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Public Green Space Injustice in High-Density Post-Colonial Areas: A Case Study of the Macau Peninsula, China

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Abstract: Public green spaces (PGSs) play a positive role in urban social sustainability and solidarity, as all urban dwellers can access them without discrimination or restrictions, but urbanization usually leads to an extreme shortage of PGSs and thus it becomes an important spatial resource that is competed for by different groups, especially migrant populations. Taking the Macau Peninsula as an example, this study employed a hybrid analysis approach, including the spatial Gini coefficient, spatial share index and spatial quality assessment, to look at the PGS injustice in high-density post-colonial areas. The results showed that (1) there is a "spatial mismatch" in the Peninsula's PGS; (2) significant PGS service differences have been found between the colonial group (Portuguese) and immigrant group (Southeast Asian); and (3) a comparative analysis of the changes in the equity of PGSs over the past 40 years reveals that the PGS tends to be equitable overall, but the differences between groups have gradually increased. PGS injustice mainly depends on the spatial production mechanism during the colonial period of Macau and the spatial selection and limitation of groups due to differential social integration. Based on this, this work proposes recommendations for the planning and construction of PGS in terms of urban renewal and social sustainability, as well as new reclamation areas, in Macau. This study broadens the field and helps to improve the PGS inequality in high-density post-colonial areas, aiding regional sustainable development.

Keywords: urban social sustainability; public green space; environmental injustice; space match; post-colonial areas; Macau

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1. Introduction

As an important component of the urban spatial structure, urban public green space (PGS) not only provides urban diversity but also an ecological service system and a more livable environment for its residents [1,2], forming a basic unit that contributes to public life [3]. Urban green space has been proven to benefit human health and improve human well-being [4], supporting multicultural communications and providing more potential social inclusion than other spaces [5], promoting crowd interaction and reducing social conflict and spatial isolation [6].

Many cities are gradually becoming denser, with greater urbanization, such as Tokyo, Hong Kong and New York [7]. The compact urban space will further aggravate the shortage of public green space resources in cities [8,9]. As a result, discussions of inequities in the allocation of PGS for people with different needs, spatial pattern distribution, spatial quality and financial investment are becoming increasingly significant [10]. Inequities in the spatial distribution of green space exist in both the Global North and the Global South [11,12]. Growth in populations in high-density areas also leads to a reduction in the per capita share of spatial green space [13]. With the increasing complexity of the current global social environment (e.g., migration crises, widening gap between rich and poor, etc.), the distribution and use of urban green spaces are increasingly showing inequality and

spatial segregation [14,15]. Currently, the justice of PGS in high-density urban areas is an important issue in the field of social justice, with major implications for public health and social integration [16–19].

The existing field of green equity focuses more on territorial equity, considering the difference in service scope between various areas, while the social equity dimension emphasizes "spatial matching", which addresses the matching relationship between the green space distribution and population [20]. Numerous studies have shown that there are differences in the degree to which different groups use PGS [21–25]. Green space inequity is mostly impacted by income, racial characteristics, age, gender, and low residential area groups [15,22–24,26–28]. Social status can also impact green inequity, with migrants disadvantaged in their access to urban green space and differences in social background, culture and language potentially preventing migrant groups from using parks for daily communication and activities [29]. Ethno-religious and social identity group differences further lead to unfair treatment when people use green space [30,31]. In Atlanta, Georgia, a study found that people of color (Black, etc.), and minorities have lower access to PGS and park services, and inadequate park infrastructure, park accessibility, and cultural restrictions may discourage immigrant groups from moving through green spaces [29,32].

Post-colonial areas also face further inequities due to the former colonial powers' urban planning, which often prioritized the economic growth of the colonizer [33–35]. Research shows that inequalities in the distribution and quality of PGS during the colonial period could carry over into the post-colonial period [35,36]. Colonial urban spatial patterns and plant species are also invasive in colonized areas [35]. Wealthier colonized communities generally enjoy greater PGS and plant diversity, while poorer colonized communities often exhibit limited PGS [37,38]. Moreover, during the colonial period, hierarchical communities were divided into groups to artificially isolate groups to ensure the quality of urban space use and relative rights of their own groups [33].

Green equity based on social justice believes that social groups have different abilities and needs. Most scholars believe that the distribution of public green space should be based on the principle of compensatory equity to provide more opportunities for disadvantaged groups [39–42]. Current research into the equity of PGS mostly uses various quantitative indicators, based on the scale of communities or cities. In the Global North, the main indicators in PGS are the park area per capita, park quality, park management, financial investment and park safety factors [11,43,44]. In the Global South (like Africa, Latin America and Eastern Asia), more emphasis is placed on the public green space area, quality and accessibility [12,45,46]. The literature was compiled from previous studies in 49 cases and showed that the degree of inequitable differentiation is more pronounced at the park size and park quality levels, while accessibility was relatively uncertain [22].

In general, most of the existing literature considers green spatial inequity for a single group and few studies focus on the changes in green equity from the time dimension, especially in high-density post-colonial regions. Therefore, to explore the equity of PGS, the Macau Peninsula was chosen as the study area. This study aims to address the following three questions:

(1) Is there inequity in the PGS distribution on the Macau Peninsula?

(2) As a typical high-density post-colonial and immigrant city, are there significant differences in the use of PGS between immigrant groups and colonial groups in Macau?

(3) What are the changes and trends in the overall and group equity differences on the Macau Peninsula?

The remainder of this study is organized as follows. The next section mainly introduces the information of the study case and the main methodology. The results section describes the evaluation of the spatial distribution of PGS on the Macau Peninsula, the differences between groups in terms of access to PGS services and spatial distribution, as well as the changes in equity on the Macau Peninsula in the last 40 years. In the discussion section, the analysis focuses on the causes of the inequitable spatial distribution of PGS on the Macau Peninsula, including the formation mechanism of PGS and the spatial choices and

restrictions faced by the population. The final section summarizes the main findings and provides recommendations.

2. Case and Methods

2.1. Methodological Framework

The methodological framework of the PGS justice investigation is shown in Figure 1. We consider the spatial matching of PGS from two aspects, the PGS spatial pattern and the social identity of colonial and immigrant groups, and we construct a PGS justice assessment system in high-density post-colonial areas. We determine the appropriate and suitable methodology for the research question through the spatial Gini coefficient, spatial location entropy and spatial quality evaluation to answer question 1, whether there is inequity in the PGS distribution; through the group's spatial share index to answer question 2, whether there is inequity in the spatial distribution of PGS between the colonial groups and immigrant groups; and through the time changes in identified the inequities of PGS spaces over the past 40 years to answer the question 3. By comprehensively evaluating the injustice level aspects, the spaces and groups facing serious PGS inequities are identified and we try to explain the reasons and make recommendations.

