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Analysis on the Disaster Prevention Strategy of Macau Urban Green Space

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Abstract: With the frequent occurrence of natural disasters in cities in recent years, the disaster prevention and mitigation function of urban green space has been attracting more attention from the public. Because the urban green space system not only has the function of improving environmental quality and maintaining ecological balance, but also has the function of disaster prevention and mitigation. Macau located in the coastal region of southern China suffers from natural disasters such as typhoons, rainstorms and floods. however, due to its small land size and dense population, the development of its green spaces for disaster prevention has been hampered. This paper analyzed the current situation of green space in Macau, summarized the main problems, and proposed corresponding design strategies to provide reference for the disaster prevention construction of urban green space in Macau.

1. Introduction

The most common natural disaster in Macau is typhoon. During typhoons, storm surges bring large amounts of seawater inland from the bay of Macau's inner harbour, causing flooding in Macau. These floods have caused the paralysis of the city traffic, block greening and a series of damage to a series of infrastructure. Due to the lack of land space, the narrow streets and the lack of natural barriers around the area, the resilience and recovery of the urban green space system are limited in the event of a disaster. In addition to natural disasters, there are also man-made disasters that cannot be ignored. Sudden disasters not only cause casualties, but also bring serious economic losses to the whole Macau, so it is necessary to find strategies to effectively enhance the resilience of green spaces in the constrained urban space, so as to reduce the risk of disasters.

2. Macau Urban Green Space Overview

Green space refers to the land with natural vegetation or artificial vegetation as the main form. Green space in Macao can be divided into recreational green space, road traffic green space, nursery

production green space and ecological landscape green space.[1]According to the statistics and Census Bureau, the total area of green space in the districts under the jurisdiction of Macao municipal Administration was 7110,388 square meters in 2019, up 0.4 percent from the total in 2018. Among the percentages of all types of green space in Macao in 2019, ecological landscape green space accounted for 51.4%, leisure green space accounted for 40.2%, road green space accounted for 7.9%, and nursery green space accounted for 0.5%.The proportion of green space for road traffic increased by 8.5% compared with the previous year, while the proportion of green space for nursery production decreased by 16.9%.In terms of green space per capita, the figure was 10.5 square meters in 2019, down 0.9 percent from 2018. Since the annual population increase trend of Macao is larger than the expansion of the green area under the jurisdiction of the municipal Administration, the overall per capita green area shows a downward trend.

3. Major problems with disaster prevention in Macau' s urban green spaces

3.1. Three-dimensional greening of streets

Due to Macau's limited urban land area, the width of streets and lanes in the city are generally only 3-5 meters wide, with some roads near residential areas even less than 3 meters wide.[2] It is common for people and vehicles to mix in the narrow streets and alleys, so it would not be wise to develop spacious disaster avoidance routes in the urban areas of Macau. When formulating disaster prevention and risk avoidance strategies, it is necessary to adjust measures to local conditions and respect the current situation of narrow streets and lanes and complex road network system in Macao. The scale of streets limits the ability of urban disaster prevention, but better disaster prevention and reduction can also be achieved by cultivating disaster prevention plants in street greening. However, in the field investigation, it was found that there was a lack of street greening in the urban area, in which only a small number of potted plants were placed on the balcony of residents or dotted green space was scattered in the corners of streets and lanes.[3] The scarce greening facilities cannot be organically connected to form a complete disaster avoidance channel, and the effective accessibility between the disaster avoidance channel and the disaster avoidance stronghold was greatly reduced.

