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Planning Strategies for Increasing the Occupancy Rate of Green Open Space Based on Urban Geographic Data in Macau: An Investigation of Ultra-High-Density Cities

Jitai Li [1,†], Fan Lin [2,†], Hongcan Cui [1,3], Yile Chen [4,*] and Shuai Yang [5]

[1] School of Landscape Architecture, Guangdong Eco-Engineering Polytechnic, No. 297, Guangshan 1st Road, Tianhe District, Guangzhou 510520, China; jitaili@foxmail.com (J.L.); cuihc@mail3.sysu.edu.cn (H.C.)
[2] Faculty of Business, City University of Macau, Avenida Padre Tomás Pereira, Taipa, Macau 999078, China; b20092100303@cityu.edu.mo
[3] School of Environmental Engineering, Sun Yat-sen University, No. 132 East Waihuan Road, Panyu District, Guangzhou 510275, China
[4] Faculty of Humanities and Arts, Macau University of Science and Technology, Avenida Wai Long, Taipa, Macau 999078, China
[5] School of Art and Archaeology, Hangzhou City University, No. 51 Huzhou Street, Gongshu District, Hangzhou 310015, China; samyang@zju.edu.cn
* Correspondence: 2009853gat30001@student.must.edu.mo
† These authors contributed equally to this work.

Abstract: Urban green space can effectively optimize the urban landscape and environment and provide residents with space for daily leisure and recreational activities. In order to realize the green development of Macau, this paper takes the Macau Special Administrative Region (SAR) as an example, uses the green open space occupancy rate (GOSOR) to measure the level of green open space in Macau, and researches the planning positioning of Macau City's green development, the layout mode of urban public open space, and the integration and optimization of the space in Largo of high-density neighborhoods, so as to explore the planning paradigm of Macau's green development. In addition, the research data show that the per capita green area of Macau Peninsula is on the low side and extremely unbalanced, and there is a disconnection between some of the large-scale green patches on Macau Outlying Island; therefore, this paper proposes that the planning layout mode of "green veins connecting green patches" is suitable for Macau Peninsula and that the planning layout mode of "greenways embedded in jade" is suitable for Macau Outlying Island. On the other hand, in order to improve the problem of poor living conditions in the high-density city of Macau, the study proposes to make use of the unutilized Macau Largo space and carry out the optimization and transformation of the Largo space from "gray to green", so as to release a large amount of green open space and enhance the GOSOR value of the high-density street area of Macau Peninsula.

Keywords: green open space planning strategies; green open space occupancy ratio (GOSOR); high-density city; Macau; Largo space

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1. Introduction

1.1. Research Background: Positioning of Urban Green Development Planning in Macau

After the 21st century, the trend of high-density urban development will become more obvious. High-density urban development has brought great impacts on urban space resources such as land, energy, transportation, construction, environmental sanitation, public facilities, and landscaping. Urban green spaces, as the "lungs" of Macau, can

effectively optimize the urban landscape and environment and provide space for residents' daily leisure and recreational activities [1,2]. In order to realize the green development of Macau's city, it is necessary to rationally plan public open space, advocate green living, integrate ecological and environmental protection policies, enhance the connectivity of public open space, and increase the per capita area of green open space and waterfront open space. It is necessary to integrate Macau's landscape base, green space, or public open space to construct a blue-green leisure space network so that citizens and tourists can enjoy high-quality public open space services.

As mentioned in the *Report on the Conclusions of the Consultation on the Draft Urban Master Plan of the Macau SAR (2020–2040)*, the Government of the Macau SAR has collected a total of 1265 opinions through different channels, which were collated and summarized on the website [3,4]. The top ten most popular issues (Level 2) of the draft Master Plan are, in descending order, "Residential Areas" (533 clauses), "Ecological Protection Areas" (444 clauses), "Utility Areas" (382 clauses), "Public Utilities Areas" (382 clauses), "Marine Area Use" (327 clauses), "Green Space or Public Open Space Area" (301 clauses) and "Transportation" (297 clauses), "Industrial Area" (260 clauses), "Commercial Area" (243 clauses), "Landscape" (242 clauses), and "Cultural Heritage Preservation". The draft General Plan is a hot topic in terms of specifications. The top ten most popular specific topics of the draft Master Plan (Level 3) are, in descending order, "mountains" (254 clauses), "increasing greening and open space" (242 clauses), "Alto de Coloane" (236 clauses), "the development of a new town" (236 clauses), "Nam Wan Lake Areas C and D, Colina da Penha (Penha Hill) view" (198 clauses), "Cultural heritage preservation" (170 clauses), "Hac Sha in Coloane, Coloane Back Garden" (141 clauses), "Reclamation of New Town Area D" (140 clauses), "Green travel, slow-moving traffic and pedestrianization system" (128 clauses), "Promoting Urban Renewal" (121 clauses), and "Planning and Zoning Principles" (112 clauses) [5]. It is obvious that most of the consultation comments are related to green open space in the city.

The objective of the *Macau Urban Master Plan* is to create a happy, smart, sustainable, and resilient city; to define non-urbanizable areas and related land use, and to protect natural resources and areas with landscape, archaeology, or history, or set limits on spaces that are not normally developable because of cultural value; plan landscapes and public open spaces rationally and integrate them with the natural ecological environment; and to combine mountains, water bodies, wetlands, and green spaces or public open spaces through the green network, which connects various greening nodes and water system nodes to form an organically connected blue-green network system [5].

From a satellite view of Macau, it looks like a jewel floating in a green ocean (Figures 1 and 2), with favorable conditions for urban development. According to the *Macau Urban Master Plan*, the future development of Macau is positioned towards two major goals, namely "promoting the construction of a world center of tourism and leisure" and "building a beautiful home for Macau residents". Therefore, it is necessary to adhere to the direction of green development, with ecological conservation, green planning, and green architecture as the main axes of urban construction, and to strengthen the spatial environmental protection measures along with the economic, social, and industrial development of the city so as to build a green cityscape and a quality living area that is "pleasant to live in, pleasant to work in, and pleasant to visit".

In the future urban planning and construction of Macau, efforts should be made to solve the current difficulties in further improving the quality of the urban open space environment and to satisfy the urgent demand of citizens and tourists for adequate leisure and open space. Through scientific planning, resources such as urban ecological space, waterfront space, green space, or public open space should be coordinated and organized into a system to promote the realization of the goal of urban green development.

Figure 1. Satellite remote sensing image of Macau Peninsula in October 2019. (Image source: The author captured the Google satellite image).

Figure 2. Satellite remote sensing image of Macau Outlying Island in October 2019. (Image source: The author captured the Google satellite image).

1.2. Literature Review

Urban green development is usually regarded as an important basis for protecting the ecological environment and efficient resource utilization, interacting with the level of urban economic development to create a livable [6–8], high-quality urban habitat, and then realizing the goal of joint sustainable development of the city's social, livelihood, economic, and environmental quality [9,10]. Green development is the rational coordination of the multiple development goals and realization paths of social, natural, and economic systems in cities; its essence is to enhance the quality of life of urban residents as the core, combined with the protection of the urban ecological environment, and on the basis of efficient use of

urban land resources, to establish an ideal mode of sustainable development for the urban socio-economy [11].

Regarding the planning mode of urban green development, there are various opinions from domestic and foreign experts and scholars. For example, Chen et al. believe that the level of urban green development can be measured through four aspects: sustainable urban economic development, social civilization, ecological environment, and quality level of livable construction. Among them, the indicators of urban livable construction level include detailed indicators such as the green coverage rate of built-up areas; the standard of urban ecological environment quality includes detailed indicators such as the forest cover rate [10]. Beatley et al. believe that a good ecological environment, compact urban layout, efficient land use, a convenient transportation system, and perfect infrastructure are all important elements for realizing green development in urban space development [8,12,13]. According to Shi et al., the main contents of urban green development focus on four aspects: livable life, low-carbon development, resource conservation, and environmental health; among them, the measurement of environmental health includes two indicators: the per capita green space level and the urban greening rate [14]. Li et al. argue that the implementation of park city development is one of the most important ways to realize urban green development. Among them, enhancing the accessibility, fairness, and participation of urban public space, optimizing the layout of urban space, improving the quality of urban habitat, and upgrading the service standard of urban parks and green spaces are all important components of realizing urban green development [15]. According to Yan et al., the indicator system for measuring the level of urban green development includes evaluation indicators such as the green coverage rate of urban built-up areas, the per capita green area of urban parks, the urban forest coverage rate, and the area of urban green space [16].

On the other hand, good ecosystem services are provided by high-quality urban green spaces in high-density cities, such as air quality regulation, microclimate regulation, water treatment, and cultural and educational values. They help mitigate the urban heat island effect, reduce urban flood risk, and provide habitat for biodiversity [17–19]. Besides, urban green spaces can bring positive effects to the urban living environment. The number of green spaces, their vegetation cover, and size significantly improve human well-being, particularly in health aspects [18,19]. In cities, the proportion of urban green space also has an important impact on the resilience of urban ecosystems; the proportion of urban green space should exceed 15% to ensure the health of the living environment [20,21].