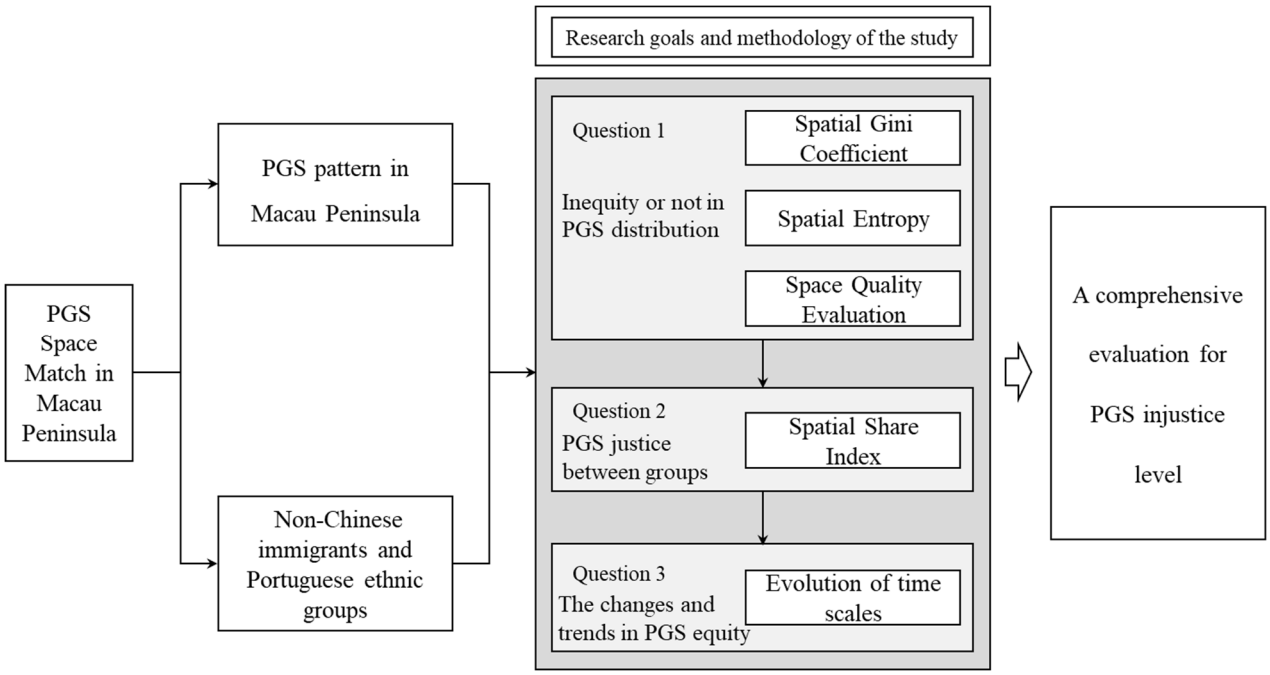


Figure 1. The questions and methodology of PGS justice research.

2.2. Study Case

2.2.1. Study Area

We chose the Macau Peninsula as the case study. Macau is a typical high-density post-colonial city in China, and it is also a city of immigrants. Macau is one of the most densely populated cities in the world, with an urbanization rate of 100% according to the World Bank WDI database [47], with a population of 68.2 million, an area of 33 km^2 and a GDP reaching USD 30.12 billion as of the end of 2021. Given the limited land resources and the large population, it has been facing a dilemmatic trade-off between the high population and providing more green space. The Macau Peninsula is the most populous and historic part of Macau, including 5 parishes, divided into 17 statistical divisions (Figure 2). The statistical division is the smallest statistical unit in Macau, established for administrative management and statistical purposes. The area of Macau Peninsula is 9.3 square kilometers, accounting for 27.4% of Macau's land area, but the population accounts for 86% of the total population of Macau, with a population density as high as 574,000 people/km^2.

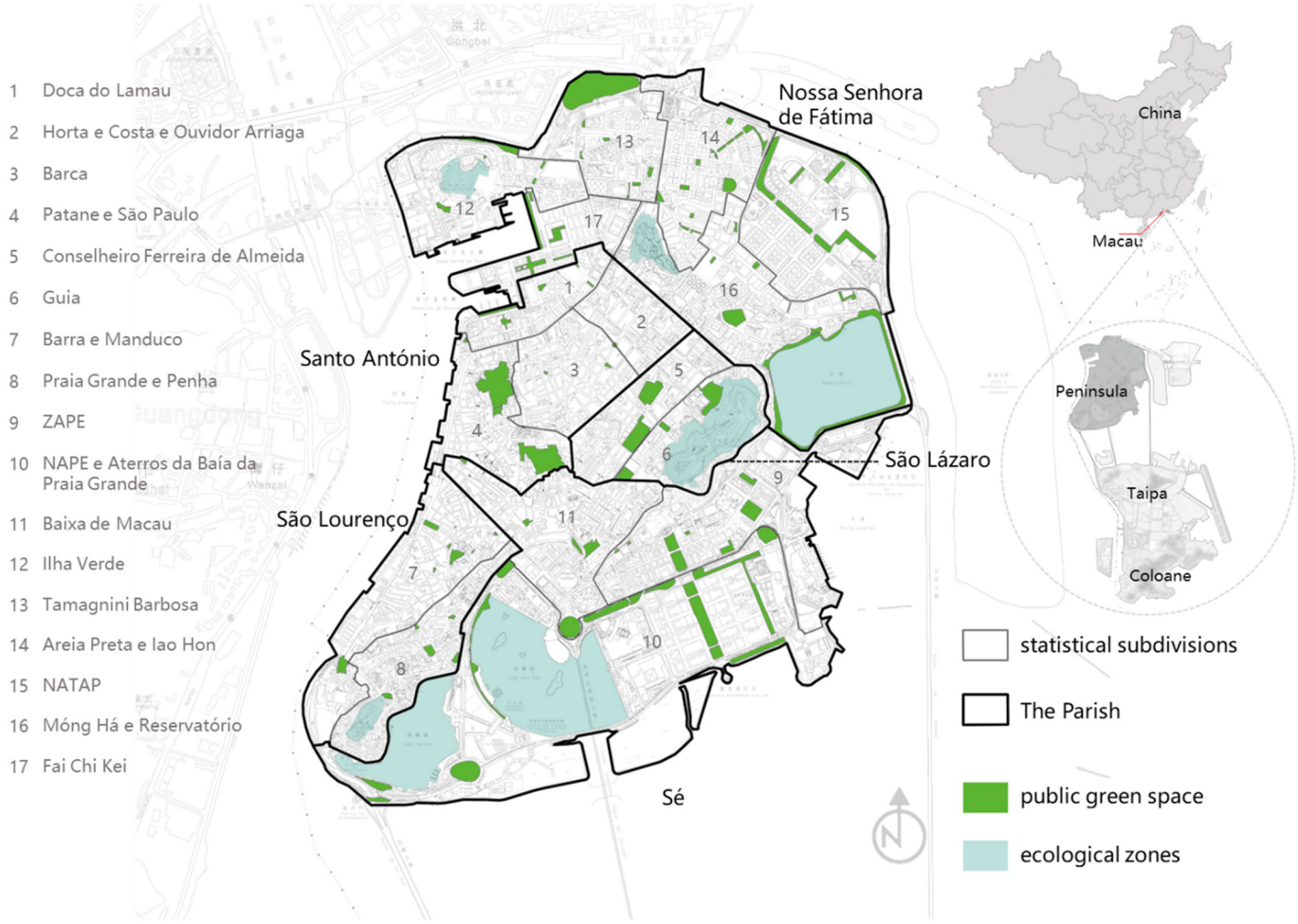


Figure 2. Distribution of PGS on the Macau Peninsula.

2.2.2. Data on PGS on the Macau Peninsula

Macau's green areas or public spaces are mainly used for outdoor activities, including leisure, recreation and cultural functions, while mountains and country parks are classified as ecological zones. The main scope of this study is to optimize the urban landscape and improve the environment and life of the residents in the green space or public space open areas, referred to as public green space (PGS). This mainly entails urban parks and gardens or urban rest areas. The per capita land area of PGS on the Peninsula is about 2.32 m^2/person, while the per capita green space in Macau is about 10.5 m^2/person; therefore, the peninsula is more characterized by high development intensity and scarce public space resources. There are 89 PGS locations on the Macau Peninsula and a total of 488,815 m^2, according to the data of case statistics from Macau Municipality Macau (IAM: https://www.iam.gov.mo/e/default/, accessed on 5 April 2024) and Macau Masterplan 2020–2040.

2.2.3. Composition of Colonial and Immigrant Groups in Macau

Macau is a city with a diverse population. On the Macau Peninsula, Chinese (including Macau) account for 89.2% of the total population, and foreign nationals are mainly divided into Southeast Asians (8.9%), Portuguese (1.3%), and other countries (0.6%).

This work selected the Portuguese and the Southeast Asian immigrant groups in Macau as the study population. A large percentage of the Portuguese population are descendants of Portuguese in Macau during the colonial period, who speak Portuguese as their first language and for whom Portuguese culture is their native culture and identity.

The Portuguese group accounts for 9.08% of the foreign population in the Peninsula. The largest and most representative group of immigrants in Macau is the Southeast Asian group, consisting mostly of Filipino, Thai, and Indian people, with the largest number being Filipino. Southeast Asian nationalities account for 87.70% of the foreign population.