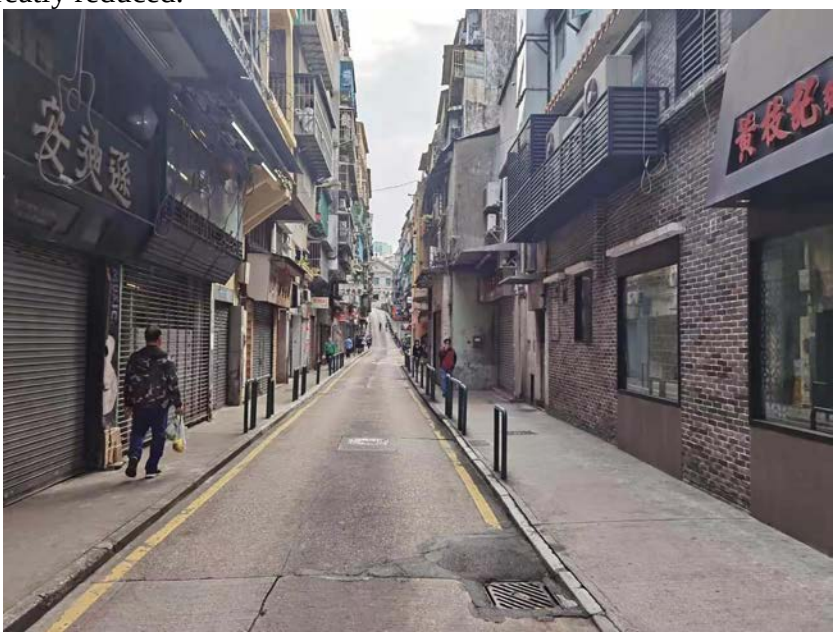

Figure 1: Current status of streets and alleys in St. Anthony Parish, Macau

(Source: Source: Photo by authors)

3.2. Form of urban layout

Macao has a subtropical monsoon climate. Typhoon weather mainly occurs in summer and autumn when southeast wind prevails. However, the streets of Macao Peninsula are mostly southeast oriented. When the trend of urban streets is parallel to the prevailing wind direction of typhoon, the damage of street greening will be more serious than when the wind direction is perpendicular to the street direction. Because most of the city streets in Macau are distributed among high-density buildings, when the road direction is consistent with the wind direction, it is easy to form a "narrow pipe effect", thereby enhancing the destructive power of wind. What is different is that in the central area of the outlying islands of Macao, the urban streets are mainly north-south and east-west, which are rarely consistent with the wind direction. Therefore, the impact of typhoons in the central area of the outlying islands is often lower than that in the coastal areas of the peninsula.

3.3. Growing environment of plants

The fine growth of plants needs plenty of sunshine, but the high-rise buildings in Macao often block the greening of the streets. Poor growth or partial crown of street trees due to lack of light or uneven irradiation for a long time. Too small planting hole is also one of the factors affecting root development. There is no lack of phenomenon of planting big trees in some small tree holes in Macao, resulting in blocked root extension and poor development of trees, increasing the probability of trees tilting during disasters. Due to the long-term influence of surrounding seawater, the soil in coastal areas has a high degree of salinization, which inhibits the growth of plant roots and affects the growth and development of plants. In the typhoon season, the erosion of soil by frequent heavy precipitation makes the soil water content surge. Long-term flooding leads to the lack of support and traction of plant roots, and also affects the growth of plants. In addition, the soil layer of some parks in Macao is covered with soil on the basis of landfill. There are too many impurities in the soil, which is not conducive to the normal growth of trees.

3.4. Plant configuration and maintenance

When screening plant species, many factors need to be considered, such as plant morphology, material, root system, disease and insect resistance and so on. In some areas with strong wind, some trees with poor wood properties often break their branches or trunk due to strong wind, such as Jacaranda mimosifolia D. Don, Lagerstroemia speciosa (L.) Pers and other plants. In relatively open areas, landscape trees with huge tree crowns are generally the main scenery of the green space landscape in the form of solitary plants. However, due to their dense branches and leaves and low air permeability, the wind resistance is large. When a typhoon strikes, it is often easy to break the trunk. In some important areas of fire prevention, tree species with high oil should not be planted, such as Pinus, etc. Tree species with small canopy and low canopy density should not be used as flood control plants, such as Paulownia, etc.

In terms of plant maintenance, the hard pavement with poor water permeability will make it difficult for the air roots of plants to penetrate into the soil, and the roots cannot grow normally. The function of plant fixed facilities is to mainly assist the tree species with slow growth speed or poor wind resistance to straighten out the tree shape, which is not easy to be affected by typhoon. However, in some streets, the aging of fixed facilities is easy to cause trees to be blown down during typhoon weather. For example, the street trees on Evora Street are poorly protected and

cannot withstand strong winds.