From the viewpoints of the above scholars, we can see that the construction of a high-quality human environment is one of the ultimate goals of urban green development. The quantity and quality indicators of green open space, such as urban parks, urban green coverage, green space per capita, and the percentage of green open space, have a direct impact on the level of urban green development. Therefore, urban green development should mainly start from the perspective of enhancing the quality of the living environment through the scientific planning of green open space, improving the quality of the urban environment and ecological livability according to local conditions, solving the problems of lack of natural space and insufficient healthy open space caused by excessive urbanization, and promoting the sustainable development of the city.

2. Study Area and Methods

2.1. Study Area: Macau SAR

The Macau SAR is located on the southeast coast of China, on the west bank of the outlet of the Pearl River Delta, adjacent to Guangdong Province, and about 60 km away from the Hong Kong SAR. The Macau SAR consists of two major parts: the Macau Peninsula and the Macau Outlying Island. There are a total of 7 parishes in Macau, 5 of which are

located on the Macau Peninsula (Nossa Senhora de Fátima, Santo António, São Lázaro, Sé, and São Lourenço), and 2 are located on Macau Outlying Island (Nossa Senhora do Carmo and São Francisco Xavier). In 1840, the Macau Peninsula covered only 2.78 km^2 [22]. According to statistics from the Macau Cartography and Cadastre Bureau (DSCC), the land area of Macau was 32.9 km^2 in June 2018, including 9.3 km^2 of Macau Peninsula (refer to Figure 1 in Section 1.1), 7.9 square kilometers of Taipa Island (refer to Figure 2 in Section 1.1), 7.6 km^2 of Coloane Island, and 6.0 km^2 of Cotai City (refer to Figure 2 in Section 1.1) [23,24]. Additionally, the newly built urban area occupies 1.4 km^2, while the Macau Port Management Area, an artificial island located at the Zhuhai-Macau Port of the Hong Kong-Zhuhai-Macau Bridge, occupies 0.7 km^2. However, this figure does not include the 1.1 km^2 of the new campus of the University of Macau in Hengqin, Zhuhai City, and the adjacent 0.6 square kilometers of the Australian port area at the Hongqin Port. In 2020, the population density of Macau's urban area was about 20,800 people/km^2, which is one of the highest in the world [25] (Demographia World Urban Areas, 2021). Among them, the urban area of Macau Peninsula is only 9.3 km^2, and the population density is about 58,300 people/km^2, which is one of the most densely populated cities in the world [26,27]. This paper covers the entire territory of the Macau SAR (including the Macau Peninsula and Macau Outlying Island), and the relevant aggregated data mainly focus on the urban built-up area (Figure 3), with an area of 31.8 km^2.

Figure 3. Location of the Macau Peninsula and Macau Outlying Island. The small amount of Chinese text is from Zhuhai City, but it is not within the scope of this study. (Image source: The author's annotations are based on Google satellite images).

The content and objectives of the study are:

(1) Understand the current land scale and distribution of green open space in Macau.
(2) Combine with field research to read the satellite remote sensing image maps of Macau, organize and analyze the current state of green open space information, compile a summary table of various types of green open space sites based on the relevant statistical results, and draw a map of the current state of green open space distribution in Macau.
(3) Conduct detailed statistics on the number, area, and boundary of green open space in Macau, and then enter them into ArcGIS (10.7 version) after topology proofreading to establish a database of green open space in Macau and analyze the status of Macau's background resources of green open space on the basis of this database.

2.2. Data Sources and Methodology

The contents of the basic data collected for the research work of this paper are mainly:

(1) Urban Green Space Classification Standard (2015) by the Civic and Municipal Affairs Bureau of Macau;
(2) 1:10,000 AutoCAD (2020 version) base map of the current state of urban green space in Macau (2020);
(3) A 1:1000 AutoCAD map of the whole territory of Macau (October 2020);
(4) Remote sensing image map of Macau (October 2020) with 0.6m accuracy;
(5) Other land data and population data are from references [28–33], as a supplement to the above.

The research work adopts the method of comparing remote sensing image maps with AutoCAD maps combined with on-site surveys and utilizes AutoCAD (2020 version) and ArcGIS (10.7 version) software to extract information, process images, and output the results of Macau's existing green spaces, water bodies, and other patches. In 2015, the urban green area of Macau Peninsula was 1,349,608 m^2; the urban green area of Macau Outlying Island was 9,612,915 m^2. As a result of new statistics, by the end of 2020, the urban green area of Macau Peninsula was 1,817,215 m^2 (Figure 4), and the urban green area rate of Macau Peninsula was 16.08%. Based on the resident population of the Macau Peninsula of 532,700 in 2021, the average per capita green area of the Macau Peninsula is only 3.3 m^2. The urban green area of Macau Outlying Island is 10,511,160 m^2 (Figure 5), the urban green area ratio of Macau Outlying Island is 46.5%, and based on the resident population of 149,700 in 2021, the per capita green area of Macau Outlying Island will be 65.79 m^2, which is significantly higher than that of Macau Peninsula and is about 20 times that of Macau Peninsula.

Regarding the study of the service radius of urban green space, considering that Macau has the characteristics of a small urban scale and urban area, the study set up green space service radii of 100 m, 200 m, and 300 m, and analyzed whether all residents of Macau can use urban green space within walking distance. The study and analysis of the green space service radius used ArcGIS software (10.7 version) to analyze the service radius of 100 m to 300 m of Macau's urban green space. The analysis results show that on the Macau Peninsula, the green space service radius of 100 m can cover part of the urban area, the green space service radius of 200 m can cover most of the urban area, and the green space service radius of 300 m can basically cover all urban areas (Figure 6). On Macau Outlying Island, the green space service radius of 300 m can cover most of the urban area (Figure 7). However, for the high-density urban areas of the Macau Peninsula and Macau Outlying Island, although the green space service radius of 300 m serves most of the urban residents, the problem of low per capita green space rate caused by the low urban green space area still exists.

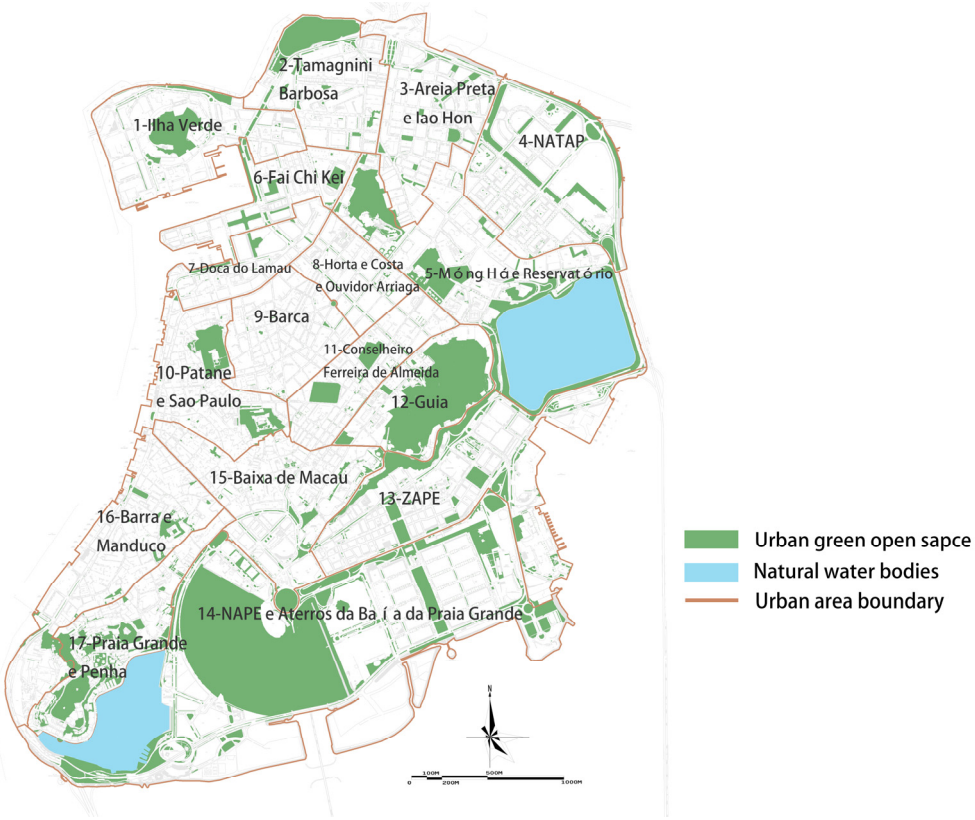

Figure 4. Distribution of green open space in 17 precincts of Macau Peninsula. (Image source: Drawn by the author).

