

Research Article

Green Space Planning and Landscape Sustainable Design in Smart Cities considering Public Green Space Demands of Different Formats

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The fast urban development leads to many complex problems. A smart city aims to solve these problems using scientific approaches. Urban Green Space (UGS) is a fundamental component of urban infrastructure. It needs to be upgraded simultaneously with the concept of the smart city. Methods of smart UGS planning and sustainable landscape design help integrate ecological performance and other functions of UGS. Smart UGS planning is a technical management tool and a human-centered smart application. A novel UGS classification method based on function combinations is proposed in the present work. Five types of UGS (Scenic UGS, Residential UGS, Commercial UGS, Office UGS, and Road UGS) in Baqiao District of Xi'an, Shaanxi Province, are selected as sample sites. Interviewees' socio-economic attributes, visiting frequencies, and differences in demands are investigated. Eventually, the UGSs researched in this work are optimized based on public preferences and the current conditions of the sites. Results demonstrate the following. (1) The public's preference for different types of UGS is different considerably. (2) Based on the public's preference, Scenic UGS is improved in terms of quantity, function, and management; Residential UGS is upgraded regarding quantity and accessibility; and Commercial UGS, Office UGS, and Road UGS are improved in terms of quality. The results could provide methodological references for planning different types of UGS and innovative insights for smart UGS planning and sustainable landscape design.

1. Research Background

Accelerated urbanization has produced many tricky problems. A smart city aims to solve these problems using intelligent approaches, achieving sustainable development [1]. At present, smart city construction has covered multiple fields, such as architecture, transportation, home furnishing, ecology, and public services [2]. Statistics revealed that as of the end of 2019, smart city construction in China was concentrated in several outstanding digital economies, smart city operators, and service providers, such as Baidu, Alibaba, and Tencent. Other areas should also develop simultaneously. Upgrading software at all levels is not only the need for urban development but also the intelligent integration of a country's urban governance and human activities. Smart

city construction has become an inevitable urban development trend in the world today, promoting the sustainable development of cities. Urban Green Space (UGS) is a key element of smart city construction. Adhered to the "New Urbanism" and the "Ultra High-Level" strategies, it keeps exploring its competitive advantages in terms of policy directions and urban development demands. Amidst the information technology innovations, how can UGS adapt to the demands for sustainable development in smart city construction? How to help cities enter the high-quality development stage through smart construction [3, 4]? These two issues have become the focuses of today's smart UGS planning.

Under the sustainable development strategy, the premise of UGS planning and design is to coordinate the

relationships among population, economy, resources, and the environment so that public space planning can be in a virtuous circle. Besides a helpful tool to plan urban lands and spaces, the UGS planning system is also a platform for practicing ecological civilization [5]. To manage and use urban data, Lv et al. constructed a 3D analysis and visualization urban management platform based on city information [6]. This platform could provide a series of e-government services, including environmental protection, green space planning, and urban resource monitoring and evaluation. Smart city landscape construction occupies nearly one-third of urban land [7], exerting a significant impact on sustainable urban development. UGSs, such as parks, squares, and affiliated green spaces, reflect the level of urban development to varying degrees. In the meantime, ecological greening is also an excellent approach to improve urban ecology [8, 9]. Anguluri and Narayanan designed a green index suitable for the local urban environment. They incorporated this index into smart city planning. The final result confirmed the importance of UGS planning in urban planning [10]. While the public gradually realizes the importance of ecological civilization, the initial environmental demand has been upgraded to the urban environmental demand coordinated with society, economy, and ecological environment. This demand matches the essential pursuit of the smart city.

At present, explorations about green space planning and sustainable landscape design in smart cities are still at the preliminary stage. The unified conclusion and methodology have not yet been formed. Green space planning shall adapt to the development of different countries and cities. In 2016, the Eleventh People's Congress of Xi'an, Shaanxi Province, issued the Xi'an Park Regulations Insurance, proposing to construct community parks near residential areas with convenient transportation and concentrated public services. This proposal reveals the impact of urban construction on livability and the pursuit of sustainable development. In the meantime, it also puts forward higher requirements for UGS's service levels. Research on smart UGS includes three aspects: the intelligentization of UGS spatial layout, the intelligentization of human-land relationships, and the intelligentization of green space facilities. In the present work, UGSs in Xi'an Baqiao District are used as sample sites. The importance of studying the public's preference for UGS can be confirmed by analyzing the current status and problems of UGS in Xi'an. UGS planning based on residents' demands can promote smart city construction and sustainable UGS development in Xi'an. The innovative point is the UGS planning strategies that meet the regional characteristics and consider residents' demands, and urban development policies are proposed from a sustainable perspective, providing methodological references for planning different types of UGS and innovative insights for smart UGS planning and sustainable landscape design.