Figure 2 Current status of street tree maintenance facilities in the streets of Evora, Macau

(Source: Photo by the author)

4. Design principles of green space disaster prevention

4.1. Maintain the original green space environmental structure

While strengthening the function of disaster prevention and reduction of urban green space system, it should continue to maintain the original basic functions such as viewing, recreation and entertainment, so as to achieve the combination of disaster relief and stability of green space environmental structure. Modern urban green space system can not only meet the daily cultural and entertainment needs of citizens, but also realize urban ecological balance through the functions of self-regulation and self-recovery. It is an organic whole with ecological, economic and social benefits.

4.2. Plant the right tree in the right place

When selecting and configuring plants, it is necessary to match the local environmental conditions with the characteristics of tree species, so as to give full play to the potential of planting trees and maximize the effect of disaster prevention. Planting the right tree in the right place is a basic principle in afforestation. The so-called right place is to correctly understand the site conditions such as soil, hydrology and climate, and suitable tree is to accurately distinguish the biological attributes of tree species and determine the suitable tree species in the area. According to the geographical environment of Macao, plants that adapt to subtropical climate or tropical climate and plants with salt and alkali tolerance should be selected in terms of plant varieties.

4.3. Ensure smooth traffic system

The disaster avoidance channel requires urban secondary roads and branches to connect the surrounding disaster avoidance strongholds into a network to form a disaster avoidance system, so as to ensure the accessibility between roads and strongholds. In order to ensure that there is no conflict between urban disaster relief and risk avoidance green channels, disaster avoidance channels should not choose urban trunk roads. Disaster prevention green belts can be planted on both sides of the main disaster avoidance channels, which also plays a positive role in the smoothness of the road.[4]

4.4. Strengthen green space planning indicators

When performing the functional division of the green space system, it is also necessary to take into account the function of fire safety, for example, when it comes to the planning of waterscape facilities, it is necessary to consider the layout and design of domestic water and fire water required for disaster relief, including the layout of sprinkler and fire-fighting facilities. In terms of emergency communication and power generation facility planning, both normal and disaster communication systems should be used to ensure the normal exchange of information when disasters occur. At the same time, actively encourage the use of natural energy for power generation, so as to prevent the paralysis of urban power system from causing the normal operation of street lighting facilities. The location planning of the storage warehouse for emergency relief materials also needs to be considered. The warehouse should adopt reinforced concrete structure to enhance the seismic performance, and pay attention to the ventilation and cooling of the warehouse. In the spatial planning of disaster avoidance temporary toilets, different types of toilets need to be set according to different actual conditions.[5]

4.5. Meet the requirements of disaster prevention service radius

The disaster prevention service radius of urban green space system needs to be similar to that of resident daily recreation and entertainment, so as to ensure the accessibility and uniform distribution of disaster avoidance channels and disaster avoidance strongholds. Urban disaster prevention and risk avoidance green space in urban green space system is generally divided into emergency disaster prevention and risk avoidance green space, fixed disaster prevention and risk avoidance green space, Central Disaster Prevention and risk avoidance green space, isolation buffer green space and green evacuation channel. When planning the location of disaster prevention and risk avoidance green space, it should be considered that the service radius of emergency disaster prevention and risk avoidance green space is 300-500 meters, which is used as emergency temporary refuge. Generally, it can reach the disaster avoidance green space within 2-3 minutes, such as community green space or roadside green space. The service radius of the fixed disaster prevention and risk avoidance green space is 500-1000 meters, and the victims can reach it by walking for dozens of minutes, such as community parks and municipal parks. The service radius of central disaster prevention and risk avoidance green space is mainly 1 -3kilometers, such as comprehensive park and square park.

5. Development strategy of urban green space disaster prevention system

5.1. Reasonable planning of urban green space layout

When planning urban green space, different areas should have different green space layout

methods. In the historical urban area, through the combination of block and point green space, and the three-dimensional greening is integrated into the urban road, so as to form an organic green space network. This approach can not only beautify the surrounding environment, improve the comfort of human living but also prevent and mitigate disasters. In areas where the effect of narrow occurs or in windward areas, fast-growing and long-lived trees and shrubs with strong root systems and firm branches should be planted to enhance the wind resistance of green areas through a combination of dense and complex structures. In the mountain forest area, windbreak zones should be formed in the vertical direction of the wind, through the transformation of the forest phase, with a rich complex forest structure, in order to achieve the effect of reducing the power of typhoons. Among them, the sparse wind-permeable structure and the ventilated structure have better wind-proof effects than the compact structure that is not easily permeable. In areas where there are more wooden structures or fire hazards, some plant species with higher shading rates, high water content and low oil content should be properly planted as fire prevention plants, such as Acacia confusa Merr, Michelia macclurei Dandy, etc. Combined with the current situation of narrow streets in Macau, some climbing plants such as Parthenocissus tricuspidata can be planted as the main vegetation of three-dimensional greening, and some shrubs such as Aucuba chinensis Benth, Ligustrum lucidum can be added to enrich the plant level on both sides of the street. In places where flooding is serious, trees with wide crowns, well-developed root systems, more rain retention, and shade and flood tolerance should be planted.