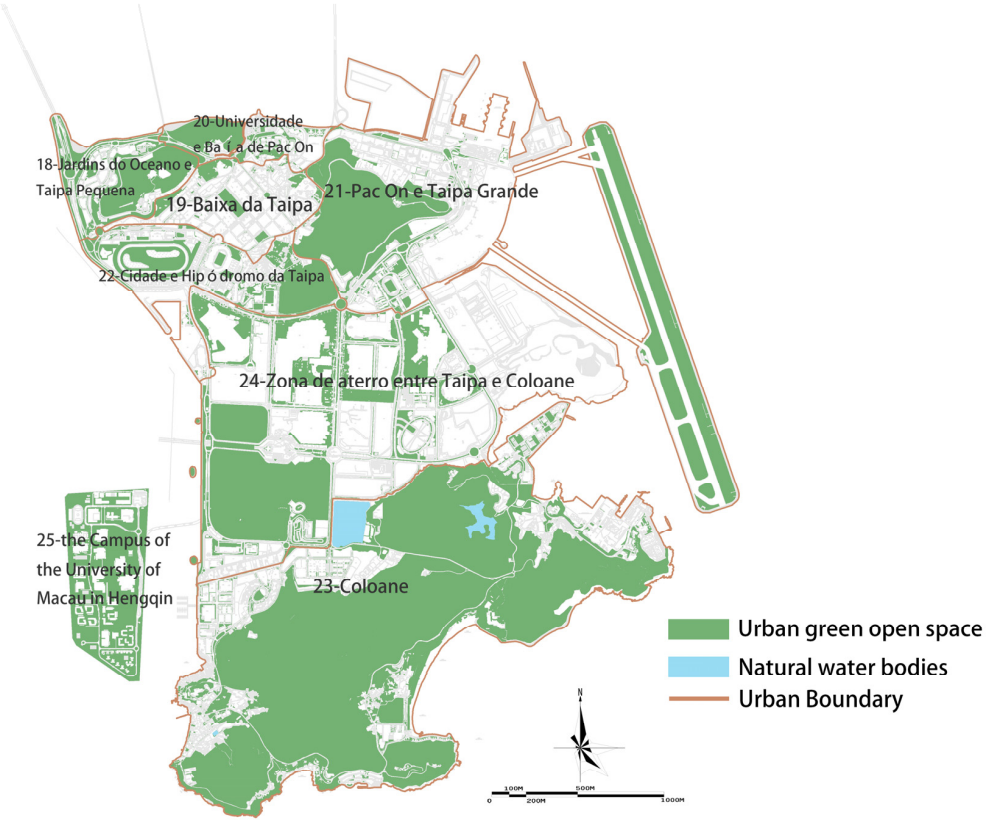

Figure 5. Distribution of green open space in 8 precincts of Macau Outlying Island. (Image source: Drawn by the author).

Figure 6. 100~300 m urban green space service radius in Macau Peninsula. (Image source: Drawn by the author).

Figure 7. 100~300 m urban green space service radius on Macau Outlying Island. (Image source: Drawn by the author).

2.3. Classification System and Definition of Public Open Space in Macau City

Corresponding to the current Macau Urban Green Space Classification Standard 2015 Edition, this paper classifies Macau's urban public open space into 3 medium categories and 10 sub-categories. The medium category includes: green space in parks (SG1), street Largo (SG2), and courtyard green space (SG3). The sub-categories are all urban green open space, except for part of Largo Plaza SG23, which is gray open space (Table 1).

Table 1. Classification attributes of open space in Macau City.

Open Space Name and Classification Code			Definition of Functional Properties of Open Space Sites	Explanation of Statistical Diameter (Corresponding to the current *Macau Urban Green Space Classification Standard 2015 Edition*)
Major Category	**Middle Category**	**Minor Category**		
Public open space (POS)	Green space in park SG1	City Park SG11	Public green spaces located in urban areas that are open to the public, have supporting service facilities and are suitable for outdoor recreational activities; the main forms are municipal parks, community parks, and specialized parks.	Corresponding to MG11 City Park
		City Garden SG12	Relying on streets, courtyards, buildings, or specific spatial environments, the public green space is characterized by the integration of plant landscaping and open space, and has a more refined landscape; the main forms include street gardens, observation decks, hotel gardens, historical gardens, cemeteries, and so on.	Corresponds to MG122, MG123, MG124, MG125, MG127 in MG12 City Garden
		Country Park SG13	A natural space located on the outskirts of the city with facilities for barbecuing, hiking, biking, etc. It provides a place for the public to enjoy the scenery of the countryside.	Corresponding to MG13 Country Park
		University Campus SG14	University campuses with lower building densities, a green space ratio of more than 50%, and easy access to activities and recreation for teachers, students, and the public, such as the Hengqin Campus of the University of Macau.	Corresponds to the University campus portion of the MG142 green courtyard
	Street Largo SG2	Street green space SG21	Greening sites supporting the construction of urban roads generally include green belts on roads and green spaces on traffic islands.	Corresponding to MG21 Road Green Space
		Facility Green Space SG22	Supporting green spaces within the sites of urban transportation infrastructure facilities, including green parking lots and green spaces within the construction sites of urban bridges, tunnels, airports, piers, stations, and other transportation facilities.	Corresponding to MG22 Facility Green Space
		Largo Plaza SG23	An open space or plaza in the forecourt of a major city building for public gatherings and events.	Corresponding to MG121 Plaza Garden
	Courtyard green space SG3	Garden by the House SG31	Green spaces within or adjacent to urban residential sites.	Corresponding to the green space next to the MG141 residence
		Green Courtyard SG32	Green space for recreation within the city's commercial and industrial districts, public buildings, and infrastructures.	Corresponding to MG142 Green Courtyard
		Temple Garden SG33	The gardens attached to religious buildings such as temples, palaces, shrines, and churches.	Corresponding to MG126 Religious Garden

Source: Statistical data provided by the author.

Table 2 shows the distribution of GOSOR indicator values of 25 urban sub-districts in the current situation of Macau. Combined with Table 2 and Figure 4, the urban sub-districts of Macau Peninsula, with sub-districts numbered from 1 to 16, generally have low per capita GOSOR values, and there is a serious imbalance in the distribution of green space among the urban areas of Macau Peninsula. For example, the lowest per capita GOSOR value is in Barca, with only 0.06, and the highest is in NAPE e Aterros da Baía da Praia Grande, with a per capita GOSOR value of 76.20. Combined with Table 2 and Figure 5, the per capita GOSOR values of the outlying islands of Macau are low compared to those of Macau Peninsula, except for Baixa da Taipa, with a zoning number of 19. Compared with

the Macau Peninsula, except for Baixa da Taipa, numbered 19, which has a low GOSOR value, the per capita GOSOR values of the rest of the Macau Outlying Island's zoning districts, numbered 17 to 25, are generally higher, and the distribution of green space on the Macau Outlying Island is relatively balanced compared with that on the Macau Peninsula.

Table 2. The study of the current status of GOSOR value in 25 urban sub-districts of Macau.

Location	City Zoning and Numbering	Urban Sub-Districts Area (km^2)	Urban Sub-Districts Green Space Area (m^2)	Urban Sub-Districts GOSOR (%)	Urban Sub-Districts Population (Ten Thousand People)	GOSOR Rate per Capita (%)
Macau Peninsula	1. Ilha Verde	0.5	64,222	12.8	2.51	2.56
	2. Tamagnini Barbosa	0.4	74,899	18.7	3.88	1.93
	3. Areia Preta e Iao Hon	0.4	30,945	7.7	7.68	0.40
	4. NATAP	0.6	84,531	14.1	7.16	1.18
	5. Móng Há e Reservatório	1.0	529,500	53.0	2.56	20.68
	6. Fai Chi Kei	0.3	30,329	9.9	2.69	1.13
	7. Doca do Lamau	0.2	10,673	5.3	3.09	0.35
	8. Horta e Costa e Ouvidor Arriaga	0.2	5167	2.6	2.82	0.18
	9. Barca	0.3	2739	0.9	4.67	0.06
	10. Patane e São Paulo	0.4	54,390	13.6	3.07	1.77
	11. Conselheiro Ferreira de Almeida	0.3	33,824	11.3	2.66	1.27
	12. Guia	0.3	202,459	67.5	0.66	30.68
	13. ZAPE	0.8	115,742	14.5	1.66	6.97
	14. NAPE e Aterros da Baía da Praia Grande	2.1	899,200	42.8	1.18	76.20
	15. Baixa de Macau	0.5	38,479	7.7	2.27	1.70
	16. Barra e Manduco	0.5	33,026	6.6	4.25	0.78
Macau Outlying Island	17. Praia Grande e Penha	0.4	100,005	25.0	1.17	8.55
	18. Jardins do Oceano e Taipa Pequena	0.8	426,973	53.4	1.03	41.45
	19. Baixa da Taipa	0.9	111,769	12.4	7.02	1.59
	20. Universidade e Baía de Pac On	0.5	206,323	41.3	1.51	13.66
	21. Pac On e Taipa Grande	4.4	1,628,139	37.0	0.87	187.14
	22. Cidade e Hipódromo da Taipa	1.4	505,008	36.1	0.57	88.60
	23. Coloane	7.6	5,451,480	71.7	3.23	168.78
	24. Cotai reclamation area	6.0	1,673,238	27.9	0	—
	25. University of Macau Hengqin Campus	1.0	662,648	60.8	—	—
Macau	Total value of Macau	—	12,975,708	Average 26.2	—	—

Source: Statistical data provided by the author. Remarks: (i) The statistical time limit of the basic data in this table is the end of 2020; (ii) The urban land includes 11.3 km^2 of Macau Peninsula, 21.6 km^2 of the outlying islands, 1 km^2 of the Campus of Macau University in Hengqin, and the total area of Macau is 33.9 km^2; among them, 2.1 km^2 of New Town A and the artificial island of the Hong Kong-Zhuhai-Macau Bridge have not yet been developed and are not included in the statistics of the indicators for the time being.