Since the return of Macau to China, due to the "One Country, Two Systems" policy, compared with the general Chinese, the Portuguese have experienced the higher levels of education and have the advantage in the Portuguese, English, and Chinese languages. As a result, they have naturally taken up key positions in government departments of Macau [48], become mediators between Macau and China, and retained a monopoly position in some high-paying industries in Macau, such as the legal profession [49]. The immigrant is an important part of the diversity of the population. Most of the immigrants in Macau are there because of the labor demand of developed countries, which draws in people from developing countries. The location of Macau has led to the influx of labor immigrants from Southeast Asian developing countries, including the Philippines, Thailand, Indonesia, and other countries. Southeast Asia has made significant contributions to the prosperity and development of Macau and is an important force in the economic construction of Macau today. Most of the Southeast Asian immigrant communities are engaged in service industries, such as the catering industry, the gambling industry, and domestic services, as well as technical-related industries [50,51].

2.2.4. Macau PGS Production Mechanism

The urban construction of Macau proper began to develop and expand following the opening up of the city in the 16th century, meaning its urban spatial environment was influenced by different historical development contexts [52]. The production of urban space in Macau is divided into three main historical phases: the period of Portuguese colonial territorialization; the period of non-territorialization under the control of the Chinese government before and after the handover; and the period of integrated construction of urban agglomerations in the Greater Bay Area (Table 1) [53].

Table 1. Political status and urban spatial development in Macau.

Macau Political Sovereignty	Spatial Order Project	Spatial Order Project	Urban Space and Development Context
Macau as "Chinese Imperial Territorial Concession"	1557–1849	The period of Portuguese colonial territorialization	Chinese and Portuguese political relations in urban spatial form
Macau with "Restricted Autonomy"	1849–1887		
Macau as a "Portuguese Territory in Chinese Land"	1887–1987		
	1987–1999	The period of non-territorialization	Macau urbanism accelerated urbanization, spatial erasure, densification and homogenization
Macau as a "Special Administrative Region of the People's Republic of China", SAR	1999–2009		
	2009–present	The period of integrated construction of urban agglomerations in the Greater Bay Area	Macau Masterplan and PRD mega city–region strategic spatial planning

Based on the historical evolution of the land area in Macau (Figure 3), 62% of the urban space on the Macau Peninsula was built during the colonial period, and the remaining urban space was mostly reclaimed from the sea and built during the non-territorial period [54]. Based on the spatial structure of economic and political aspects, the period of colonial, urban development of the Macau Peninsula can be called "a dual-core and three-community pattern" (Figure 4) [55], where the dual-core refers to the Portuguese political and religious center and the Chinese political center. The three communities were the Portuguese community, the traditional Chinese community, and the mixed Chinese–Portuguese community.

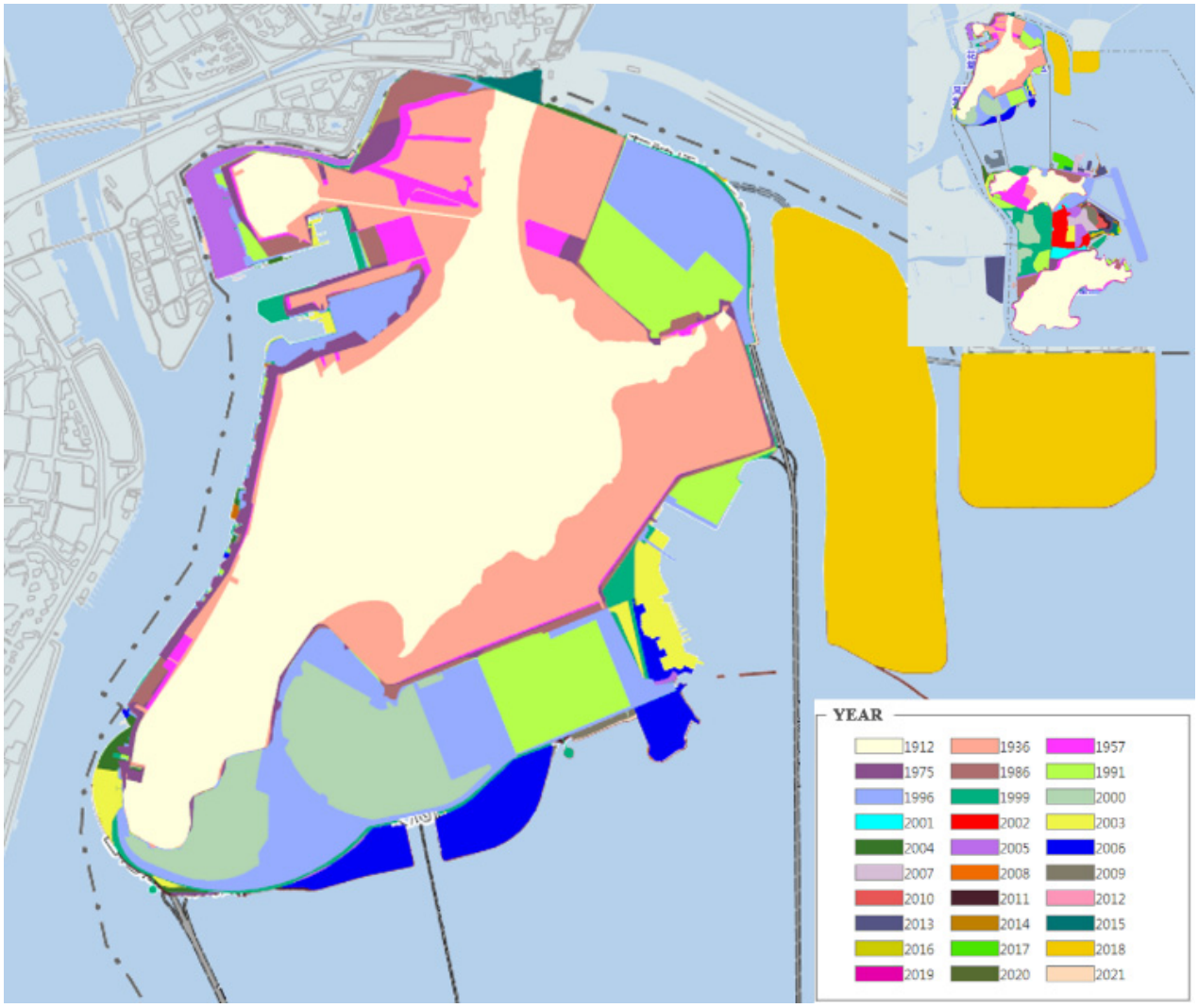


Figure 3. Historical evolution of the land extent of the Macau Peninsula (from: Macau Cadastral Bureau webmap.gis.gov.mo).

Due to the Portuguese colonial influence, the early urban construction of the Macau Peninsula continued the Portuguese tradition, adopting the "straight street" pattern, where residential groups were built around the church to form a complete inner city with one main street and seven alleys [52,56]. One of the objectives of Portuguese sovereignty after the occupation of Macau was to create an easily identifiable cultural space in terms of urban development. PGS is a powerful symbol of territorial control, and it helped Portugal to maintain and defend its national identity during the period of rule. They assist in the spatialization and territorialization of the Portuguese cultural identity, which could solidify Portugal's cultural status and induce a sense of identity and belonging among Macau residents [53]. When Portugal occupied Macau, the party responsible for urban construction in the Portuguese jurisdiction was Portugal. The creation of PGS thus originated from the political power and national cultural identity promoted by Portugal, and this was government-led. The public spaces generally took the form of squares, parks, and plazas, with a high degree of openness and large spatial area. At that time, public spaces in traditional Chinese communities lacked effective management and were mostly the result of local activities. The "li" and "wei" style (the smallest level of street unit, with a width of 1.2 m–3 m, and the basic component that constitutes the assembly and division of residential buildings in Macau) of housing in the Chinese communities also led to a generally higher residential density than in the Portuguese communities. Therefore, the

spatial scale of public spaces in the Chinese communities was generally smaller than that in the Portuguese communities [57], where public spaces mainly manifested in enclosed architectural spaces and street spaces, which were characterized by inward aggregation, small areas, and scattered distribution. This led to the coexistence and continuation of different cultures in spatial forms.