2. Urban Green Space Planning and Landscape Design in Smart Cities

2.1. Urban Green Space System Planning in Smart Cities. Building a smart city system that sticks to the sustainable development strategy with open and self-adaptive

technologies can meet the demands of the ecological chain in smart city construction. This solution consists of a network, a cloud platform, and a center. The perception layer, edge layer, network layer, platform layer, and application layer are connected to establish a neural network that integrates and interconnects multisource heterogeneous networks, on-demand distribution, and local edge intelligence [11]. Figure 1 shows the global architecture of the smart city. Apparently, information infrastructure is the foundation of smart city development. Only by integrating and collecting information infrastructure data can a convenient, efficient, flexible, and innovative operation and service model be provided for urban public management and services. A cloud platform supported by city panoramic data and unified data/business services forms comprehensive management and emergency command center of resource convergence and sharing, intelligent decision-making, and cross-departmental coordination and linkage in cities [12]. The collaborative application of multiple approaches and technologies in the ecological strategy-oriented UGS planning reveals that ecological environment improvement planning is gradually developing and improving at the level of urban spatial planning [13, 14]. Based on the intelligent urban system, the intelligent implantation of the UGS system planning can significantly improve the intellectual level of regional management, support the scientific, efficient, intelligent, and refined green space management, enhance the intellectual ability of regional services, and provide convenient, practical, intelligent, and accurate green space services. By creating a novel pattern of smart green space consisting of "green space brain" plus "global smart services" can the planning vision of urban regional management, intelligent iteration of service system functions, and multiple upgrades be fulfilled.

The UGS system planning is often based on the urban site elements and urban style, which requires big data storage. The smart city system can integrate big data. Before planning the urban space as per the "smart" concept, the spatial layout of the area and the characteristics of the natural ecological environment [15] shall be considered; then, the UGS system can be planned rationally in combination with the urban road network layout and land-use type [16]. According to the big data statistics, the urban form can be macroscopically divided into the core type, the star type, the satellite type, and the linear type, as shown in Figure 2. A reasonable urban structure is of great value to the layout and ecological effects of the urban ecological network. The green areas of core-type cities usually exist in the form of dots or belts, mostly green ecological patches in the artificially constructed environment. Cities of the star type often have more than two intersecting development axes, around which urban activities are concentrated. Besides urban built-up areas, green spaces are also distributed on different radiation lines [17]. Satellite cities are centered on and distributed around large cities. UGS is distributed between satellite cities and central cities in the form of large green spaces. Cities of the linear type develop along transportation corridors, whose UGSs are distributed around these corridors as well. Besides, the urban form and ecological green space present the corresponding relationship in the layout. A mosaic relationship is formed between

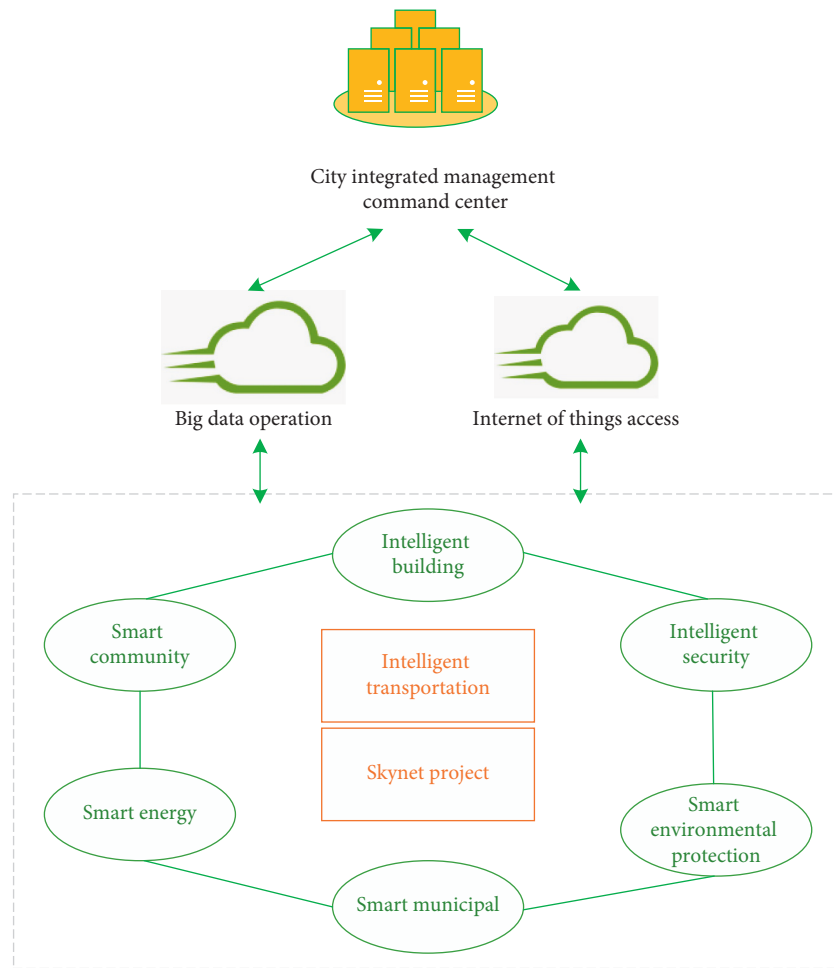


FIGURE 1: The overall framework of smart city.