3. Layout Patterns of Public Open Spaces in Macau City

Combined with the analysis of Macau's high-density urban status, the urban public open space layout model needs to give full consideration to strengthening the connectivity between small and medium-sized open spaces. Therefore, the ideal structural pattern for the overall layout of urban public open space in Macau should be "green space in park SG1, street Largo SG2, courtyard green space SG3", and other green space patches, which are interconnected with green veins and green paths through streets and largos and linked to the open space layout such as ecological wetlands and natural bodies of water (Figure 8).

As shown in Figure 8, due to the high density of buildings on the Macau Peninsula, the proportion of green open space land is relatively low, and it is appropriate to adopt the planning mode of "green veins and green patches" for the layout of public open space on the peninsula. That is to say, through the relatively slim "green veins" of streets and lanes, city parks (SG11), city gardens (SG12), street green spaces (SG21), facility green

spaces (SG22), largo plazas (SG23), gardens by the house (SG31), green courtyards (SG32), and temple gardens (SG33) should be connected to each other in a space chain so as to form a more complete system of open space for the public. The ecological system of the Outlying Island has been developed to form a more complete system of open space for the public. The ecological environment of the Outlying Island has a better foundation, and the land use is relatively spacious, so the planning layout model of "greenways embedded in jade" can be adopted. Through wider "greenways", the various small types of "emerald"-shaped public open spaces in the Outlying Island urban area (city parks SG11, city gardens SG12, country parks SG13, university campuses SG14, and Largo plazas SG23, etc.) can be connected to form a green open space system that takes into account the functions of public recreation and ecological protection.

Figure 8. Ideal layout of public open space in Macau City. (Image source: Drawn by the author).

3.1. Macau Peninsula: "Green Veins and Green Patches" Planning Model

In this paper, the term "green veins" is defined as small to medium-sized linear green spaces, specifically referring to the street green space SG2 in the urban open space classification system of Macau, including the street green space SG21, the facility green space SG22, and Largo Plaza SG23. "Green Spot" is the abbreviation of green space patches, i.e., green space in the form of blocks, such as green space in park SG1 and courtyard green space SG3.

Unlike the urban planning practice in the Chinese Mainland, where greenways are mostly developed to connect with city parks, in the high-density urban areas of the Macau Peninsula, many streets and lanes do not have the width of greenways required by the national standard, nor do they have sufficient backup land resources (Figure 9).

Therefore, for the construction of the public open space system on the Macau Peninsula, it is appropriate to adopt the planning layout mode of "green veins and green patches". That is to say: through planning to change the existing attributes of some urban land, to form some new-shaped parks and green spaces (green patches); at the same time, vigorously

promote the implementation of measures to increase the greenness of building facades in streets and lanes, to increase the greenness of narrow streets, so that they can form miniature green corridors (green veins) in the city, like capillary vessels. On this basis, the new "green veins" and "green patches" planned for the Macau Peninsula will be connected to existing linear green spaces, such as road greenery, and linked with various "green patches" to form public open spaces that are actively adapted to the high-density urban environment. This will form a planning paradigm for a public open space network that actively adapts to the high-density urban environment (Figures 10 and 11).

Figure 9. Cramped green space on Macau Peninsula. (Image source: Photographed by the author).

In order to facilitate comparison, this study will divide open space green patches on the Macau Peninsula according to the size of the area into five levels, defined as R for the Peninsula green patches area code, using ArcGIS (10.7 version) statistics to calculate the number of green patches in the current green open space I~V level, and the results are shown in Tables 3 and 4.

Table 3. Indicators of the current status of the number of green patches in the open space of the Macau Peninsula.

Scale Classification	Size of Green Patches (m^2)	Number of Plots
Class I	$R \geq 5000$	35
Class II	$2000 \leq R < 5000$	17
Class III	$1000 \leq R < 2000$	41
Class IV	$200 \leq R < 1000$	97
Class V	$R < 200$	80
Total		273

Source: Statistical data provided by the author.

Table 4. Statistics on the number of open space green patches on Macau Peninsula by size class.

Category Coding	Open Space Green Patches Category	Number of Open Space Green Patches R Graded Plots				
		Class I ($R \geq 5000$)	Class II ($2000 \leq R < 5000$)	Class III ($1000 \leq R < 2000$)	Class IV ($200 \leq R < 1000$)	Class V ($R < 200$)
SG11	City Park	18	3	9	12	0
SG12	City Garden	12	6	13	43	12
SG31	Garden by the House	1	2	5	11	0
SG32	Green Courtyard	0	2	12	26	62
SG33	Temple Garden	2	3	2	4	6
	Total	33	17	41	97	80

Source: Statistical data provided by the author.

From Tables 3 and 4, it can be seen that the layout of green patches in the public open space of the Macau Peninsula is dominated by the small size of Class IV and Class V block green spaces, which are 97 and 80, respectively, with the main forms of green courtyard SG32 and city garden SG12. The large size of Class I and Class II block green space is smaller, which are 33 and 17, respectively, with the main forms of city park SG11 and city garden SG12. There are a total of 41 medium-sized Class III parcels of green space, mainly in the form of city gardens (SG12), city parks (SG11), green courtyards (SG32), and gardens by the house (SG32). Overall, the layout of green patches in the existing public open space on the Macau Peninsula is relatively scattered, with larger green patches (such as Parque Municipal Dr. Sun Yat Sen, Parque Municipal da Colina da Guia, and Nam Van Lake Park) mainly concentrated in the northern, eastern, and southern parts of the city. In the northwestern, northeastern, western, and central parts of the Peninsula, such as Areia Preta e Iao Hon, Doca do Lamau, Patane e São Paulo, Conselheiro Ferreira de Almeida, Barca, Horta e Costa e Ouvidor Arriaga, Barra, and other high-density urban districts, the size of individual green patches in the public open space is generally small, mainly in the form of green courtyards and gardens by the houses, with a lack of green veins linking with each other, making it difficult to form a system (Figure 11).

Figure 10. Layout of existing green patches and new planning green patches on Macau Peninsula. (Image source: Drawn by the author).

Figure 11. Existing green veins and planned new green veins on Macau Peninsula. (Image source: Drawn by the author).

In 2020, the total area of public open space on the Macau Peninsula will be about 1,585,981 m^2. With a resident population of 539,800 on the peninsula [34], the per capita area of public open space will be about 2.94 m^2. According to the international urban green space system planning standards, the residents' holiday service demand for nearby city parks accounted for about 10% of the total population [35–37]; the peak number of people served at the same time in the public open space of the Macau Peninsula during the holidays is estimated to be about 53,980, and the per capita area of the public open space is about 29.4 m^2/person, close to the *People's Republic of China Code for the design of public park (GB51192-2016)* in the definition of the comprehensive park per capita activity area indicators (30~60 m^2/person) of the lower limit [38–40]. In order to raise the activity area of public open space per capita for Macau Peninsula residents above the national standard (30 m^2/capita), it is necessary to flexibly utilize the existing urban land resources, partially change the attributes of the existing land, and increase the supply of public open space by combining the measure of "turning gray into green (turning gray open space into green open space).

For example, the status of Ilha Verde Hill and Colina da Barra (Barra Hill) on the Macau Peninsula is that they are not open to the public and they are not public open spaces. However, through planning, their land status can be changed from landscape woodland to city park, which can not only increase the area of public open space on the Macau Peninsula by 82,341 m^2, but also solve the problem of a serious shortage of public open space in the northwestern part of the peninsula, Ilha Verde District, and the southwestern part of the peninsula, Barra District. After calculation, by adjusting the attributes of the existing green

space through planning means, the total area of public open space on the peninsula can be increased to 1,668,322 m^2, and the indicator of per capita activity area of public open space can be increased to 30.9 m^2, which can reach the bottom line of green space service in urban parks stipulated by the national standard.