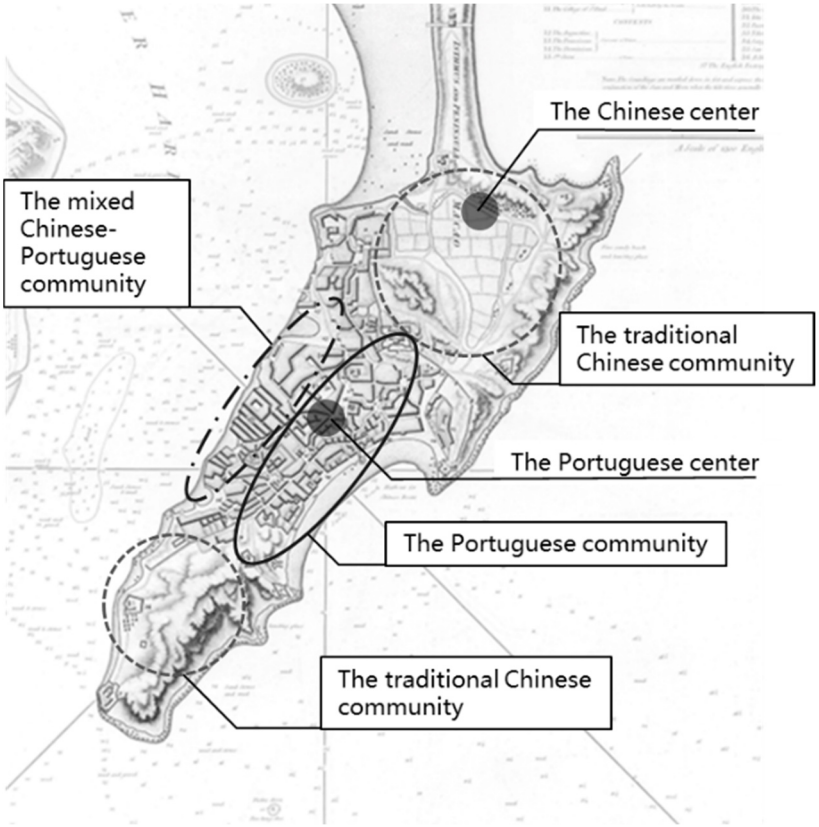


Figure 4. Location and range schematic diagram of the dual-core and three-community pattern on the Peninsula in the period of Portuguese colonial territorialization (from: drawing based on the literature).

During the period before and after Portuguese rule, when Macau was a Chinese territory, a series of land reclamation projects were carried out on the Macau Peninsula, including NAPE e Aterros da Baía da Praia Grande, Areia Preta e Iao Hon and NATAP. The urban form was divided into equal neighborhoods, in contrast to the old city fabric, and the generation of urban PGS changed. Subsequently, the integration of Hong Kong, Zhuhai and Macau into the Greater Bay Area accelerated, the city of Macau developed rapidly, and urbanization accelerated, along with urban reclamation and expansion development and high-density construction. During this period, PGSs on the Macau Peninsula were mainly transformed on a small scale, retaining their original spatial structure. The newly reclaimed areas fit the urban spatial development laws of a market-oriented economy, and the production of public green spaces was endowed with economic attributes.

During the period of integrated construction of urban agglomerations in the Greater Bay Area, the main expansion areas of Macau's urban space are the Taipa and Coloane, with a lot of entertainment resort complex buildings focusing on the gaming industry.

Overall, Macau's urban PGS arose from three main sources: differences in the political economy between China and Portugal, the design and culture of Sino–Portuguese integration, and the development of a diverse society [53]. In the process of the urban spatial evolution of the Macau Peninsula, the urban form became a unique spatial pattern resulting from the combination of Chinese culture, architectural street space and contemporary

development, in accordance with the historical and political development between China and Portugal, also impacted by the Portuguese focus on confirming and preserving its political status.

2.3. Methods and Data

2.3.1. Data Sources

This study involves two main data sources, PGS resource data and population data. The PGS resource data are divided into PGS area and quality as the main equity measures, and the PGS area data are derived from satellite aerial maps in 1980, 1991, 2001, 2011, and 2021 combined with publicly available information from the Macau Municipal Affairs Bureau (MSD) and the Cadastral Bureau (CGB), while the PGS quality data are derived from the Analytic Hierarchy Process (AHP) method. Population data are obtained from the Macau Statistical Yearbook for the resident population in terms of statistical districts and parishes, as well as for the foreign population.

2.3.2. Spatial Gini Coefficient and Spatial Entropy

Firstly, in order to measure whether there is inequity in the distribution on the Macau Peninsula, a measurement indicator was established to respond to question 1. The spatial Gini coefficient is a concept commonly used to measure social equity [19,42,55]. Through 2021 PGS area data and population data, the spatial Gini coefficient and the Lorenz curve analysis methods were used to establish quantitative indicators of equity in the spatial distribution of PGS. The Gini coefficient is calculated by the formula:

$$G = 1 - \sum_{k=1}^{n} (P_k - P_{k-1})(R_k + R_{k-1}) \quad (1)$$

where P_k represents the cumulative proportion of population variables, $k = 0 \ldots n$, $P_0 = 0$, $P_n = 1$; R_k represents the cumulative proportion of public green space resource variables, $k = 0 \ldots n$, $R_0 = 0$, $R_n = 1$. Just like the income distribution, the value of the spatial Gini coefficient is between 0 and 1 [29]. The smaller the Gini coefficient, the more equal the match between the PGS resources and population distribution in Macau, and vice versa. A Lorenz curve graph is drawn to measure the distribution of PGS resources among the statistical population. The spatial units within the research scope are arranged from low to high according to the per capita share of PGS resources, and each segment is based on 10% of the population.

However, the spatial Gini coefficient and Lorenz curve cannot show the spatial heterogeneity of the "spatial match". Therefore, spatial entropy is used to measure the ratio of PGS resources per capita of the statistical population within each spatial unit to the PGS resources per capita of the statistical population within the whole study area, and thus to express the spatial inequity of the PGS distribution [9]. The spatial entropy is calculated by the formula:

$$LQ_j = (T_j / P_j) / (T / P) \quad (2)$$

where LQ_j represents the entropy of spatial unit j, T_j represents the amount of PGS resources in spatial unit j, P_j represents the population of spatial unit j, T represents the total amount of PGS resources in the study area, and P represents the total population in the study area. If the entropy of a spatial unit is greater than 1, this indicates that the per capita level of PGS resources in that unit is higher than the overall level of the study area, and vice versa.

2.3.3. Spatial Share Index

In response to question 2, whether there is inequity in the spatial distribution of PGS between the Portuguese and Southeast Asian groups, it is necessary to measure whether the level of access to public green space resources for each group is at or above the average for the entire statistical population, so the spatial share index is proposed for this purpose. First, the proportion of PGS resources enjoyed by the groups is measured in relation to the

total population. Then, based on the proportion of PGS resources enjoyed by the group and the proportion of their population to the total population, the spatial share index of its public green space resources is calculated:

$$F = \left(\sum_{j=1}^{n} P_j X_j \right) / P \quad (3)$$

where j represents the spatial unit, total 17, P_j represents the proportion of the population in spatial unit j to the total population, X_j represents the proportion of PGS resources in spatial unit j to the total study area, and P represents the proportion of the population to the total population. If the share index F value is greater than 1, this indicates that the group enjoys a higher share of PGS resources compared to the average, and vice versa.

2.3.4. Space Quality Evaluation

The spatial quality of PGS is one of the important indicators of the equity of green space. Equitable differences in the quality of PGS mainly include the park activity facilities and park maintenance and safety [22], and the quality evaluation of PGS is mainly divided into three dimensions: usability, ecology and landscape [58,59]. Based on the literature and the actual situation of PGS in Macau, this study chose three dimensions of green space: use and ecology, cultural landscape and maintenance inputs. Among these, the use and ecological and cultural landscape indicators are based on the AHP scoring method, where 489 users were invited to score the 89 PGSs by a random questionnaire survey, using a scoring system of 1–5 on a Likert scale. The data of the maintenance input indicators are based on the average of the maintenance and management costs of green areas published by the Macau municipality. Based on the previous research results [43,44,56,57], different weights are given to the indicators for evaluating the quality of public green space, with a weight of 0.5 for the use and ecological level of PGS, a weight of 0.2 for the cultural landscape of PGS, and a weight of 0.3 for the financial investment in maintenance and management. The mean, median and standard deviation of the quality of each PGS were calculated using descriptive statistics.