5.2. Plant selection and configuration for optimizing green space disaster prevention system

According to the principle of planting the right tree for the right place, the types of vegetation should be selected according to the geographical environment and the disaster situation, as well as the need to consider the growth characteristics and seasonal differences of tree species in each area, and use a variety of different seasonal vegetation for mixed configuration, so as to improve the disaster prevention effect of urban green space. When planting disaster prevention trees around disaster shelters in cities, it is necessary to build a vegetation compound structure to effectively prevent the spread of disasters, such as the establishment of fire prevention zones around urban disaster prevention green areas, it is possible to choose native tree species for plant configuration. Arbors can choose Michelia macclurei Dandy, Banyan, etc, while shrubs can choose Cycas revoluta, Ligustrum lucidum, Syringa pubescens Turcz and so on, and match other ground cover plants. Through this multi-layer combination of arbors, shrubs and grass to form a three-dimensional landscape structure, so as to prevent the fire from spreading. When setting the windbreak belt around the prevailing wind direction of the city, it should be noted that the best windbreak effect should be achieved in the form of mixed planting of various windbreak vegetation, and the planting direction of windbreak should not be in parallel with the prevailing wind direction. While paying attention to the disaster prevention function of urban green space, it is necessary to take into account the landscaping, ecology, saving and other functions of green space, so as to provide beautiful ecological landscape environment for citizens. [6]

5.2.1. Selection of fire-resistant plants

Fire-resistant plants generally are chosen more water content, less oil, high canopy closure and thick bark of fire-resistant species, such as Aucuba chinensis Benth, Camellia japonica L, Fatsia japonica, Podocarpus macrophyllus, Michelia macclurei Dandy, Ligustrum lucidum, Buxus megistophylla Levl, etc. [7]

Table 1: Analysis of fire-resistant plant species

(Source: drawn by author)

Species	Name	Family & Genus	Growth habit	Ornamental value	Flowering & fruiting period
arbor	Acacia confusa Merr.	Leguminosae sp. & Acacia wattle	Light-loving, semi-shade tolerant, drought-resistant ridge	Golden yellow flowers, slightly fragrant	Flowering: Mar-Oct Fruiting: Aug-Dec
	Michelia macclurei Dandy	Magnoliaceae & Michelia L.	Prefers warm and humid climate, suitable for acidic soil, tolerant of barrenness and drought	White flowers, tall and magnificent trees with umbrella-shaped crowns	Flowering: Mar-Apr Fruiting: Sep-Nov
	Ficus microcarpa L. f.	Moraceae & Ficus	Prefers soft acidic soil, not drought tolerant, likes sunlight	Large canopy; Suitable for individual planting	Flowering: May-Jun
	Buxus megistophylla Lévl.	Buxaceae Dumort. & Buxus L	Light-loving, shade tolerant, slightly acidic and slightly alkaline soil can be grown	Can be used as hedge or symmetrical planting	Flowering: Mar-Apr Fruiting: Jun-Jul
	Viburnum odoratissimum Ker.-Gawl.	Adoxaceae & Viburnum Linn.	Prefers warm climate, slightly shade tolerant	Fragrant flowers, white corolla, fruits first red and then black	Flowering: Apr-May Fruiting: Jul- Sept
shrub	Cycas revoluta Thunb.	Cycadaceae Persoon & Cycas Linn.	Slightly shade tolerant, prefers slightly acidic soil	Evergreen and shiny leaves in all seasons	Flowering: Aug-May Fruiting: Jul- Sept
	Aucuba chinensis Benth.	Garryaceae & Aucuba	Not hardy to cold or drought	Evergreen foliage	Flowering: Jan-Feb Fruiting: Feb of the following year
	Fatsia japonica (Thunb.) Decne. et Planch.	Araliaceae & Fatsia Decne. Planch.	Shade tolerant, preferably planted in moist, sandy soil	Beautiful leaf shape, evergreen foliage plant	Flowering: Oct-Nov Fruiting: Apr
	Ligustrum lucidum Ait.	Osmanthus Lour. & Ligustrun L.	Sun-loving, moisture tolerant, shade tolerant	Dense foliage, suitable as a roadside tree as a barrier	Flowering: May-Jul Fruiting: May of the following year
	Camellia japonica L.	Theaceae & Camellia	Prefer warm and humid climate, suitable for semi-shade environment	Flowers are mostly red, light red or white	Flowering: Dec-Mar of the following year