The existing green veins of the Macau Peninsula are mainly concentrated in the northern, southern, and southeastern parts of the city, with road green space and street green space as the main forms of existence; in the central part of the city, there is a serious lack of green veins connecting the parks and green spaces. Therefore, the new green veins in the plan are mainly concentrated in the central old town area of the Macau Peninsula, aiming to enhance connectivity between parks and gardens in this area (Figure 12). Take the planning of green veins between Parque da Fortaleza do Monte and Jardim de Luís de Camões as an example. At present, only Rua de São Paulo and the internal roads of Rua de São Paulo Park have road green belts and street trees, the rest of the roads (such as Rua de Santo António, Travessa de S. Paulo, and other road sections) are all hard-paved gray open space, and only part of the road sections have a small number of potted plants with minimal green visibility, which makes it impossible to form a green vein network connecting with Rua de São Paulo. Through the "gray to green" planning strategy, it can be used to strengthen the three-dimensional greening of roads and streets to enhance the green visibility of spaces like Rua de Santo António and other sections of the green veins, planning green veins, and connecting the existing green veins to form a network of green vein systems. This will not only increase the area of public open space on the Macau Peninsula but also enhance the interoperability between various types of green spaces in the urban area.

Figure 12. "Green Veins and Green Patches" planning model for public open spaces on Macau Peninsula. (Image source: Drawn by the author).

3.2. Macau's Outlying Island: The "Greenway with Jade" Model

In urban planning terminology, a greenway is a linear green open space that is generally equipped with slow-moving roads [34]. In this section, "emerald" is defined as large green space patches, which mainly include city parks (SG11), country parks (SG13), and university campuses (SG14). Except for the Taipa central district in the high-density northwestern part of Macau, which has a low percentage of green open space, the rest of Macau's outlying islands have a relatively large amount of public open space, and the distribution of public open space is relatively even. In the rest of the urban areas, public open space is more abundant and evenly distributed, and the urban roads and their green spaces are wider. Therefore, the layout of public open space on the outlying island of Macau can adopt the "greenways embedded in jade" planning model, making full use of the existing greenway network to enhance connectivity between large and medium-sized green patches on the outlying island (Figures 13 and 14).

Figure 13. Cramped green space on Macau Outlying Island. (Image source: Photographed by the author).

Since the green patches on the outlying island of Macau are usually bigger, this study divides them into five groups of different sizes (Table 5). The area code of the green patches on the outlying island is Y, and ArcGIS was used to count the number of green patches on the outlying island of Classes I–V. The results are shown in Tables 5 and 6.

Table 5. Current Indicators of the number of green patches in the open spaces of Macau Outlying Island.

Scale Classification	Size of Green Patches (m^2)	Number of Plots
Class I	$Y \geq 10{,}000$	41
Class II	$5000 \leq Y < 10{,}000$	14
Class III	$1000 \leq Y < 5000$	63
Class IV	$200 \leq Y < 1000$	58
Class V	$Y < 200$	46
Total		222

Source: Statistical data provided by the author.

Figure 14. The current layout of the "Jade" green spot in the public open space of Macau's outlying island. (Image source: drawn by the author).

Table 6. Statistics on the number of green patches in Macau's outlying island by size classification of open spaces.

Category Coding	Open Space Green Patches Category	Number of Open Space Green Patches Y Classified Plots				
		Class I (Y ≥ 10,000)	Class II (5000 ≤ Y < 10,000)	Class III (1000 ≤ Y < 5000)	Class IV (200 ≤ Y < 1000)	Class V (Y < 200)
SG11	City Park	8	3	4	7	0
SG12	City Garden	18	3	16	17	8
SG13	Country Parks	4	0	0	0	0
SG14	University Campus	2	0	0	0	0
SG31	Garden by the House	2	2	19	7	12
SG32	Green Courtyard	6	6	22	24	23
SG33	Temple Garden	1	0	2	3	3
	Total	41	14	63	58	46

Source: Statistical data provided by the author.

From Tables 5 and 6, it can be seen that there is not much difference in the number of green patches in open spaces of Classes I, III, IV, and V in Macau's Outlying Island, which are 41, 63, 58, and 46, respectively. In terms of layout, the larger-scale green patches of Classes I and II are mainly located in city park SG11, city garden SG12, country park SG13,

and green courtyard SG32, which are more evenly distributed in the northern, central, and southern parts of the island. The medium-sized Class III and IV green patches are mostly city parks (SG11), city gardens (SG12), gardens by the houses (SG31), and green courtyards (SG32), while the smaller-sized Class V green patches are mostly gardens by the houses (SG31) and green courtyards (SG32). Therefore, from an overall point of view, the distribution of green patches in Macau's Outlying Island is relatively uniform, and the larger ones are the Parque Natural da Taipa Grande, Zona de Lazer da Marginal da Taipa, Parque Natural da Barragem de Hac Sá, Parque Natural da Barragem de Ká Hó, etc. Greenways have been planned and basically completed between those large green patches (Figure 15). In the central area of Taipa in the northwestern part of the island, there are still small green areas in the urban area, with mainly green courtyards and gardens by the houses, and the connection of greenways between urban parks is sporadic.

Figure 15. Layout of existing greenways and new planning greenways in the outlying island. (Image source: Drawn by the author).

By the end of 2020, the area of public open space on the outlying island of Macau will be 6,691,680 m^2; the resident population of the city will be 142,000 [24–27]; and the per

capita area of public open space will be 47.1 m^2. This indicator is of an excellent standard in both domestic and overseas cities. The current construction standard of greenways on the outlying island is higher than that of the Peninsula. Except for the phenomenon of "disconnected" greenways in individual neighborhoods, large green patches in the eastern, southern, and northern parts of the outlying island can basically be connected by greenways. In terms of the proportion of green open space, the ecological environment of Macau's outlying island has already reached an excellent standard and can provide better ecological services for the residents, so there is no need to plan for new parks and green spaces to expand the area of public open space, as in the case of the Peninsula. The new greenways to be planned for the outlying island mainly focus on the Baixa da Taipa district, the Cidade e Hipódromo da Taipa district, and the Universidade e Baía de Pac On district, as well as some of the disconnected greenway networks in the Coloane district to supplement and connect and to strengthen the systematic connectivity between large-scale green spaces such as city parks, country parks, and university campuses, realizing the "greenways embedded in jade" planning model (Figure 16).

Figure 16. Macau Outlying Island public open space "Greenway with Jade" planning model. (Image source: Drawn by the author).

4. Discussion: Gray Open Space Utilization—Macau Largo Space Integration and Optimized Utilization Strategy

Macau's high-density urban areas are characterized by a small amount of green open space per capita and a lack of green space backup resources. This section focuses on the study of open space in largos and streets in such high-density urban areas and explores the integration and optimization planning strategy of how to effectively utilize the "gray open space". Using the combination of the ArcGIS (10.7 version) spatial database and on-site investigation, through the analysis of an AutoCAD map of the whole area of Macau, researchers found 26 open spaces with the potential of "turning gray into green" in the high-density urban areas of Macau, with a total area of about 31,456 m^2, excluding the Largo that has been included in the urban green open space. Among them, there are 21,506 m^2 in the Peninsula high-density urban area and 9950 m^2 in the Outlying Island high-density urban area (Figures 17 and 18, Table 6).

