant community in Site A was

59.2%, the highest canopy closure is 75% of the A1 quadrat, and its carbon sequestration is also the largest. The community canopy density in Site B quadrature was 33.75% on average, the highest was 37% of B1.

3. Diameter at breast height of plants

The diameter class structure of the study area was quite different (Figure 6b). The larger the diameter of the plant, the larger the carbon sequestration. The average diameter of plants with the largest diameter at breast height of the A1 quadrat was 30cm, and the annual carbon sequestration of the quadrat was about 499.25kg/hm².

4. Community density of plant community

The study shows that the A1 plot has the highest community density of 2500 plants/ha (Figure 6c), and its carbon sequestration is also the largest, while the B2 plot has the smallest community density of 600 plants/ha, and carbon sequestration is minimal.

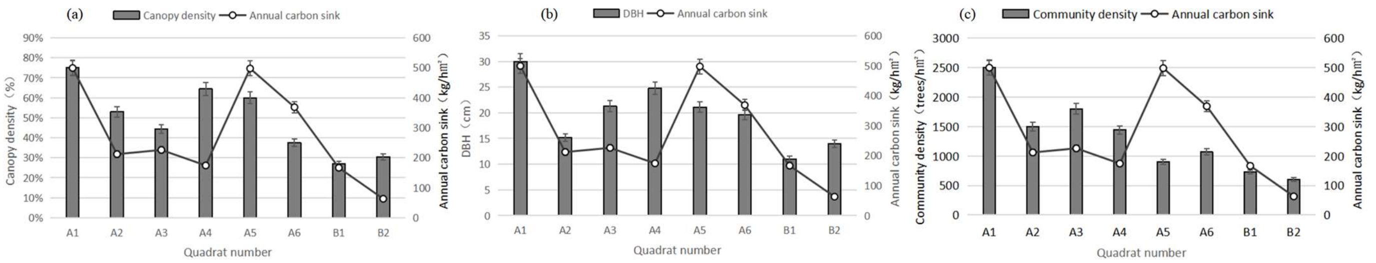


Figure 6. Relationship between carbon sequestration and (a) canopy closure, (b) diameter at breast height and (c) community density.

4. Discussion

4.1. The relationship between the distribution of carbon sequestration in urban green space and land-use change

The research shows that from 2000 to 2019, the structure and distribution of urban carbon sequestration changed greatly: the carbon sequestration of plants showed an upward trend from 2000 to 2019, but the carbon sequestration density decreased year by year, Soil carbon sequestration increased rapidly from 2000 to 2007, but the growth rate began to decrease from 2007 to 2019. In terms of total carbon sequestration, the carbon sequestration density in the main urban area of Xi'an decreased year by year with the growth of construction land. According to domestic and foreign research, the main reason for the change of urban carbon sequestration is the changing urban land-use[33-35]. Land-use change has a great impact on the material cycle and energy flow of the urban ecosystem, which changes the structure, process and function of the ecosystem, and then significantly affects the carbon allocation of each part of the ecosystem[36-39]. The impact of land-use change on the carbon cycle of terrestrial ecosystems depends on the type of ecosystem and the way of land use change, so land-use change may bring both carbon emissions and carbon sequestration[40-42]. Consistent with previous research results, changes in urban land-use types are the main reasons for changes in urban carbon sequestration distribution, which are mainly reflected in the following aspects: First, different land-use types have different carbon sequestration capacities, compared with urban green space and cultivated land, forest land has the largest carbon sequestration[43]. Second, changes in land-use types have a great impact on urban carbon sequestration[44]. For example, from 2000 to 2014, the area of cultivated land in Xi'an decreased significantly, the area of construction land increased significantly, and the carbon sequestration showed a sharp downward trend; Finally, the structure of land-use also affects urban carbon sequestration[45].

From a practical point of view, changes in urban carbon sequestration are mainly affected by major urban policies and activities. With the continuous acceleration of urbanization in Xi'an, the area of urban construction land has increased rapidly in recent years, while the area of forest land and cultivated land has continued to decrease, resulting in gradual changes in the structure of urban carbon sequestration[46, 47]. Forests account for nearly 50% of the city's total land area in 2000, which slowly decreased by 11,730 hm^2 from 2000 to 2007, but from 2007 to 2019, the forest area increased. This may be related to the formulation of relevant policies. In recent years, Xi'an Municipal Government has attached great importance to the construction of urban green space. The area of urban green space in Xi'an increased from 4,502 hm^2 in 2004 to 12,140 hm^2 in 2010, and the green coverage rate in built-up areas increased from 30.06% in 2004 to 37.50% in 2010.