3. Results

3.1. Evaluation of the Spatial Justice of PGS on the Macau Peninsula

The PGS defined in this study mainly includes parks, gardens and open space areas declared by the Macau municipality, and the measured PGS area per capita is 0.92 m^2/person, far less than the data provided by the government. Figure 2 shows that the current PGS on the Macau Peninsula is small and fragmented, and it is unevenly distributed within the spatial units. PGSs are mainly concentrated around the urban area of the peninsula, with more PGSs in the NAPE e Aterros da Baía da Praia Grande reclaimed area outside Patane e São Paulo, and fewer in the Barca, Horta e Costa e Ouvidor Arriaga areas. By calculating the spatial Gini coefficient (Formula (1)) of 17 statistical units, the spatial Lorenz curve (Figure 5) shows that there is a large gap in the distribution of PGS between the populations of the statistical areas in the Macau Peninsula, and the Gini coefficient of PGS for the total population is relatively high (0.58 > 0.5).

Based on the spatial location entropy value (Formula (2)), as divided into five levels according to the natural break point classification method, and analyzed based on the spatial distribution pattern of per capita PGS resources (Figure 6), the results show that the per capita distribution of PGS among the different areas of the Macau Peninsula is mainly characterized by the southeastern area being higher than the central and western areas. There is a significant negative correlation (p = 0.009 < 0.05) between the spatial location entropy value and population density, indicating that areas with higher population density have lower levels of PGS.

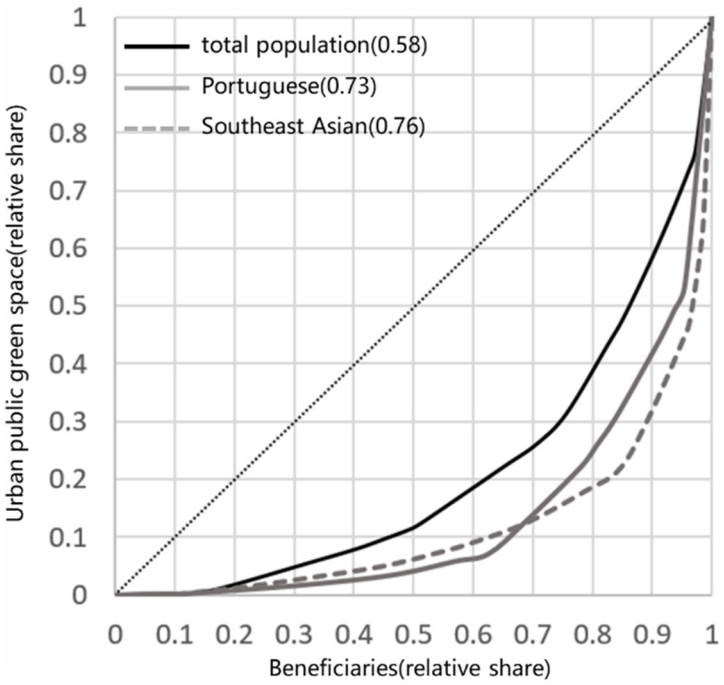


Figure 5. Gini coefficient and spatial Lorenz curve of the PGS distribution among different population groups.

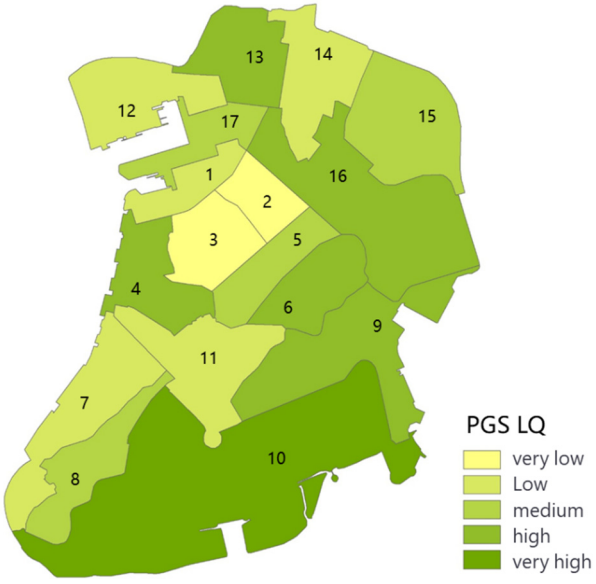


Figure 6. The spatial distribution pattern of the per capita public green space resources based on the spatial entropy values.

There are also spatial differences in the quality of PGS on the Macau Peninsula (Table 2). Figure 7a shows that the central area, including Patane e São Paulo, Barca, and Baixa de Macau, has relatively low scores for spatial quality, with median scores of 2.196, 2.216, and 2.275. Areia Preta e Iao Hon, Fai Chi Kei, and Praia Grande e Penha, on the other hand, have higher scores for spatial quality, with median scores of 3.843, 4.055, and 4.135. The overall pattern of PGS quality shows that the north and south areas have higher quality than the central area, and the eastern side of the central area has higher quality than the western side. The Guia district (São Lázaro) has relatively stable and high-quality PGS, while the Baixa de Macau district has more varied spatial quality (Figure 7b).

Table 2. Statistics on PGS quality for spatial units on the Macau Peninsula.

	Spatial Unit	Mean	Median	Max	Min	SD	Variance
1	Doca do Lamau	2.751	2.827	3.195	2.368	0.323	0.105
2	Horta e Costa e Ouvidor Arriaga	2.473	2.473	——	——	——	——
3	Barca	2.216	2.216	2.338	2.093	——	——
4	Patane e São Paulo	2.546	2.196	4.337	1.518	0.984	0.968
5	Conselheiro Ferreira de Almeida	2.630	2.630	3.150	2.110	——	——
6	Guia	3.678	3.735	3.762	3.538	0.122	0.015
7	Barra e Manduco	2.567	2.599	3.098	1.877	0.504	0.254
8	Praia Grande e Penha	3.913	4.135	4.340	2.897	0.584	0.341
9	ZAPE	2.679	2.527	3.785	1.893	0.732	0.536
10	NAPE e Aterros da Baía da Praia Grande	3.650	3.728	4.200	3.105	0.312	0.097
11	Baixa de Macau	2.604	2.275	4.215	1.680	1.017	1.035
12	Ilha Verde	3.339	3.180	4.383	2.362	0.774	0.599
13	Tamagnini Barbosa	3.496	3.527	3.937	3.060	0.270	0.073
14	Areia Preta e Iao Hon	3.661	3.843	3.960	3.102	0.291	0.085
15	NATAP	3.611	3.657	4.228	2.815	0.452	0.205
16	Móng Há e Reservatório	2.947	2.826	4.187	2.305	0.583	0.340
17	Fai Chi Kei	3.727	4.055	4.303	1.980	0.985	0.971

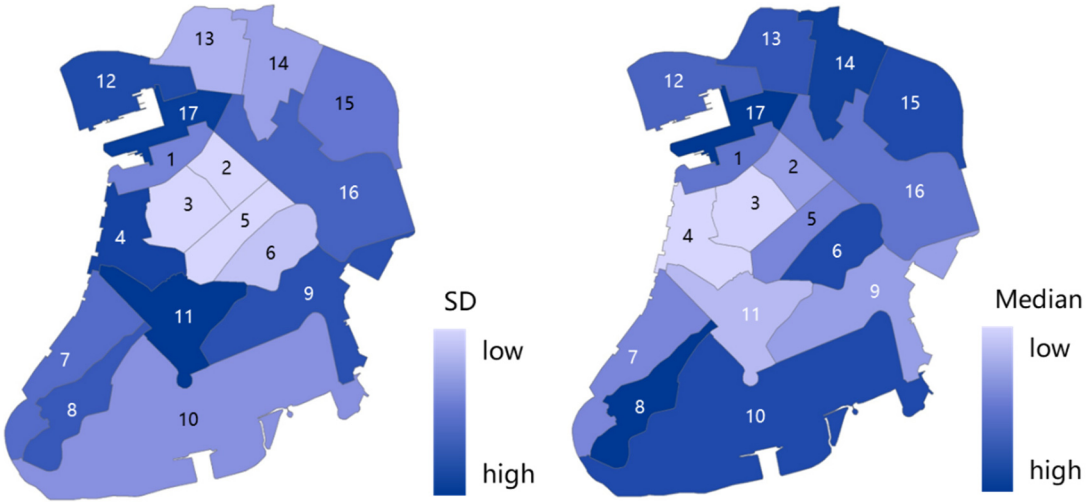


Figure 7. PGS quality on the Macau Peninsula: (**a**) standard deviation, and (**b**) median scores.