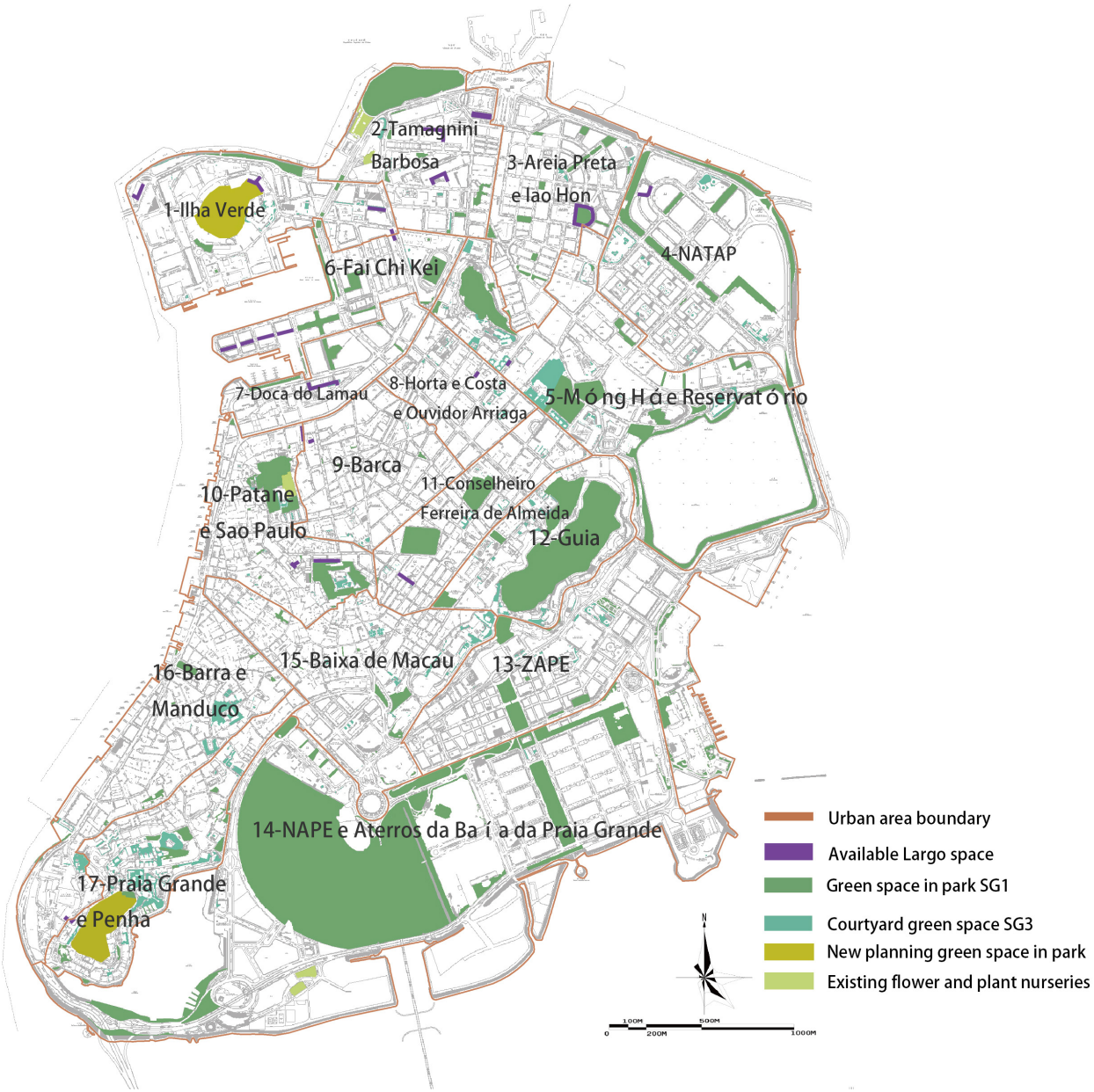

Figure 17. Spatial distribution of Largo space in the high-density urban area of Macau peninsula that can be "turning gray into green". (Image source: Drawn by the author).

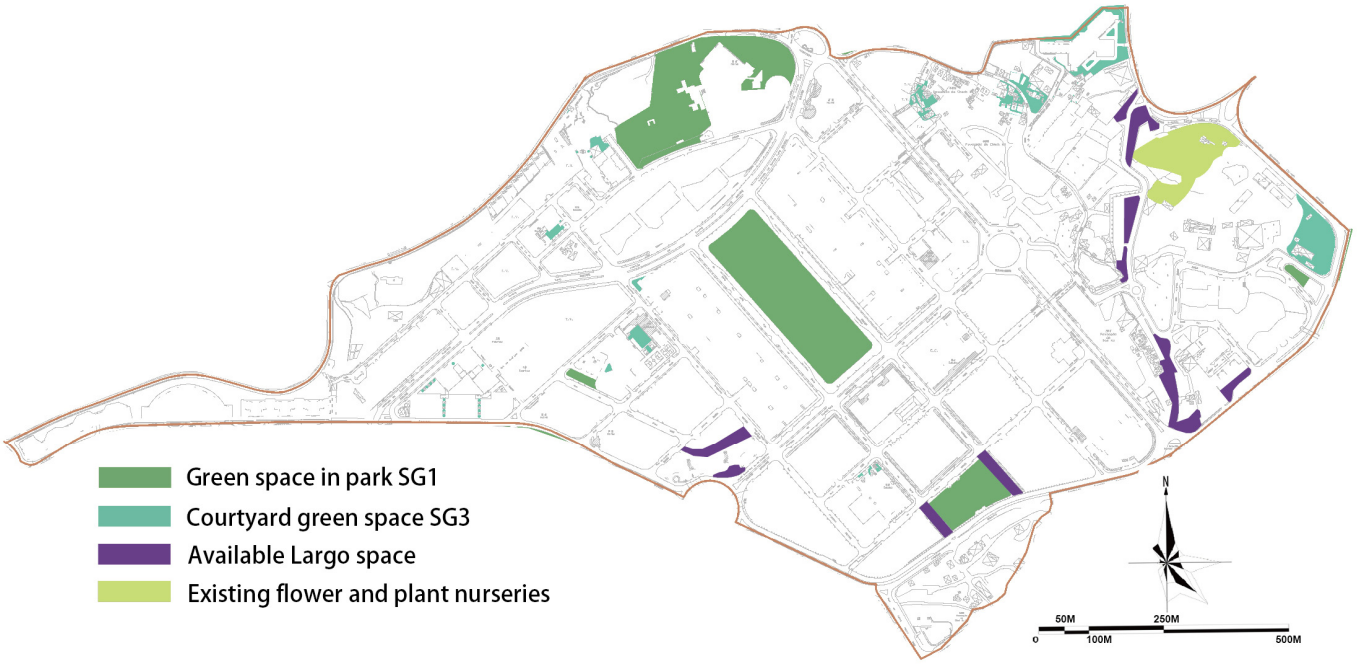

Figure 18. Spatial distribution of Largo spaces in the Baixa da Taipa district, Macau's outlying island, which can be "turning gray into green". (Image source: Drawn by the author).

Among the 12 high-density streets in Macau listed in Table 7, the gray open space available at present can be broadly classified into two categories: one is the Largo space with only a small number of flower pots and green belts on the roads, and a large area of the ground is not yet greened (Figures 19 and 20); and the other is the open space on the streets and the Largo space that is not greened (Figures 21 and 22). In the course of this paper, a larger number of Largo spaces were inspected, so the integration and optimization strategies of the Largo spaces on the Peninsula were taken as examples, such as the Largo de Santo Agostinho and Largo de Santo Antonio, and the Largo spaces of Rua dos Hortelãos, Rua de Seng Tou, and Rua de Coimbra on the outlying island (Table 8). The spatial integration and optimization of the remaining Largos can be similarly applied.

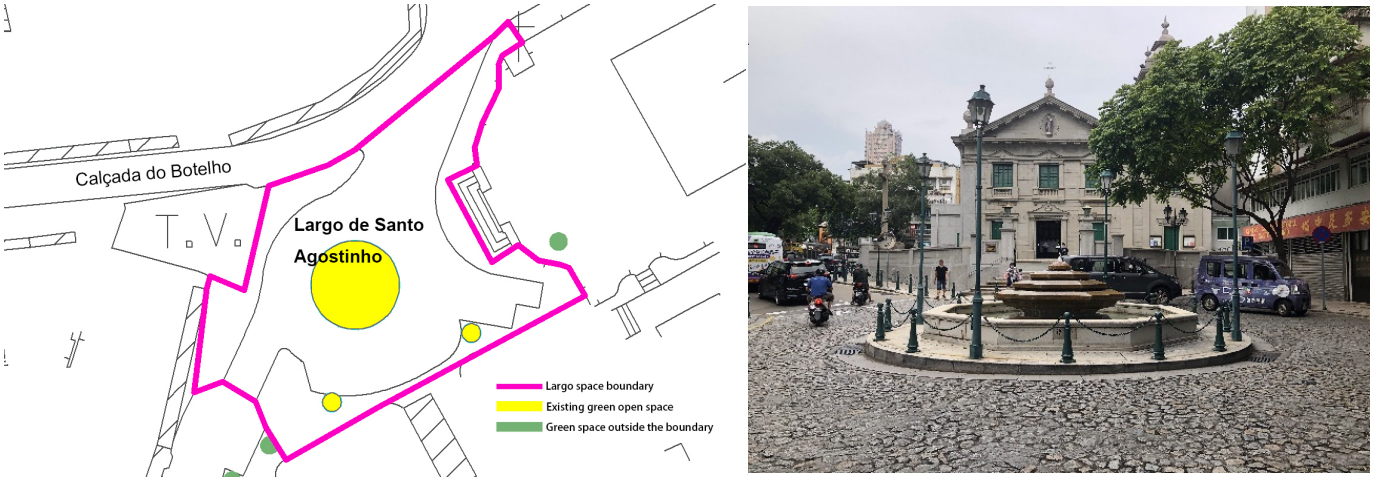

Figure 19. Gray open space available in Largo de Santo Antonio. The small Portuguese characters in the picture are Calçada do Botelho and Largo de Santo Antonio, which represent local place names and have no specific meanings. (Image source: Drawn and photographed by the author).