5.2.2. Selection of windproof plants

Windproof plants are generally selected from wind-resistant species with fast growth rate, firm root system, firm branches and long life, and their crowns are preferably spire-shaped or column-shaped, such as Magnolia grandiflora L., Archontophoenix alexandrae (F. Muell.) H. Wendl. et Drude, Salix babylonica L., Pinus massoniana Lamb., etc.[8]

Table 2: Analysis of windbreak plant species

(Source: drawn by author)

Species	Name	Family & Genus	Growth habit	Ornamental value	Flowering & fruiting period
	Magnolia	Magnoliaceae&Magn	Slightly shade tolerant,	Large, white or light	Flowering:

arbor	grandiflora L.	olia	suitable for moist and well-drained soil	yellow flowers, beautiful tree shape	May-Jun Fruiting: Sept- Oct
	Archontophoenix alexandrae (F.Muell.) H. Wendl. et Drude	Palmae& ArchontophoenixH. Wendl. Drude	Sun-loving, cold intolerant, very drought intolerant, water intolerant	Evergreen in all seasons, excellent foliage plant	Flowering: Apr Fruiting: Apr - Jul
	Salix babylonica L.	Salicaceae& Salix	Cold resistant , salinity resistant, drought resistant	Beautiful tree shape, excellent waterfront landscape plant	Flowering: Mar- Apr Fruiting: Apr-May
	Pinus massoniana Lamb.	Pinaceae Spreng. ex F. Rudolphi & Pinus Linn	Not tolerant to waterlogging, not tolerant to salinity	Beautiful, tall and majestic, suitable for solitary tree planting	Flowering: Apr-May Fruiting: Oct-Dec of the following year
	Juniperus chinensis Linnaeus	Cupressaceae& Juniperus	Slightly shade tolerant, cold and heat resistant	Beautiful shape of the tree	Flowering: Apr Fruiting: Nov of the following year

5.2.3. Selection of waterlogging prevention plants

Flood prevention plants are generally selected from tree species with large crown size, deep and extensive root system, large depression, strong humidity tolerance and stable growth, such as: Sapium sebiferum, Mulberry, Fagus sylvestris, Oleander, and Hojicha.

Table 3: Analysis of some flood control plant species

(Source: drawn by author)

Species	Name	Family & Genus	Growth habit	Ornamental value	Flowering & fruiting period
arbor	Triadica sebifera (Linnaeus) Small	Euphorbiaceae & SapiumP.Br.	Sun-loving, strong resistance to short-term flooding	Neat crown and beautiful foliage	Flowering: Apr- Aug
	Morus alba L.	Moraceae & Ficus	Resistant to cold and moisture	Broad canopy, dense foliage, economic tree species	Flowering: Apr- May Fruiting: May- Aug
	Taxodium distichum (L.) Rich.	Cupressaceae& Taxodium	Water-logging tolerant, low-temperature tolerant, sun-loving	Beautiful tree shape, lush foliage	Flowering: May Fruiting: Oct
	Juniperus chinensis Linnaeus	Cupressaceae& Juniperus	shade tolerant, cold and heat resistant	Beautiful tree with neat conical crown, can be a solitary tree	Flowering: Apr-Fruiting: Nov of the following year
	Pterocarya stenoptera C. DC.	Juglandaceae& Pterocarya	Sun-loving, moisture-tolerant, likes deep, moist soil	Canopy spreading ,dense foliage	Flowering: Apr-May Fruiting: Aug- Sept
shrub	Nerium oleander L.	Apocynaceae & Nerium Linn	Intolerance to cold	Pink or white corolla	Flowering: Jun-Oct
	Lespedeza bicolor Turcz.	Leguminosae sp.& Lespedeza Michx.	Drought tolerant, salinity tolerant, Highly adaptable	Reddish purple corolla	Flowering: Jul-Aug