3.2. PGS Services for Colonial and Immigrant Groups

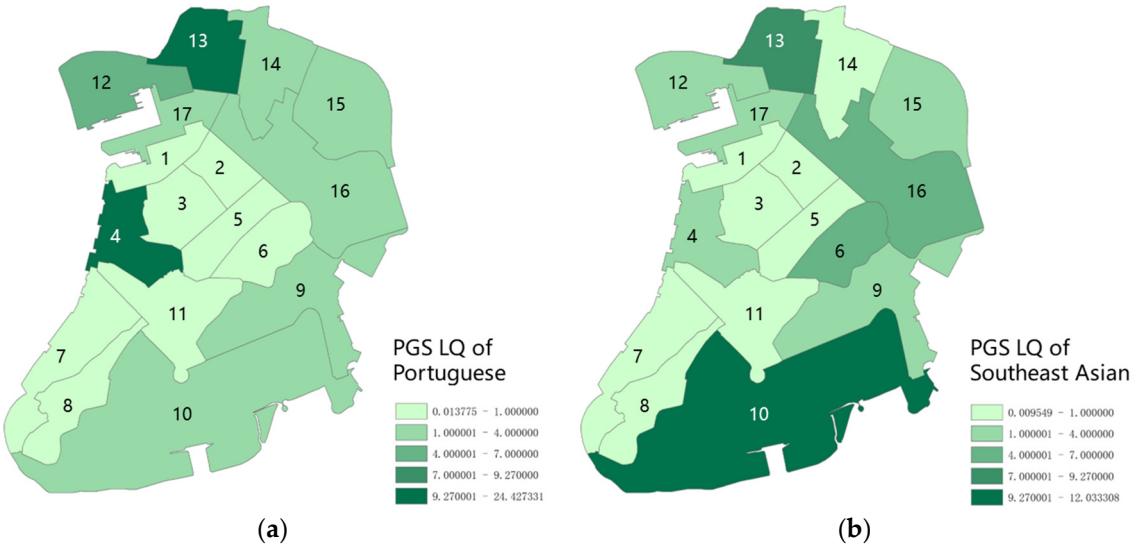
The PGS services on the Macau Peninsula also show certain differences among different groups. According to Formula (1) and Figure 5, the Gini coefficient (G) for PGS among Southeast Asian nationals is 0.73 and Portuguese nationals is 0.76. There is a significant gap in the distribution of per capita PGS among non-Chinese ethnic groups, and the Portuguese group has the largest gap in the allocation of per capita PGS resources, followed by the Southeast Asian group. Based on Formula (3), we obtained the spatial shares of different populations on the Macau Peninsula (Table 3). The share index (F) of the PGS resources enjoyed by the Chinese group is 1.009, which is approximately equal to 1. This suggests that the native group has the same average of all the groups of PGS resources as the social average share on the Macau Peninsula. The Chinese group has the same access to green space as the overall population, which is also related to their population percentage. The proportion of the Chinese group on the Macau Peninsula is 89.7%, which is relatively large. Therefore, the group equity is equal to the overall. The share index (F) of PGS resources enjoyed by foreign groups is 0.9184, slightly lower than 1, indicating that the share of PGS resources enjoyed by foreign populations is slightly lower than the overall level. It is worth

noting that the spatial share index (F) of PGS resources enjoyed by the Portuguese group is 1.654, while that of the Southeast Asian group is 0.822. The spatial share of Portuguese nationals is significantly greater than 1, while that of Southeast Asian nationals is less than 1. Moreover, the spatial share of PGS resources enjoyed by the Portuguese group is twice that of the Southeast Asian group. The distribution of PGS resources among foreign groups is highly unequal, with the Portuguese group having a clear advantage and the Southeast Asian group not reaching the average level. The phenomenon of inequality is therefore obvious.

Table 3. Spatial share values for different national groups on the Macau Peninsula.

	Chinese in Peninsula	Non-Chinese	Portuguese	Southeast Asian
Spatial share values F	1.009	0.9184	1.654	0.822

To explore the spatial inequality of PGS between the Portuguese and Southeast Asian groups, the spatial location entropy index (Formula (2)) was used to measure the spatial location entropy values between populations. The location entropy values (LQ) were divided into five levels (very low, low, medium, high, very high). The results (Figure 8a) indicate that the spatial distribution of PGS among the Portuguese population is relatively even and the differences are small. The Tamagnini Barbosa and Patane e São Paulo areas have higher location entropy values. Compared with the Portuguese group, the spatial distribution of PGS among the Southeast Asian group is more varied (Figure 8b), with the highest location entropy value in the NAPE e Aterros da Baía da Praia Grande area. The spatial entropy distribution shows that both the Portuguese and Southeast Asian groups experience a gradually increasing trend of per capita PGS resources from the central area to the periphery. The location entropy values in the central urban areas (Doca do Lamau, Horta e Costa e Ouvidor Arriaga, Barca, Conselheiro Ferreira de Almeida, Baixa de Macau, Barra e Manduco, Praia Grande e Penha) are less than 1, indicating that the per capita PGS resources of both groups in these spatial units are lower than the average level. The location entropy values in the remaining peripheral areas are all greater than 1, indicating that the per capita PGS resources of both the Portuguese and Southeast Asian groups are higher than average. This reflects the fact that the population density of the Portuguese and Southeast Asian groups is higher in the central urban areas, and the location entropy of the Portuguese population shows more significant agglomeration characteristics.



(**a**) (**b**)

Figure 8. Spatial entropy in the PGS: (**a**) Portuguese, and (**b**) Southeast Asian.

We used the Spearman correlation coefficient to compare the rankings of the population density of the Portuguese and Southeast Asian groups (Figure 9a,b) with the evaluation values of PGS quality (Figure 8). It was found that the correlation coefficient of the Portuguese group is $p = -0.297$ (t = 1.202, not significant), indicating no significant correlation between the population density of the Portuguese group and the quality of PGS. However, the correlation coefficient of the Southeast Asian group is $p = -0.691$ (t = 3.704), indicating a negative correlation between the two. This shows that the higher the population density of an area, the lower the quality of the PGS.

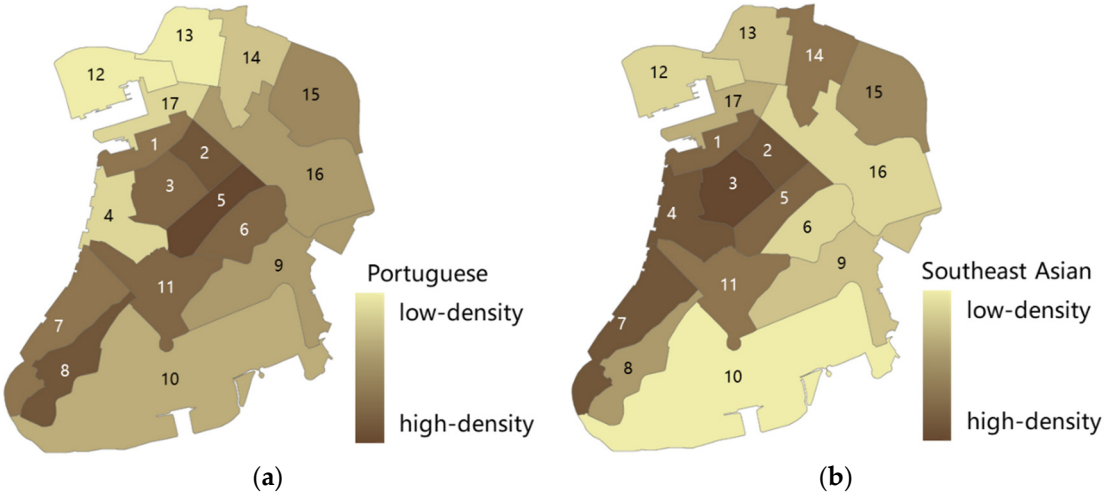


Figure 9. Population density on the peninsula: (**a**) Portuguese, and (**b**) Southeast Asian.