Table 7. Survey on available gray open space resources in high-density neighborhoods in Macau.

Town Planning Districts	Number of Largos Available (Excluding Parkland Already Included in SG1)	Availability of Largo Space Area (m^2)
Ilha Verde	3	3230
Tamagnini Barbosa	3	4216
Areia Preta e Iao Hon	1	797
NATAP	1	639
Fai Chi Kei	1	3846
Doca do Lamau	1	2565
Horta e Costa e Ouvidor Arriaga	2	253
Barca	0	0
Patane e São Paulo	6	4911
Conselheiro Ferreira de Almeida	1	743
Barra	1	306
Baixa da Taipa	6	9950
Macau Peninsula	20	21,506
Macau Outlying Island	6	9950
Macau Total	26	31,456

Source: Statistical data provided by the author.

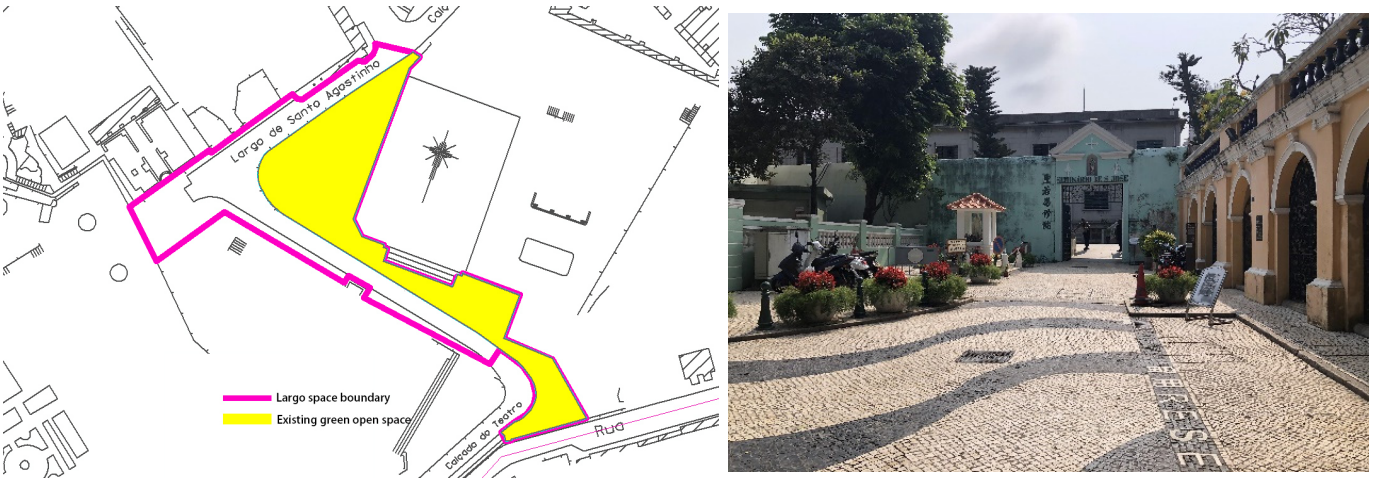

Figure 20. Gray open space available in Largo de Santo Agostinho. The small Chinese characters in the picture is St. Joseph's Seminary and Church (**right**), which represent local place names and have no specific meanings. (Image source: Drawn and photographed by the author).

Table 8. Examples of available gray open space in high-density neighborhoods in Macau.

No.	Name	District	Site Marginal Surface Area (m^2)	Existing Green Space (m^2)
1	Largo de Santo Agostinho	Barra	1638	887
2	Largo de Santo Antonio	Patane e São Paulo	613	51
4	Rua dos Hortelãos	Baixa da Taipa	3270	359
5	Rua de Seng Tou	Baixa da Taipa	897	0
6	Rua de Coimbra	Baixa da Taipa	1170	0

Source: Statistical data provided by the author.

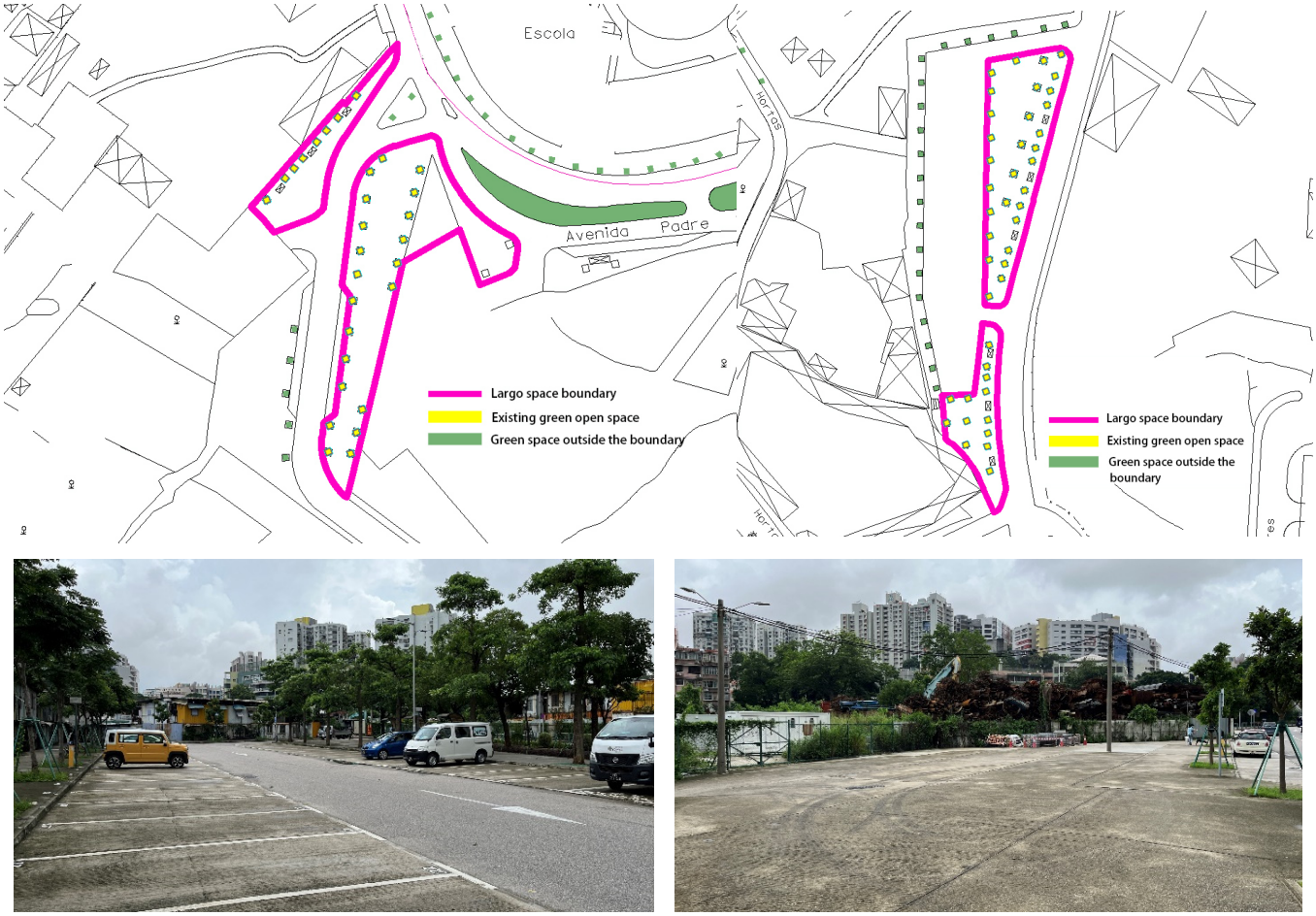

Figure 21. Gray open space available at Rua dos Hortelãos. The small Portuguese characters in the picture are Avenida Padre Tomás Pereira (**left**) and Rua dos Hortelãos (**right**), which represent local place names and have no specific meanings. (Image source: Drawn and photographed by the author).

Figure 22. Gray open space available at Rua de Seng Tou. The small Portuguese characters in the picture are Rua de Seng Tou and Jardim da Cidade das Flores, which represent local place names and have no specific meanings. (Image source: Drawn and photographed by the author).

Among the high-density streets on the Macau Peninsula, the existing greening rate of the Largo de Santo Antonio is less than 10%, with only a small number of flower pots that can be counted as green space; Largo de Santo Agostinho is mainly greened through the roadway green belts for the pedestrian space, and there is still a large area of ungreened

paved space (Figures 19 and 20). From Table 8, it can be seen that the area of the Largo de Santo Antonio that can be counted as green space in its current state is only 51 m^2, while the area within the boundary of the whole Largo space area is 613 m^2, and the greening rate of the gray open space is less than 1/10 of the total area of the Largo space. According to the statistics in Table 7, if the gray open space in the largos of the high-density streets on the Macau Peninsula is transformed from "gray to green", it can release about 21,506 m^2 of green open space.