5.3. Strengthen the conservation and management of disaster prevention plants

5.3.1. Plant planting form

The combination planting of diverse tree species can further enhance the landscape effect and disaster prevention ability of disaster prevention plants by forming the planting form of plant community with rich layers. For example, the combination planting form of fast growing trees and slow growing trees, and the combination planting form of foliage plants and flower plants can be adopted.

For road traffic greening, vegetation needs to control the distance between vegetation. In the late stage of densely planted trees, thinning treatment is needed to create space for the growth of trees. For street trees with too sparse spacing, multi-row planting or increasing vegetation should be properly carried out to form a closely connected green space system.

5.3.2. Soil improvement

In some country parks, landfills and soil layers coexist. This results in poor or softened soil fertility, which affects root development and nutrient uptake of native tree species. In order to improve the soil environment, the garbage needs to be removed first, then the thickness of the soil in the green areas of the park and the size of the tree holes need to be increased so that the roots of vegetation can absorb nutrients from the soil. Finally, it is necessary to backfill acidic soil and increase organic fertilizer to change the softness of soil and improve the ventilation and drainage performance of soil.

5.3.3. Hard pavement

Some of the greenery along the street is affected by the impermeable hard pavement, which makes it difficult to drain away the underground water in time and causes root rot. In view of this phenomenon, it is recommended to use permeable pavement or grass instead of impermeable pavement. The size of the vegetation tree hole facing the street can be appropriately expanded. If conditions permit, the independent tree hole can be changed into a strip of green space to increase the disaster prevention of the green space. At the same time, drainage can be carried out through construction means such as buried drainage culverts or ventilation pipes to further improve the permeability of the soil.

5.3.4. Post-care

Regular pruning adjustment is needed for trees with large crowns and lush foliage to keep the tree shape permeable and comfortable. When pruning the tree shape, it is necessary to ensure that the tree shape is sparse, strong, low and even. Generally, the initial planting is thin and weak, and its root system is not fully expanded and developed, so it needs to be planted deeply and increase the resistance of the vegetation by adding fixtures to reduce the degree of damage. In addition, the maintenance of reinforcement facilities should be regularly patrolled and inspected by professionals, and the damaged infrastructure should be repaired and rectified. [9]

5.4. Realize dynamic management of vegetation information

To realize dynamic management of vegetation information, firstly, information statistics of all the vegetation currently covered by green areas in Macao are conducted, and then the collected information is analyzed by big data to visualize the effective dynamic information and achieve real-time monitoring of green area conditions. Secondly, a daily patrol and supervision mechanism should be established to strengthen the maintenance management and conservation of trees. At the same time, an early warning mechanism for disaster weather should be established to fully assess the impact of disaster in the area and to promptly trim the vegetation with potential safety hazards.

Finally, a post-disaster green space assessment mechanism should be established for inspection and repair of damaged trees, and centralized treatment of damaged green space and information management.

6. Summary and Prospects

Macau, as one of the most densely populated regions in the world, has received public attention from the beginning to the end of its urban green space development. At the same time, various social sectors hope to explore effective implementation strategies to balance the development of Macau's economy and green space environment.

With the promulgation and implementation of Macau's Urban Master Plan, the region will continue to promote the green development process of the city. By incorporating the concept of green low-carbon and recycling, the spatial layout and green space construction of the new city will be further planned systematically, and the green space nodes will be organically linked to form a complete green network structure. For the current situation of the Macau Peninsula, a gradual micro-renewal approach is adopted to improve the urban green space, thereby alleviating the lack of green space and uneven distribution of land use on the peninsula. In addition, the construction of disaster prevention green space is also an indispensable part of the urban green space system, and the future construction of disaster prevention green space in Macau should also be controlled and controlled by technological means, such as Internet technology, to achieve intelligent green space management. By improving the overall resilience of the city through the improvement of the urban green space system, the city will be able to better cope with future climate extremes, while beautifying the city and providing a comfortable and healthy living environment for local residents.

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