3.3. Changes in PGS on the Macau Peninsula, from 1980 to 2021

To explore the trend of equity in PGS on the Macau Peninsula, we used parishes as spatial units to compare and analyze the spatial Gini coefficient and entropy values of PGS on the Macau Peninsula in 1980, 1991, 2001, 2011, and 2021 (Figure 10). The results (Figure 11) show that, first, from the perspective of the entire Macau Peninsula, the change in the Gini coefficient reflects that the distribution of public green space resources and population showed a phased upward trend followed by a continuous downward trend over the past 40 years, and this is currently stable within a relatively equity and reasonable range (0.3–0.4). The changes in the distribution of the location entropy (Figure 12) showed that with the changes in the urban land space and population, the fluctuation of the entropy values of PGS in each parish of the Macau Peninsula has decreased, and the differences have become stable since 2001. The entropy values from large to small are Sé, São Lázaro, Santo António, Nossa Senhora de Fátima and São Lourenço, indicating that the per capita level of public green space resources in Sé and São Lázaro is higher than the overall level of the Macau Peninsula, as the entropy values of these two parishes are stable above 1. The entropy values of São Lourenço, Santo António, and Nossa Senhora de Fátima, on the other hand, are less than 1, indicating that the per capita level of PGS resources in these parishes is lower than the overall level of the Macau Peninsula.

Secondly, the group differences in the distribution of PGS have gradually become more prominent. The spatial Gini coefficient of the Portuguese group showed an initial increase followed by a slight decrease over time, and it is currently within a reasonable range (0.3–0.4). However, over the past 20 years, the spatial Gini coefficient of the Southeast Asian group has shown a significant increase, with a Gini coefficient of 0.446 (0.4–0.5) in 2011 and a value of 0.591 (>0.5) in 2021. This suggests that the per capita distribution of PGS resources for non-Chinese immigrants, as represented by Southeast Asians, has become increasingly unequal each year, and the current gap is significant, with a trend of increasing inequality. Meanwhile, the difference in the Gini coefficients between the foreign immigrant groups and colonial groups has also gradually increased, indicating that the gap

in inequality between the groups has gradually expanded, and the inequity distribution of PGS resources enjoyed by immigrant groups has further worsened.

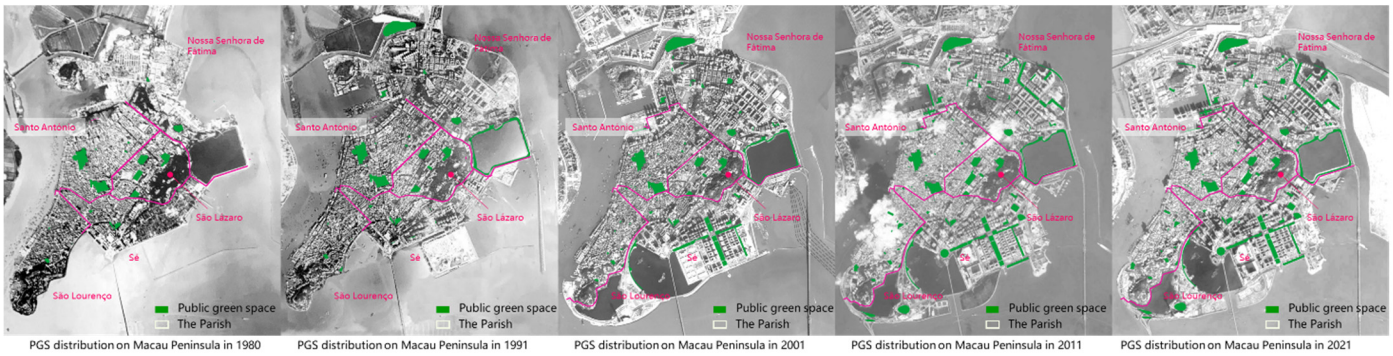


Figure 10. The 1980, 1991, 2001, 2011, and 2021 distribution and changes in PGS.

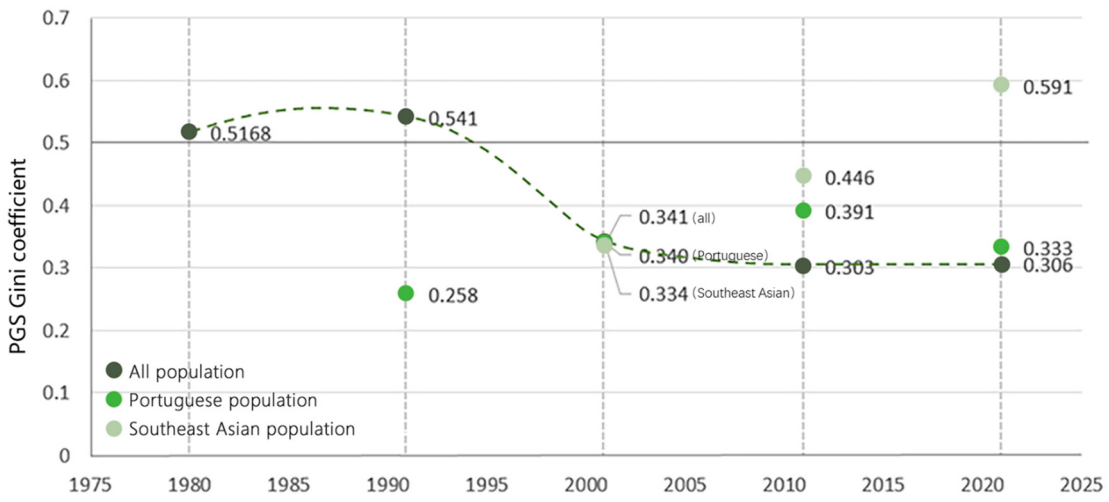


Figure 11. Comparison of the Gini coefficients for PGS on the Macau Peninsula from 1980 to 2021.

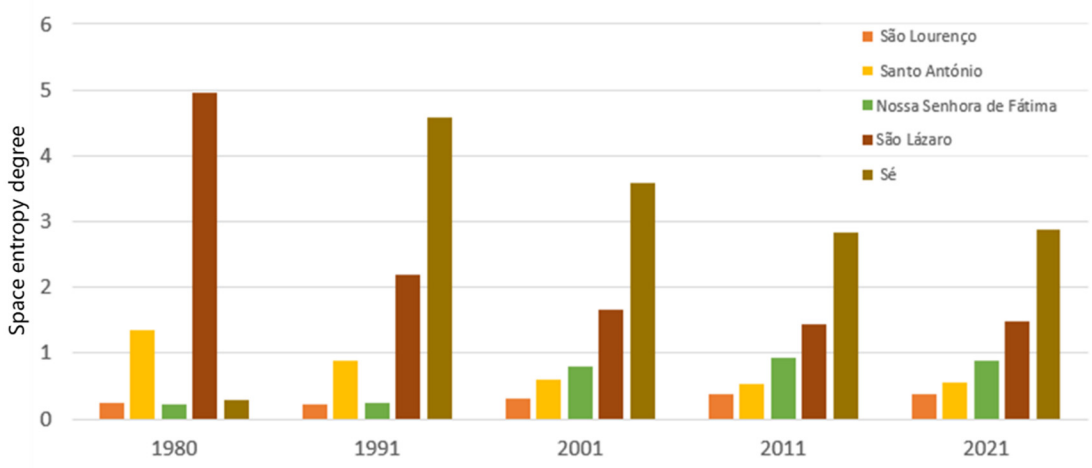


Figure 12. Comparison of the spatial entropy values of PGS among parishes on the Macau Peninsula from 1980 to 2021.