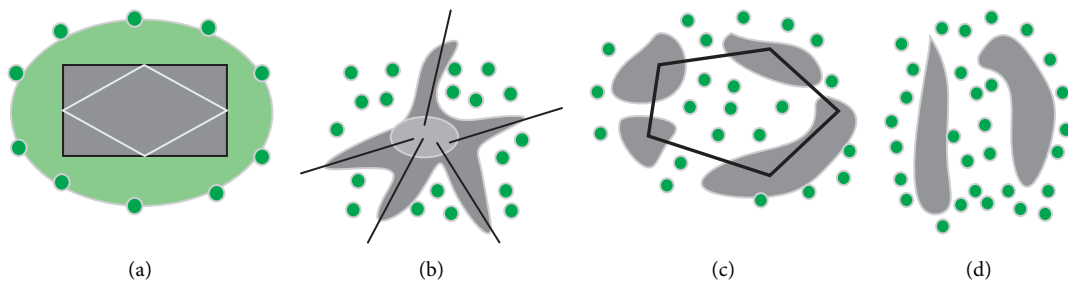


FIGURE 2: Different city types and green space distributions: (a) core type; (b) star stye; (c) satellite type; (d) linear type.

the green space and the city. The urban ecological environment space can determine the development of the urban form. The green space landscape can serve as an example; patches in the landscape are point-shaped factors, such as green spaces in parks, green spaces at squares, and the building space system [18–20]. The ecological corridor is a linear element of the landscape, which is an ecological network system composed of crisscross corridors and ecological patches. Corridors can make the basic spatial pattern of the ecosystem integral and, simultaneously, have ecological service functions, such as protecting

biodiversity and preventing soil erosion. The matrix is the surface element of landscape, the background ecosystem or land-use form in the patch mosaic, and the landscape element with the largest area and the best connectivity.

Big data applications are vital in smart UGS system planning. However, in fact, cities keep developing regardless of smart digital technology. Smart UGS planning should be not only a technical management tool but also human-centered smart applications. Traditional urban space planning is based on successful industrial city transformation

and renewal, which is different from urban space planning under the guidance of ecological strategy. From the urban spatial planning perspective, the pursuit of the environment has formed corresponding ecological strategies at both the macrolevel and microlevel. The UGS system planning shall include both a macro-based design, namely, a perfect ecological system, complex ecological functions, and high-level construction standards, as well as a humanistic demand-oriented microdesign, that is, a beautiful landscape environment, large activity facilities, complete commercial equipment, and theme facilities with artistic and humanistic characteristics, creating a novel type of green space with “people-orientation” and intelligent perception.

2.2. Sustainable Landscape Design in Smart Cities.

Landscape construction is the core to construct national ecological civilization and urban ecological civilization. The innovation of science and technology has brought more opportunities to the sustainable design of the landscape. New methods and techniques make the landscape design more intelligent. The sustainable landscape design aims to achieve the virtuous cycle of the landscape and shall coordinate the development of the site and people. The existing sustainable landscape designs include sustainable landscape patterns, sustainable landscape materials, sustainable landscape use, and sustainable management techniques. .

- (1) *Sustainable Landscape Patterns.* The landscape pattern should be rationally arranged in accordance with the characteristics of the surrounding environment to maximize the function, considering the sustainable principle of smart green space. For example, the continuity and aesthetics of the green belt on the street shall be considered. The residential landscape aims to provide residents with a pleasant environment and a landscape that meets people’s leisure and viewing needs. The industrial landscape emphasizes the functions of enclosing the landscape, purifying the air, and isolating noise. The landscape design of parks and plazas must meet the demands of the public while fully embodying aesthetics and urban characteristics.
- (2) *Sustainable Landscape Materials.* Landscape materials include soft landscape and hard landscape. Soft landscape refers to plant landscape; the sustainable plant landscape design can apply the native plants and configure natural wild plants [21]. Hard landscape refers to the application of ecological materials. Ecological materials refer to materials with excellent environmental coordination and good performance such as local materials, ecological permeable bricks, ecological concrete, and water filtration systems.
- (3) *Sustainable Landscape Use.* Adequate irrigation equipment shall be equipped on the road to improve or replace the soil that is not suitable for plant growth together with the urban drainage system [22]. Various plants in the park can provide diversified habitats for animals and help increase the

capacity of green carbon sinks. Compatible ecological service functions can meet perceived needs and provide life support features [23]. In the meantime, rational use of natural elements, such as light, wind, and water, reduces resources and energy consumption [24, 25].