4.2. Changes in carbon sequestration with the growth of plant biomass

A single plant biomass study shows that the diameter at breast height and community density of urban green space plants are significantly positively correlated with carbon sequestration (Table 4). When the diameter of plants in urban green space is in the range of 10-20 cm, the carbon sequestration and efficiency of plants are larger. Although there are many studies showing that plants with larger diameter at breast height and more biomass have higher carbon sequestration capacity, this trend is not linear. With the growth of plants, the carbon sequestration efficiency of large trees will grow slowly, so in the design of low-carbon urban green space planting, it is not necessary to focus only on the carbon sequestration brought by planting large trees, but the carbon sequestration provided by planting medium-sized plants is equally important in the long term[48].

Comparing the carbon sequestration efficiencies of different types of plant communities shows that, the canopy density of arbor-shrub-grass plant community is recommended to be 40%- 70%, and the canopy density of arbor-grass plant community is recommended to be above 85%, and the DBH of trees is preferred to be 10-20 cm.

In general, the higher the canopy density of the plant community in the green space, the more complex the hierarchical structure, and the higher the carbon sequestration[49], but its landscape function needs to be considered in the design of the green space. There is evidence that denser plant communities have high concentrations of pollutant uptake capacity and high allergenicity[50, 51]. Therefore, it is recommended to choose a suitable density for plant growth, which not only attracts residents and provides multifunctional space, but also promotes carbon sequestration in the long term.

Table 4. Correlation analysis between characteristic factors of plant communities and carbon sequestration

Characteristic factors of plant communities	**Canopy density**	**DBH**	**Hierarchical structure**	**Community density**	**Carbon fixation**
Canopy density	1				
DBH	.828*	1			
Hierarchical structure	0.483	0.657	1		
Community density	0.820*	0.953**	0.57	1	
Carbon fixation	0.621	0.859**	0.747*	0.889**	1

4.3. Implication for planting design for promoting carbon sequestration in urban green space

4.3.1.Suggestions for low-carbon green space planting design

The study summarizes trees with high carbon sequestration capacity: *Platanus orientalis, Salix babylonica, Koelreuteria paniculata, Melia azedarach*, among which *Salix babylonica, Koelreuteria paniculata* and *Melia azedarachare* native plants in Xi 'an; Shrubs with high carbon sequestration include *Lonicera maackii, Nandina domestica, Rosa (Floribundas Group), Rosa xanthina*; Herbs with high carbon sequestration are: *Iris pseudacorus, Zephyranthes candida, Stipa lessingiana* (Table 5).

The urban green space in Xi'an is being vigorously constructed, among which the urban green space of different sizes radiating outward from the ring park is the skeleton of the entire urban ecosystem. In the urban built environment, the area of urban green space cannot be expanded indefinitely, so the planting design for the improvement of carbon sequestration is very important for the sustainable development of the city.

In order to maximize the improvement of urban carbon sequestration, the relationship between low-carbon green space and planting design should be considered before making decisions. This paper reveals the relationship between planting design and urban carbon sequestration, and concludes that it can be directly applied to planting List of high carbon sequestering plants in design. In the process of low-carbon planting design, while enriching plant species with high carbon sequestration efficiency and low carbon emission should be selected. Research shows that although plants can absorb CO_2 through photosynthesis, their consumption and maintenance of wild plants cause carbon emissions. The carbon emission caused by grassland maintenance is three times that of forest land. Among them, the carbon emission of herb layer mainly comes from irrigation, the carbon emission of shrub layer mainly comes from waste transportation, and the carbon emission of woodland and ground cover comes from fertilization**Error! Bookmark not defined.**. In terms of plant species, the carbon sequestration of deciduous trees is greater than that of evergreen trees, and the carbon sequestration of deciduous shrubs is greater than that of evergreen shrubs. Therefore, in the planting design, an appropriate proportion of evergreen plants and deciduous plants can be selected to play a good ecological benefit to the surrounding environment.

Table 5. Cluster analysis of plants with different levels of carbon sequestration capacity.