4. Discussion

Our study contributes to previous research on the complex spatial relationships between PGS and various social groups, especially in high-density post-colonial areas. We considered that in the case of the inequity distribution of PGS, compared with the colonial group, the immigrant group's enjoyment of PGS is an example of inequity rather than injustice, and the gap may increase over time. The reasons for this result may come from three aspects: different spatial production mechanisms of PGS in different historical periods in post-colonial areas, different restrictions and perceptions of PGS among different national groups, and social isolation caused by urban land expansion. This perspective and the results may be applicable to other postcolonial regions.

4.1. Spatial Equity and Production of PGS

On the Macau Peninsula, whether based on statistical units or parishes, different spatial units exhibit different patterns of PGS, and there are significant differences in the spatial distribution and spatial quality of PGS. This is consistent with previous research findings [60–62]. There was significant injustice in the PGS distribution during the colonial and segregation periods, which continues in the post-colonial period, and this study found that it may be due to the spatial production mechanism of PGS in different historical periods.

As noted above, the development of PGS on the Macau Peninsula can mainly be divided into two periods: the colonial period (1557–1987) and the non-territorial period (1987–2009) [53]. During the colonial period, PGS in Macau was divided based on the colonial government's leadership, and the form that PGS took in different communities was completely different. During the non-territorial period, urban construction was dominated by urban renewal and land reclamation. The production of urban public spaces was transformed from being led by political power to a diversified market economy supply, leading to a bias toward economic efficiency and social value. This increased the total amount of urban PGS but also affected the balance of the distribution of urban PGS. Urban development tended toward high density [63], and due to the high value of land, the production cost of PGS was high. At this time, PGS was a product of a market-oriented economy and there was a relative lack of public spaces, which was not conducive to equitable use for low- and middle-income residents.

Therefore, the uneven distribution of PGS on the Macau Peninsula has been determined by the production mechanisms and different patterns of urbanization. The production of PGS on the peninsula is characterized by political power and land value. The spatial representation of political power under colonial leadership and the monopolization of capital by the business-oriented city have led to the inequitable distribution of PGS on the Macau Peninsula. Different mechanisms of spatial production in e urbanization development have led to PGS inequality. This research result provides new insights into environmental justice and urban sustainable development in the process of urban renewal and development.

4.2. Social Integration of Groups of PGS

The results show that among non-Chinese groups, the Portuguese group is above average in terms of the PGS spatial share and quality, while the Southeast Asian immigrant group is at a disadvantage in the use of PGS. This shows that the colonial settlers' extensive occupation and racial segregation of urban PGS will continue into the post-colonial period. Even if the group accounts for a small proportion, they still have an advantage. Different from previous studies [64–67], this research shows that the deeper reason for the differences in PGS usage among groups is social integration rather than solely economic status, while economic status is also one of the factors that affects social integration.

In terms of the use of PGS, the spaces most frequently used by the Portuguese group are the church square, the square, etc., and these spaces are mainly used for religious and cultural activities. Due to the long-term colonial rule, the Portuguese group has a high degree of social integration into Macau. Their economic, socio-cultural, and political dimen-

sions have achieved a high degree of social integration, and their living areas are mostly colonial gathering places and areas with higher land values. Therefore, the Portuguese group has fewer restrictions regarding its choice of PGS, it has greater autonomy, and it has more opportunities to choose high-quality PGS for its activities.

Macau is an immigrant city, and the stress of immigration poses significant risks to mental health. A social network of friends can help alleviate the stress of Filipino domestic workers in Macau [68]. The Southeast Asian immigrant communities often choose low-cost leisure activities for socializing due to their economic status [69] and therefore more frequently use PGS than other groups [51]. Taking the roundabout at Avenida do Conselheiro Ferreira de Almeida (Three Lamps) as an example, it is common to see Southeast Asian immigrant workers gathering in this PGS, which exhibits periodic and spatially fixed characteristics [70]. The social network relationships developed by immigrant communities also play a role in their integration by providing social and emotional support. PGSs serve as an effective means of supporting group social integration. However, due to factors such as language, culture, economic status, and education level, the Southeast Asian immigrant group in Macau may experiences spatial segregation in PGS. Their beliefs and ideologies may also hinder their social integration. Therefore, the Southeast Asian group has limited choices in terms of PGS due to their individual characteristics and social network relationships, as well as their lack of autonomy. Due to group clustering and economic status, they tend to choose PGS with lower quality.

Overall, the inequity of PGS access among the foreigner group on the Macau Peninsula is influenced by their social identity, which leads to external inequity. The power distribution of social identity affects the spatial division, and the spatial selection also reflects the construction and recognition of identity. This study shows that social integration has an impact on the inequity of PGS. The groups with higher social integration levels tend to enjoy higher-quality PGS services, while those with lower social integration levels have poorer access to PGS.

4.3. Spatial Equity Development and Trends of PGS

Analysis of the changes in the equity of the PGS distribution on the Macau Peninsula in the past 40 years shows that equity has improved compared to the colonial period and that the gap in the overall population has gradually narrowed. Previous studies have indicated that the group differences in equity of access to PGS in Macau narrowed from 2010 to 2015 [65]. However, the findings of this study diverge from that, under the longer-term research dimension, as there are still significant differences between spatial units in each district. What is more important is that the unfair differences in PGS between groups are further aggravated. This shows that group inequity differences in the same region may improve in a short period of time but intensify in the long-term dimension. Related research should extend the time as much as possible to better grasp the development trend of injustice.

With the transformation of the public space production mechanism and the unified planning and construction of the city, the matching relationship between PGS in each district of the Macau Peninsula has gradually become fairer. This is related to the fact that the urban planning of Macau encourages a large number of small PGSs rather than a single large PGS and provides the "density" of PGS rather than the scale. However, the injustice index difference between the Portuguese and Southeast Asian groups has gradually increased. This means that although urban renewal and a series of new land reclamation projects on the Macau Peninsula may have alleviated the overall inequity of PGS to some extent, they may have further aggravated differences in PGS use between groups, intensifying conflicts between groups and hindering groups' social integration.

5. Conclusions

The results responded to the research questions, identifying that (1) there is a "spatial mismatch" in PGS on the Macau Peninsula; (2) among different nationality groups, there are

significant differences in PGS services between colonial groups (Portuguese) and immigrant groups (Southeast Asians), with Portuguese groups having better use of PGS than Southeast Asian groups; and (3) a comparative analysis of the changes in PGS inequity in the past 40 years found that PGS overall tends to be equitable, but the differences between groups are gradually increasing. The reasons are that the city's public space production mechanism affects the equity of PGS, and with the continued impact of colonialism and urbanization, the inequality experienced by non-Chinese groups may be further aggravated. Social integration is also an important factor affecting the inequity of PGS. Especially in post-colonial areas, the use of PGS by different nationality groups should be paid attention to.

The results of this study can provide a reference for relevant urban planners and administrators seeking to optimize the city's spatial layout and reduce the PGS inequality. We make the following recommendations for the design and management of future urban renewal in Macau and other similar regions:

- During the urban renewal process, the focus should be on identifying and updating those PGSs with insufficient distribution and low-quality scores. The government could intervene in PGS and provide more preferential policies for the areas lacking PGS.
- To improve PGS, especially in areas with a high density of non-Chinese groups, the government should pay more attention to the cultural diversity of PGS, for example, adding some landscape installations and facilities with different cultural characteristics to help immigrant groups improve social integration and help immigrant groups improve social integration.
- Emphasis should be placed on the public participation of the immigrant groups in the urban renewal process of PGS, especially the participation of vulnerable groups, which can help them find a sense of social belonging.
- It is also necessary to increase the special planning of PGS and formulate unified planning and management goals for PGS.

There are also limitations in this study. There are many heterogeneities among the social and economic factors, topography, historical protection, and construction development conditions in the statistical units of the Macau Peninsula, which may affect the statistical results to some extent. The year selected for the study is combined with demographic data and existing map data. If other years are added in the future, the research will be improved and optimized.

This article considers the changes and trends in PGS injustice in the long-term dimension and understands the differences in PGS equity through comparisons between specific groups. This study provides a new perspective to investigate PGS inequity and identify the priority areas where the PGS inequity needs to be alleviated in future urban green space system planning and policymaking. Additionally, this study help can better understand and solve the problem of urban spatial inequity in high-density post-colonial areas and also contribute to the sustainable development of society.

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