- (4) *Sustainable Management Techniques.* Integrating the Internet of Things (IoT) technology with modern ecological parks to establish a large-scale smart park database can intelligently connect people and nature, achieving mutual induction, mutual understanding, and mutual interaction between humans and nature [26]. Figure 3 displays the basic structure of the smart park management platform. The open park information management based on the geographic information system (GIS) can comprehensively manage the information of urban gardens. By setting up hierarchical permissions, it provides a complete management platform for UGS planning and management, green space status and historical data, plant species, and diversity protection. GIS has powerful analysis functions and is gradually being applied to research cities. Using GIS, designers can better optimize the functional positioning of urban areas [27]. Lv et al. put forward a big data storage management scheme for the building information model (BIM) based on Web Virtual Reality GIS (WebVRGIS). In this scheme, BIM was connected to the integrated spatial and semantic information at all stages of urban architecture. A revolutionary transformation of urban information management was achieved in the entire life cycle [28]. On the operating system of Windows, combining GIS and computer achieved automatic landscaping management. This system is supported by GIS and intelligent decision-making of greening tree species. Functions such as query, editing, and analysis can be realized; on this basis, graphics can be output. In this way, the digital information system solves not only data processing but also the dynamic management of the connection between the system and the reality and the coordinated output and input. It provides technical aspects for the large scope of urban management and the difficulty of implementing supervision. Smart parks depend on the sensor nodes and wired and wireless communication networks deployed in urban gardens, realizing intelligent perception, irrigation, early warning, analysis, and other garden management works. Finally, fine cultivation, visual management, and intelligent decision-making can be balanced.

2.3. *Layout and Elements of Urban Green Space.* The development of a smart city emphasizes the quality of the environment. As a key component of urban infrastructure, UGS is a critical factor in evaluating urban quality. Since the reform and opening-up, China has gradually regarded the urban UGS construction as a prerequisite for improving the

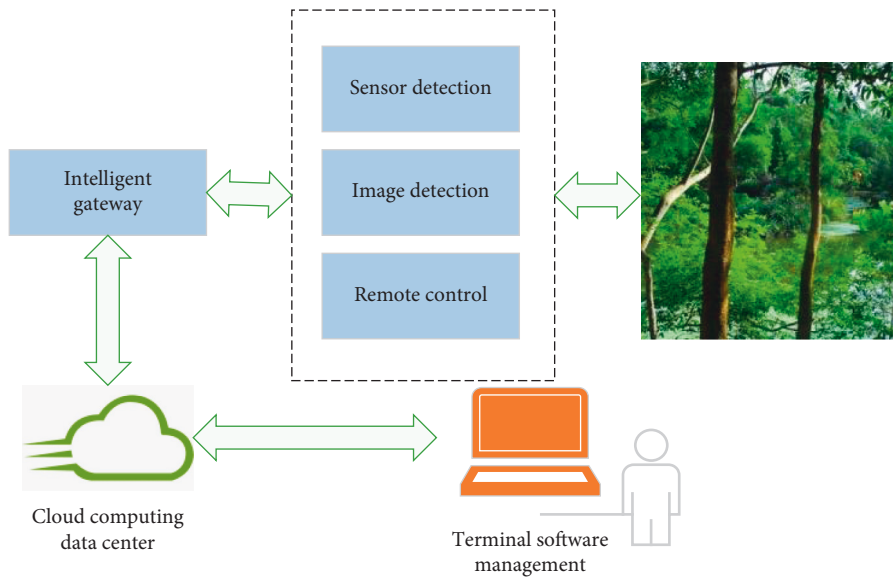


FIGURE 3: Smart garden management platform.