Tree species name	Plant names		
	Type I plants	**Type II plants**	**Type III plants**
Arbor	*Platanus orientalis*	*Salix babylonica, Koelreuteria paniculata, Melia azedarach, Ulmus pumila, Celtis sinensis, Magnolia grandiflora, Photinia serratifolia*	*Styphnolobium japonicum, Ligustrum japonicum, Juniperus chinensis 'Kaizuca', Pinus tabuliformis, Acer pictum, Osmanthus fragrans, Acer buergerianum, Punica granatum, Pinus bungeana, Prunus cerasifera 'Atropurpurea', Acer palmatum 'Atropurpureum', Eriobotrya japonica, Prunus davidiana, Acer palmatum*
Shrub	*Lonicera maackii , Rosa (Floribundas Group), Nandina domestica*	*Rosa xanthina, Kerria japonica, Spiraea salicifolia, Chimonanthus praecox, Forsythia suspensa, Ligustrum sinense, Jasminum nudiflorum, Photinia × fraseri,Pittosporum tobira , Ligustrum quihoui, Buxus bodinieri, Buxus sinica var. parvifolia*	*Amorpha fruticosa, Weigela florida, Buxus megistophylla, Juniperus procumbens, Pyracantha fortuneana*

Ground cover plants	*Iris pseudacorus*	*Physostegia virginiana, Carex giraldiana Kukenth, Zephyranthes candida, Stipa lessingiana*	*Iris tectorum, Miscanthus sinensis 'Gracillimus', Pennisetum alopecuroides, Oxalis corymbosa, Juncus effusus, Hedera nepalensis var. sinensis, Miscanthus sinensis, Ophiopogon japonicus , Coreopsis basalis, Lolium perenne, Fatsia japonica , Dianthus plumarius L., Ophiopogon bodinieri, Pennisetum alopecuroides 'Little Bunny', Arundo donax 'Versicolor', Cynodon dactylon , Poa annua*

Note: The thresholds of carbon sequestration of three types of trees were above 141.07kg/hm^2, 80.74-141.07kg/hm^2, and below 80.74kg/hm^2, the three types of plant carbon sequestration thresholds for shrubs are above 11.087kg/hm^2, 6.11-11.087kg/hm^2, and below 6.11kg/hm^2, herbs The three types of plant carbon sequestration thresholds are respectively 4.32kg/hm^2, 2.3-4.32kg/hm^2, and below 2.3kg/hm^2.

4.3.2. Extraction of planting design models on promoting carbon sequestration

As a place to serve human beings, urban green space is mainly used for leisure, recreation, ornamental and fitness activities, and plant design should combine the main functions of urban green space. We can't just emphasize planting more plants and increasing the area of urban green space. Therefore, based on the actual project application, this paper proposes three different plant community configuration design modes to provide a scientific basis for planting design (Table 6).

1. " Arbor -shrub-grass" type plant community

The" arbor -shrub-grass" type plant community is mainly used in park green space, residential green space and other sites, and mainly plays the function of ecological benefit (Table 6). The following points are required in plant design. Tall deciduous broad-leaved trees should be selected for the upper layer of trees, because the leaf area is large and the gap between the leaves is large, so that the lower layer plants can fully absorb sunlight and rainwater; the middle layer of large shrubs Plants with higher branches and leaves should be selected, such as *Lonicera maackii and Chimonanthus praecox*, and small shrubs should be selected with dense branches and leaves, such as *Nandina domestica* and *Spiraea salicifolia*; ground cover plants should be resistant to Drought and shade-tolerant plants, such plants mainly include *Zephyranthes candida* and *Iris tectorum*.

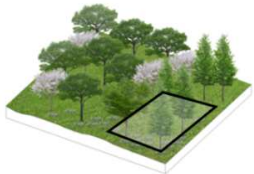
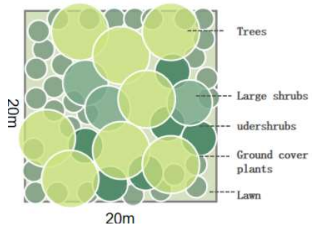
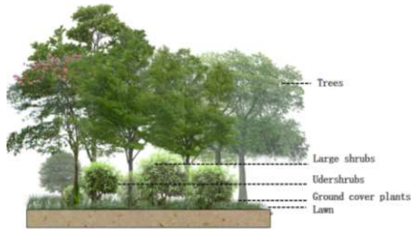
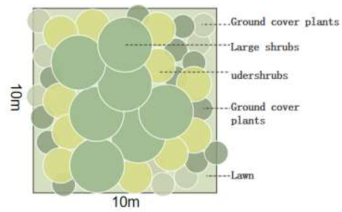
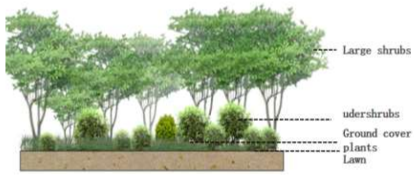
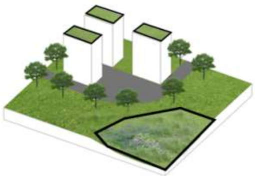
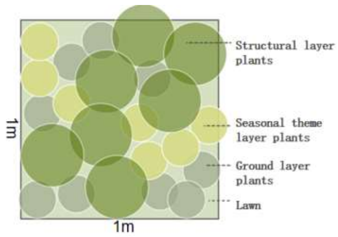
2. "Shrub-grass" type plant community