The GOSOR indicator is an important indicator to measure the level of urban habitat, the GOSOR indicator can not only help urban planners to measure the current level of green space development and construction of the city to meet the requirements of the city's master plan policy on the total amount of urban green space; GOSOR indicators can also be combined with GIS charts to analyze whether the total amount and distribution of green space in the city meets the needs of residents in different urban areas, thus helping the government and urban planners to formulate relevant strategies for the construction of green space in the city, and to achieve the goal of optimizing the development of green space in the future. The GOSOR formula could be represented as:

$$\text{GOSOR} = \text{total urban green space}/\text{total urban land area}$$

Through rational integration and optimization of the space in Largo, the GOSOR value of green open space in 10 of the 11 high-density districts on the Macau Peninsula can be directly increased, and the GOSOR value of 4 of these districts can be increased by more than 1.0%. This demonstrates that the implementation of the strategy of "turning gray into green" in the Largo space of high-density streets in Macau has significant effects on enhancing the naturalness of street space, which is conducive to improving the quality of the human environment in high-density cities.

For example, the current situation of Rua dos Hortelãos in the Baixa da Taipa district, an outlying island of Macau, only has a small number of flower pots as road greenery (Figure 21), and Rua de Seng Tou and Rua de Coimbra are basically without any greening, and there is still a large area of gray open space that is not yet utilized (Figures 22 and 23). According to Macau's urban green space statistics standard, if the green coverage rate of these Largo spaces can be increased to more than 30% by replanting trees, the site can be counted as a green open space, releasing 9950 m^2 (about 1.7 Jardim da Cidade das Flores) of green open space, which can directly increase the GOSOR value of Baixa da Taipa district from 12.40% to 13.52% (Table 9). Therefore, adopting proactive planning strategies to optimize and utilize this type of gray open space can effectively improve the green appearance of high-density streets and solve environmental problems such as the low per capita area of green open space caused by the continuous growth of the number of residents in the Baixa da Taipa district in recent years.

Due to the problems of land constraints, high building density, and tight reserve land resources in the high-density urban areas of Macau, there is basically no land in the urban reserve that can be directly planned as new green space. Therefore, for policymakers and urban planners, it is important to transform the front land space from "gray to green". For example, if the space in front of the residential buildings on the Macau Peninsula is transformed into a green space and children's recreational facilities are added, a small green square like a pocket park can be formed for the children in the neighborhood to play, which can effectively improve the actual living environment and satisfaction of the residents. For instance, if the decision-maker transforms the gray space of Rua de Seng Tou and Rua de Coimbra in Figures 22 and 23 into a green open space and adds some park benches and other facilities, it can be directly used as a community park, effectively

alleviating the overcrowding problem of existing urban parks in the high-density urban areas of Macau, which is caused by the low GOSOR value.

Figure 23. Gray open space available on Rua de Coimbra. The small Portuguese characters in the picture are Rua de Coimbra and Jardim da Cidade das Flores, which represent local place names and have no specific meanings. (Image source: Drawn and photographed by the author).

Table 9. Comparison of GOSOR value after upgrading from "gray to green" in Largo spaces of high-density districts in Macau.

Name of the City District	Area (km^2)	Available Gray Open Space Area (m^2)	GOSOR Value (%) for Current City District	Upgraded Urban District GOSOR Value (%)
Ilha Verde	0.5	3230	12.84	13.49
Tamagnini Barbosa	0.4	4216	18.72	19.77
Areia Preta e Iao Hon	0.4	797	7.74	7.94
NATAP	0.6	639	14.09	14.20
Fai Chi Kei	0.3	3846	9.90	11.18
Doca do Lamau	0.2	2565	5.34	6.62
Horta e Costa e Ouvidor Arriaga	0.2	253	2.58	2.71
Barca	0.3	0	0.91	0.91
Patane e São Paulo	0.4	4911	13.60	14.83
Conselheiro Ferreira de Almeida	0.3	743	11.27	11.52
Barra	0.5	306	6.61	6.67
Baixa da Taipa	0.9	9950	12.40	13.52

Source: Statistical data provided by the author.

On the other hand, some historical cities in the northern Mediterranean, such as Rome, Athens, and Barcelona, can provide Macau with good examples of high-density urban landscape planning experience. These cities usually have narrow streets, a long architectural history, limited open space, and an urban form characterized by high-density housing with a high emphasis on public squares and plazas. In the landscape planning experience of historic cities in the northern Mediterranean, the narrow streets and alleys typical of historic Mediterranean cities are often transformed into "green veins" through the planting of street trees, the installation of green benches, and the creation of small pocket parks. In addition, traditional Mediterranean architecture often includes courtyards and terraces. These spaces can often be combined with greenery, water features, and sitting

areas to form small outdoor gardens that create microclimates and improve the quality of life for residents. These experiences of utilizing narrow urban spaces for greening are worthwhile lessons for high-density cities such as Macau.

Due to the limited land in Macau, it is possible to expand the urban land area through further land reclamation in the future. If the eastern part of the Macau Peninsula continues to expand its territory, the study recommends the following: (1) Extend the "green veins and green patches" model to the eastern expansion areas. This involves creating linear green spaces (green veins) along new streets and lanes and integrating larger green patches (parks and gardens) to enhance connectivity and accessibility. (2) Given the high-density nature of the expansion, incorporate rooftop gardens and vertical greening on new buildings to maximize green space without consuming additional land. If the Macau Outlying Island continues to expand its territory, (1) apply the "greenways embedded in jade" model to the expansion areas. This involves creating wider greenways to connect large green patches such as city parks, country parks, and university campuses, forming a comprehensive green open space system. (2) Develop ecological corridors to connect natural areas and enhance biodiversity. These corridors can also serve as recreational paths for residents and tourists.

5. Conclusions

Urban green development should mainly start from the perspective of upgrading the quality of the urban living environment and, through scientific planning of green open space, improving the quality of the urban environment and ecological livability level according to local conditions, solving the problem of a shortage of natural space caused by over-urbanization, and promoting the sustainable development of the city. The future positioning of Macau's urban development includes actively promoting the two major goals of building a "World Center of Tourism and Leisure" and a "Beautiful Home for Macau Residents" and insisting on the direction of green development, with ecological conservation, green planning, and green architecture as the main axes of Macau's urban development. To further improve the environmental quality of urban open space to satisfy the urgent demand of citizens and tourists for adequate leisure and open space; to strengthen the environmental protection of urban space; and to build a green cityscape and a quality living area that is "pleasant to live in, pleasant to work in, and pleasant to visit".

On the one hand, the ideal structural pattern for the overall layout of Macau's urban public open space should be "green space in park SG1, street largo SG2, courtyard green space SG3", and other green space patches, which are interconnected with green veins and greenways through the streets and largos and linked with the open space layout of ecological wetlands and natural water space. Among them, the planning layout of "green veins connecting green patches" is appropriate for the Macau Peninsula, while the planning layout of "greenways embedded in emerald" is suitable for the outlying island of Macau. On the other hand, as a unique term for urban open space in Macau, "Largo" has the same concept as traditional European street squares, as well as small open spaces in the gaps between buildings and pedestrian streets. In the high-density urban areas of Macau, except for some parked Largo spaces and community open spaces, most of the Largos are still underutilized "gray open spaces". If they are optimized and transformed from "gray to green", a large amount of green open space can be released, which will directly increase the GOSOR value of the 10 high-density districts on the Macau Peninsula, and the GOSOR value of four of them will increase by more than 1.0%. This will have a good effect on improving the naturalness of Macau's urban space and the quality of its citizens' environment.

The study of the high-density city of Macau is externally valid. Many cities around the world are facing the challenge of providing adequate green open spaces amidst increasing urban densities. The findings from this research can offer valuable insights and practical solutions for these cities, helping them optimize their limited land resources and enhance the quality of life for residents. As in the case of other international mega-cities such as Tokyo and Shanghai, the urban center of the city is a high-density urban area, and the human environment still needs to be upgraded. Therefore, in the context of the high-density city of Macau, the research result of optimizing the GOSOR indicator and thus enhancing the level of urban habitat can provide reference value for other megacities in similar circumstances to enhance the urban habitat in the future. However, due to the research conditions, this study also has certain limitations. For example, the study proposes various planning strategies but does not delve deeply into the practical challenges of implementing these strategies. Factors such as land ownership, funding constraints, and bureaucratic procedures could hinder the realization of the proposed green space expansions and optimizations. For future study, with the growing trend of smart cities, there is an opportunity to integrate green space planning with smart city technologies. This can involve using sensors to monitor environmental conditions in green spaces, employing data-driven approaches to optimize green space maintenance, and utilizing digital platforms to engage citizens in green space management and planning.

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