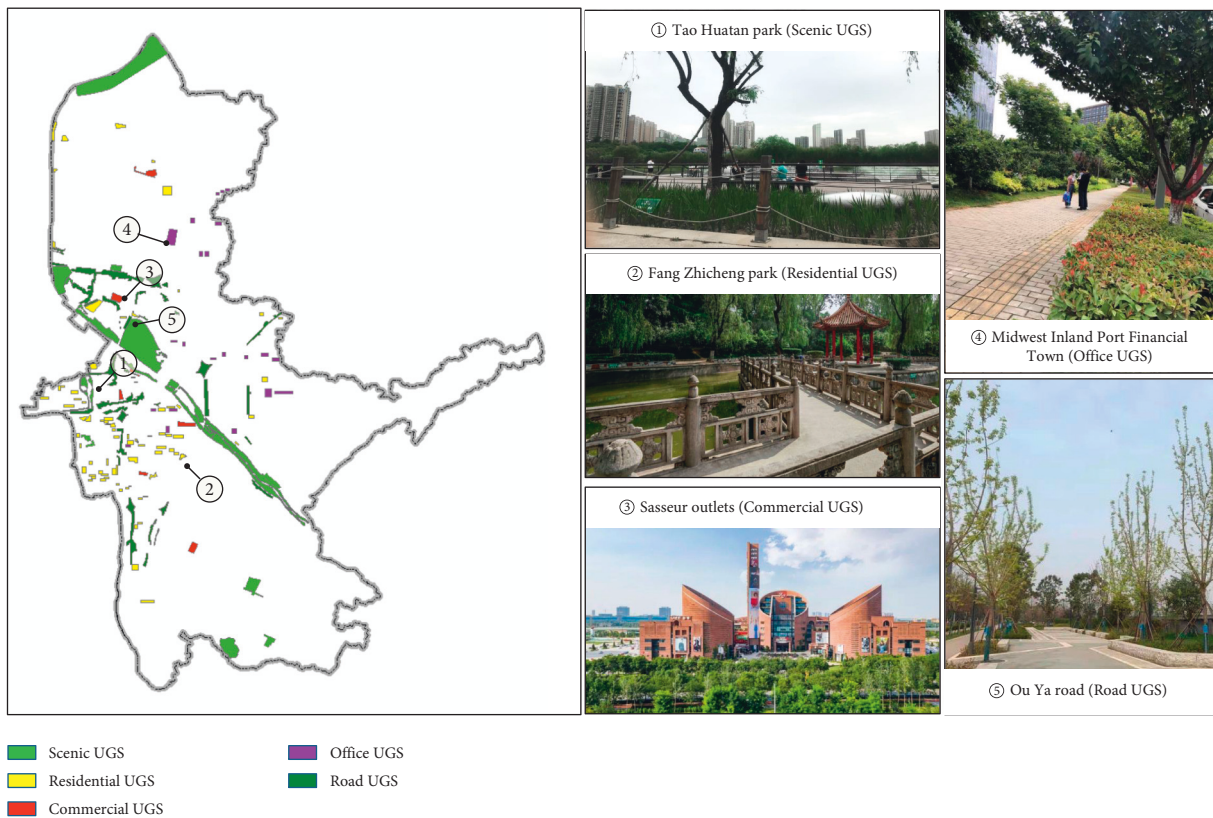


FIGURE 4: Spatial distribution of major UGSs in Baqiao District as well as the locations and images of the selected study sites.

living environment. The fairness and convenience of the UGS layout have significantly affected the quality of life. The supply of UGS can be evaluated from three aspects: quantity, accessibility, and quality. In particular, quantity refers to the area of UGS in a given area, and accessibility indicates service radius; these are the key factors affecting the spatial layout of green space [29, 30]. Quality is also an influential

criterion for evaluating UGS. The layout of UGS can be circular radial, wedge radial, networked, and based on local characteristics. The most common layout in China is the circular radial type. Since China has not yet issued a unified guideline to configure UGS per capita, there are differences in implementation and indicator settings in different regions. Setting indicators in accordance with the actual needs

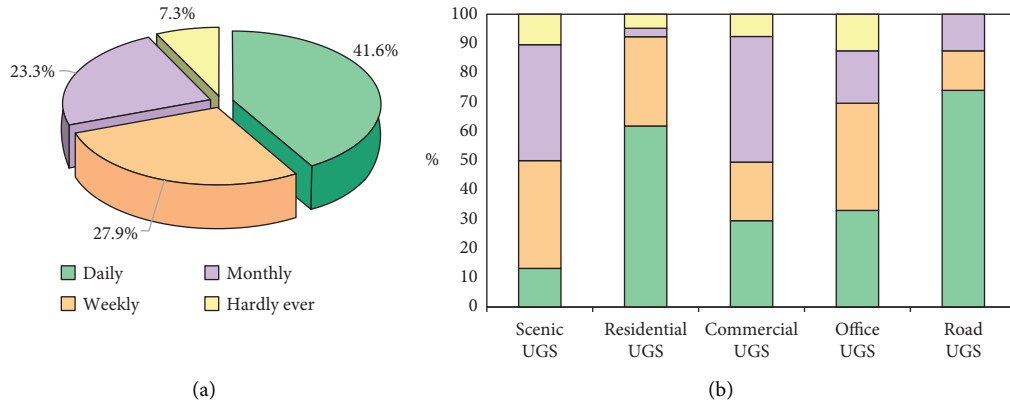


FIGURE 5: Graph of how often respondents accessed all UGSs (a) and each UGS (b).

of the site is conducive to the sustainable development of urban UGS.