The "shrub-grass" type plant community is mainly used in the square green space and road green space (Table 6). The main functions are ornamental, protection and ecology. In the design, attention should be paid to the collocation and combination of shrubs and ground cover plants. Tree species with a height of more than 3m and large and sparse leaves should be selected for the large shrub layer, such as *Lonicera maackii* and *Cercis chinensis*. The small shrub layer plants should be evergreen shrub hedges with a height of more than 1 m and small and dense leaves, such as *Buxus megistophylla* and *Ligustrum quihoui*. Ornamental herbs below 50cm are generally selected for the ground cover. In addition, shade-tolerant, flood-tolerant and drought-tolerant plants should be selected, such as *Oxalis corymbose* and *Miscanthus sinensis*.

3. Ground cover plant communities

Referring to Thomas Rainer and Claudia West's community layered design model for the landscape of ground cover plants-"structural layer+ seasonal theme layer+ ground cover layer"[52], the structural layer is composed of tall herbs with vertical structure, and the seasonal theme layer contains beautiful plants that bloom in fixed seasons. The ground cover layer is mainly some low-growing herbs, which play a role in soil and fertilizer conservation. Ground cover plant communities are mainly used in small green spaces, such as roof gardens, road green spaces, and bioretention facilities (Table 6). Among them, the structural layer plants should choose species with tall plants and sparse leaves, such as *Penstemon digitalis, Chrysanthemum indicum*； the seasonal theme layer plants should choose plants with a height of 30-60cm, large crown width and dense leaves, such as *Coreopsis basalis, Saponaria officinalis*; the ground cover plants should choose plants with low plants, which can cover the soil to avoid exposed topsoil, such as *Festuca glauca, Sedum sarmentosum*.

Table 6. Design pattern of high carbon sequestration plant community in urban green space.

Types of plant community	Types of application sites	Layout mode	Vertical layout mode
Arbor-shrub-grass plant community	 Park green space, residential green space, etc.		
Shrub-grass plant community	 Square green space, road green space, etc.		
Ground cover plant communities	 Road green space, roof greening, bioretention facilities, etc.		

5. Limitations of the study and future research prospects

In this study, the carbon sequestration of common garden plants in Xi 'an was monitored and evaluated. The monitoring time lasted only one year (from September 2020 to December 2021), so it is necessary to study the relationship between plants and carbon dioxide from a longer time dimension. While most of the carbon sequestration in urban green spaces is due to trees rather than shrubs and grasses, combining various plant species in urban green spaces can multiply carbon sequestration[53]. At present, the research on the design of low-carbon green space needs a lot of research on the design mode of high-carbon sequestration plants, which can further support the application of practical projects. Due to the rapid development of the city, the planning of green space is fragmented, and the research on the carbon sequestration of green space still needs to study the spatial characteristics of green space. In addition to considering the carbon sequestration benefits of urban green space, we still recommend that stakeholders focus on balancing the basic functions of urban green space, such as the relationship between human behavior and needs and biodiversity, to become the focus of human sustainable development decision-making, and to accelerate the realization of Strategic goals for carbon neutrality and carbon peaking.

6. Conclusions

This study focused on the relationship between quantitative indicators of carbon sequestration in urban green space and plant planting design, and screened plant community types with higher carbon sequestration efficiency. The results showed that the carbon sequestration of urban green space showed a decreasing trend year by year with the change of forest structure, and this difference was mainly related to the characteristic factors of urban green space plant community: Plant carbon sequestration has a very significant positive correlation with DBH and community density, a significant positive correlation with hierarchical structure, and a positive correlation with canopy closure. According to the research recommendations, the canopy density of the arbor-shrub-grass plant community is 40%-70%, and the canopy density of the Arbor-grass plant community is more than 85%, and the DBH of trees are preferably 10-20cm. In addition, we put forward a list of high carbon sequestering plants including *Styphnolobium japonicum, Salix babylonica, Pittosporum tobira, Spiraea salicifolia, Iris pseudacorus,* and summarized three types of green space plant design patterns in different green spaces and habitats. The planting mode proposed in this paper can provide theoretical guidance for the design practice of low-carbon planting. It is suggested that in the future research, plant community characteristic factors should be considered as the indicators of low-carbon plant design, and an appropriate plant community fabric model should be established, so as to provide a scientific basis for the planning and design of low-carbon urban green space and explore the sustainable design approach of urbanization ecological process.

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