2.4. Current Status and Problems of the Urban Green Space in Xi'an. Xi'an is located in the Guanzhong Basin and the middle reach of the Yellow River Basin. It is the largest central city in Northwest China, covering an urban area of 5145.66 km² (Xi'an Statistics Bureau, 2020). Lately, the UGS construction in Xi'an begins to focus on improving the quality of the ecological environment, promoting sustainable development, and vigorously accelerating the construction of an ecologically livable city. As a key component of urban landscape and infrastructure, UGS is a crucial factor in evaluating the construction of ecologically livable cities.

Currently, the green coverage rate of built-up area in Xi'an reaches 39.32%; the per capita green area of urban parks is 11.62 m² (Shaanxi Provincial Statistics Bureau, 2019). The structure of the Xi'an UGS system is clear, mainly circular road corridors and radial road network greening. However, the current greening network system is imperfect, and the ecological corridor lacks connections with green patches. With the intensification of urbanization in Xi'an, although the local government pays attention to the construction of urban UGS through investment, the occupation of UGS in the city has not been completely eliminated. In the case of relatively limited urban construction space, UGS is unevenly distributed and insufficient in scale, accompanied by the phenomenon of function mismatch. Studying the difference in public demand for different forms of UGS can help realize the reasonable supply of urban public service facilities and the optimal allocation of public resources.

Simultaneously, in the context of economic development and social progress, the public's demand for a better life is increasingly widespread, including the need for a high-quality urban material space environment. The focus of urban development has gradually shifted from the spatial expansion and layout of public service facilities to the diversity and difference of spatial individual behavioral needs. Therefore, in traditional physical space planning, increasing the demand analysis of the behaviors of different residents is

a prerequisite for promoting the harmonious coexistence between residents and the urban built-up environment.

In this regard, the present work aims to interpret the differences in the public's demands for different forms of UGS based on the actual situation of sample sites, thereby providing innovative insights for smart UGS planning and sustainable landscape design. This solution takes the public's preference for the scale, distance, and quality of different forms of UGS into account. To accomplish the research goal, UGSs in Xi'an Baqiao District are researched. (1) What preferences do Xi'an citizens have for the UGS researched? (2) How to optimize the researched UGS based on-demand differences?

2.5. Survey Objects and Research Methods. With a total land area of 325.3 km², Baqiao District is the largest administrative district in the urban area of Xi'an. It is rich in UGS types, with a permanent population of 703,900. Its urban greenery covers an area of 120.36 km². Because UGS is often defined as a public product maintained by public institutions and allowed access, the study area excludes farmland and nature reserves. Open spaces such as parks, squares, and subsidiary green spaces are researched in the present work. According to local government policies and land-use zoning, we put forward a novel method for green space classification based on functional composite combining the radiation range of different scales of UGS, considering the main land-use properties within the UGS radiation range, and defining the main types of UGS. This classification was helpful to realize the regionalization functions of UGS. On this basis, UGSs in Baqiao District can be classified into Scenic UGS, Residential UGS, Commercial UGS, Office UGS, and Road UGS. Questionnaire surveys were conducted on five UGS sites in Baqiao District to investigate the preference of Xi'an citizens for the UGS researched, namely, a Scenic UGS, a Residential UGS, a Commercial UGS, an Office UGS, and a Road UGS. Figure 4 shows sites.

A total of 550 questionnaires were issued at five sites, and 524 valid copies were returned, of which 106 were returned in Scenic UGS, 105 were returned in Residential UGS, 105 were returned in Commercial UGS, 112 were returned in Office UGS, and 96 were returned in Road UGS. Afterward, SPSS

23.0 and Microsoft Excel are practiced to analyze and visualize data of the questionnaire surveys. The dataset downloaded by ArcGIS is summarized as the data for spatial analysis. The geographic information and other conditional data of the actual sites are analyzed using GIS and other software.

3. Results and Discussion

3.1. The Utilization and Demand of Urban Green Space. Descriptive statistical methods are employed to analyze the data collected through the survey. The proportions of males and females in each sample site are evenly distributed. The population aged 18–35 (43.5%) and 35–60 (37.4%) constitute the leading group, followed by those over 60 (17.2%). Only 1.9% of the interviewees are under 18 years old. Interviewees from Residential UGS account for the largest proportion of senior people (38.1%) and present a lower education level on the whole. Interviewees from Scenic UGS and Commercial UGS show a higher education level on the whole. Correlation analysis reveals that age is negatively correlated with income, while education is positively correlated with income.

Figure 5 shows how often respondents accessed UGS. Moreover, 41.6% of interviewees visit UGS every day, 27.9% visit UGS every week, and only 7.3% hardly visit UGS, indicating that Xi'an citizens are highly active in visiting UGS. Besides, there are significant differences in the frequency of visits to the five sample sites. Residential and Road UGSs have the highest access frequency, and Scenic UGS has the lowest access frequency. Correlation analysis suggests that visiting frequency has the highest correlation with time cost and transportation cost, followed by age and income; the lower the time and transportation cost, the higher the frequency of visits; the higher the income, the higher the frequency of visiting UGS. Data collected in scenic UGS prove that the visiting frequency is negatively correlated with age. The older the age, the lower the visiting frequency. At other sample sites, age is positively correlated with the visiting frequency; that is, the older the age, the higher the visiting frequency. The reason for this result is that scenic UGS is often far from the settlement, and the senior citizens usually choose to travel in close distances.

The survey on the types of UGS demanded by the public in Baqiao District points out that the demand for increased Residential UGS is the largest (60.0%), followed by Scenic UGS (22.2%). In contrast, the demand for increased Commercial UGS (7.3%) and Road UGS (9.8%) is less, and the public has almost no demand to increase Office UGS (0.7%). This result is related to the unevenly distributed UGS in Baqiao District at present. In old residences, there are few or no UGS available. Scenic UGSs are concentrated in both banks of the Bahe River. Because of the construction period, UGS in the southeast has not been opened to the public, and the whole area has not yet formed a context. Commercial UGS, Office UGS, and Road UGS are newly built in the district so that the public rarely demands to increase the scale; instead, there are needs for quality improvement.

3.2. Optimization Strategies for Different Types of Urban Green Space. Based on the differences in public demand for different types of UGS, different optimization strategies are proposed in combination with the functional layout of UGS. Scenic UGS generally refers to a large-scale and regional-level UGS whose primary goal is to protect a nationally representative natural ecosystem. It connects regional ecological corridors and builds an ecological network. In the meantime, it is also an essential ecological leisure space in the city. Its spatial layout shall be planned based on the current urban blue-green system. The current layout of the blue-green system in Xi'an is summarized as follows: (1) the green space system in the main urban area is the core taking the Weihe River as the landscape axis; (2) the water network and road network are crisscrossed; (3) the surroundings are the green belt of the city wall, the green belt of the Second Ring Road, the green belt of the Ring Road, and the green belt of the Xixian Ring Road; (4) the eight riverside ecological belts serve as ecological landscape corridors; and (5) wedge-shaped green spaces are scattered sporadically. Figure 6 illustrates the global structure of the blue-green system in the main urban area of Xi'an. Based on the current blue-green space layout and public demand in Xi'an, Scenic UGS can be upgraded in terms of quantity, function, and management. Scenic UGS should be constructed in the central urban area and its surrounding area by combining wedge-shaped green belt and ecological spacer belt, to strengthen the ecological spacer between the central urban area and its surrounding areas. With the circular green belt as the link, the Scenic UGS can connect the wedge-shaped green space inward and the ecological landscape corridor outward. Functionally, the ecological leisure feature of Scenic UGS can be strengthened to provide the public with a space to experience nature and leisure. Moreover, intelligent management systems can be applied to plan policy transmission and improve the collaborative management and control mechanism.

Based on the public demand for UGS in Baqiao District and the current distribution of UGS, Residential UGS shall be upgraded in terms of quantity and accessibility. UGSs in residential areas are mostly community parks and pocket parks. According to local policies, the area of community park and pocket park is not less than 1 hm² and 0.04 hm² respectively. The service radius of the community park and pocket park is determined to be 800 m and 500 m, respectively, by analyzing residents' travel time requirements and urban road network. With the goal of increasing the coverage and accessibility of Residential UGS, taking residential groups as demand points, community parks and pocket parks as supply points, combined with the urban road network, the location allocation model was used to get the number of supply points that cover all demand points, and combined with the UGS per capita area index, the area of supply points can be calculated. By increasing the number and area of supply points, residents' demand for the quantity and accessibility of residential UGS can be met.

Based on the difference of public demand for UGS, Residential UGS, Commercial UGS, Office UGS, and Road UGS are mainly improved in terms of quality to integrate

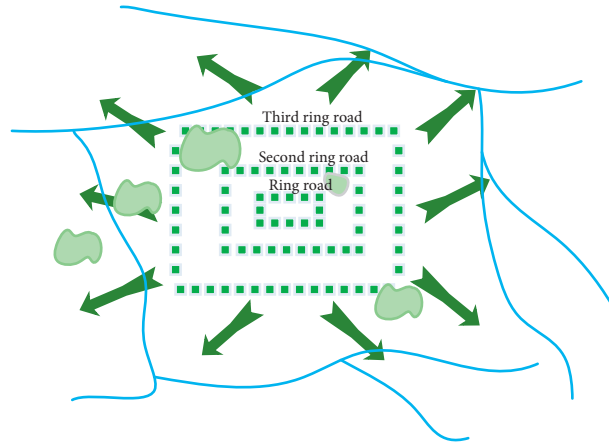


FIGURE 6: The general structure of the blue-green system plan for the main urban area of Xi'an.

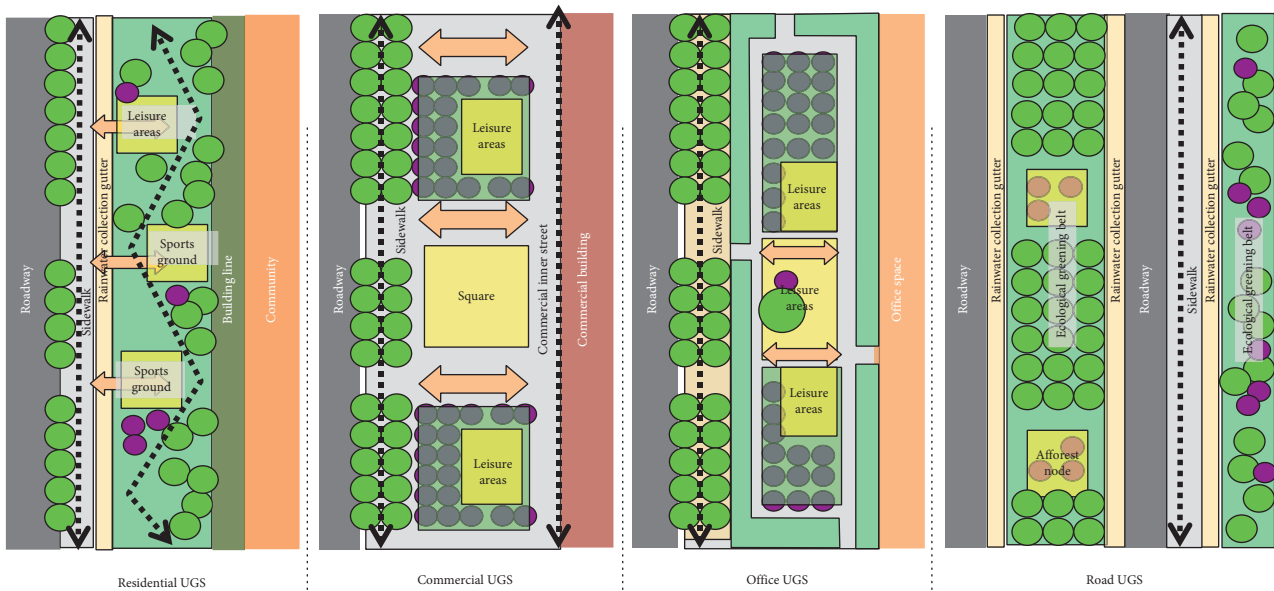


FIGURE 7: Typical UGSs plan that meets the needs of the public.

ecological performance and other functions, thereby meeting the needs of citizens from the perspective of diversified and refined supply. Residential UGS shall meet residents' demands for leisure activities and sports activities. Hence, sports facilities and rest spaces should be added. Because the majority of Residential UGS users are senior citizens, night lighting facilities should be increased considering the current situation of UGS. On the application of hard material to consider more flatter way of paving, in the meantime, a shielded space should be constructed between UGS and the residential area. The trees should enclose the junction to form a green wall to reduce the noise pollution of the public space to the residential area. Commercial UGS mainly considers the leisure activity space for passing, staying, and rest, focusing on the functions of exquisite display, and therefore municipal planning does not require large UGS. Office UGS provides a leisure space for the public to relax at work, emphasizing the atmosphere. Hence, native element landscape and plant landscaping can be increased to

create a natural atmosphere. Road UGS serves the demands of walking and passing, which should emphasize the continuity of the landscape and visual guidance, displaying the city image. Based on the functional differences, we summarize the typical layouts of different types of UGS as shown in Figure 7.

4. Conclusion

UGS planning in fast-developing countries is often limited to the unified indicators of scale and per capita area while ignoring the public's actual demands. At the same time, cities face severely eroded ecological spaces due to the very high population density, and planning new ecological spaces is especially difficult in downtowns. In this case, UGS must be smarter and capable of solving complicated problems in a limited space. Hence, the reasonable supply of land and the optimal allocation of public resources become pretty essential. As per land-use types, a novel UGS classification

method based on function combinations is proposed. UGSs in Xi'an Baqiao District are used as sample sites. A green space planning method oriented to differences in public demands is proposed through a questionnaire survey and big data analysis. Scenic UGS is improved in terms of quantity, function, and management. Residential UGS is upgraded regarding quantity and accessibility. Commercial UGS, Office UGS, and Road UGS are improved in terms of quality. A planning model based on diversified and refined land-use supply can better integrate the ecological performance and other functions of UGS. The research results can provide methodological references for planning different types of UGS and innovative insights for smart UGS planning and sustainable landscape design. However, survey interviewees rarely include young people, limiting the understanding of the public's demand for UGS. Future works can strengthen the research on the demands of young people to explore the requirement of different age groups for their better life.

Data Availability

The data used to support this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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