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Research Article

Research on Activation Design of Street Leftover Spaces on the Main Island of Macao Based on Industry 4.0 and Propagation Models

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Space has become a driver not only for knowledge, inspiration, cooperation, and policymaking, but also for high-end technology integration into the manufacturing domain. As the high-density city quarters, the Macau Peninsula carries multiple functions via its public outdoor spaces, and they are of vital significance. Closely intertwined with Industry 4.0 is therefore the next industrial revolution that is already showcasing the benefits of increased connectivity, intelligence, and flexible automation. The rapid urbanization of Macao was not guided by sound land use planning, induced the scattering of many negative spaces on narrow streets. Because of their irregular shapes and utilization difficulties, these spaces gradually become leftover spaces. A number of measurement-based street leftover spaces models have been developed over the years by researchers as well as standards bodies to model path in typical wireless environments. In this paper, the streets of Macao are analyzed based on the city characteristics. The pedestrians and spatial relationships are investigated via space syntax and SPSS regression fitting. Finally, activation design of street leftover spaces is conducted, for making better use of leftover spaces, compensate for the functional deficiencies of streets, and endow them with more vigor and vitality.

1. Leftover Space Theory and Research Status

In essence, urban leftover spaces constitute a specific type of negative urban spaces. The concept of "leftover space" (or residual space) was first introduced by Winter bottom in his work *Residual Space Re-Evaluated (2000)* in reference to "spaces which are not programmed and not connected with the surrounding environment" [1].

As urban open spaces, street leftover spaces are specific public spaces that have formed dynamically along with the development of streets. As unorganized, isolated, and vague public spaces, street leftover spaces reflect several practical problems with urban street spaces. The formation of leftover spaces is attributable to a series of factors, such as restriction by natural conditions, legacy of urban development, design negligence, and other artificial factors. The authors believe that the most influential factor is planning and design inadequacy over the course of urban development.

2. Urban Texture of the Macau Peninsula

Macao has a small land area (only ~40 km^2) that is inhabited by more than 660,000 people, and its urban facilities are well equipped. The period from the 19th to the 20th century was a stage of rapid urbanization and modernization of Macao's architectural style. During this stage, the Macau Peninsula experienced radical, revolutionary changes, and its urban morphology basically fell into a pattern (Figure 1).

As shown in Figure 2, the overall urban morphology pattern of the Huawangtang District took shape before 1889. After the emergence of high-rise buildings, this area still retained its original overall unified style and homogenization

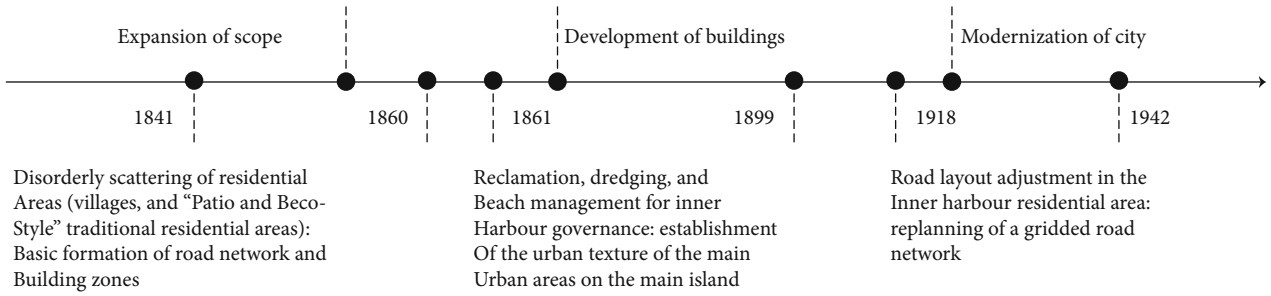

Figure 1: Time axis of urban development in the Inner Harbor residential area.

Figure 2: Historical maps of the Huawangtang District in Macao.

of social residences. This situation has greatly restricted the development of the city. Currently, the city urgently needs intervention by better design approaches.

The Industry 4.0 (I4.0) concept transforms the current industrial environment through the digitization of production, automation, and the integration of the production site

into a comprehensive supply chain. This concept consists of full network integration and real-time information exchange [2]. It is impossible to abstract the vision of the cities of tomorrow from that of the future configuration of their transport systems [3]. So designers need to incorporate digitization of production and reconcile the contradiction between narrow crowded streets and undesirable public spaces by improving the street environment.

3. Research Methods

This paper analyses the streets of Macao based on the characteristics and development history of the city and uses space syntax and SPSS regression fitting to investigate the pedestrians and spatial relationships. Finally, activation design of street leftover spaces is conducted to make better use of leftover spaces, compensate for the functional deficiencies of streets, and endow them with more vigor and vitality [4].

3.1. Field Survey. As urban negative spaces, street leftover spaces are frequently neglected by both scholars and designers; therefore, little data are available for reference in this field. In this paper, the street spaces of Shalanzi Street and Gongjiang Lane in the Huawangtang District in Macao are taken as research objects. Their quality, morphological characteristics, distribution locations, and related human activities were surveyed in the field via mapping, photography, and interviews. The collection and arrangement of the survey data laid a foundation for subsequent research.

3.2. Space Syntax. Modeling analysis was performed on the connection, integration, and choice values of leftover spaces in the overall space using space syntax. SPSS regression analysis was used to explore the topological relationships between pedestrian volume and the integration and passing values of spaces under different radii. The activation design directions of leftover spaces were explored through data analysis, to achieve the overall optimization and functional integration of street spaces [5].

4. Status Analysis of Leftover Spaces in the Huawangtang District

4.1. Research Scope. The scope of this research covers the plots within the ranges of Shalanzi Street, Camoes Grotto and Gardens, Zhengjiang Lane, and Basudaer Ancient Street in the Huawangtang District (as shown in Figure 3).

By conducting field surveys on the street leftover spaces in the Huawangtang District, the authors have found that here, and leftover spaces are mostly distributed in disorder around streets and buildings, as shown in Figure 4. These leftover spaces can be roughly classified into three types, i. e., street gardens, open spaces between buildings, and street-side open spaces [6].

4.2. Existing Problems with Street Leftover Spaces

4.2.1. Functional Singularity and Deficiencies. Motorcycles are the primary means of transportation for the residents of Macao; therefore, most leftover spaces have ended up as motorcycle parking lots. This single-purpose function also intensifies people's rejection of and sense of alienation from such negative spaces and renders the possibilities of diverse activities impossible.

4.2.2. Low Space Utilization Rate. At the level of space utilization, these places are mostly negative, lack vitality, and are regarded as unavoidable passing spaces; therefore, the overall space utilization rate is low.

4.2.3. Cramped and Repressive Environmental Spaces. There are no public spaces in these blocks, and the building layout is highly disorganized. The environmental spaces are also cramped and repressive. As ancillary spaces on streets with single-purpose function and poor environment, these leftover spaces, together with sundries that accumulated there, have further worsened the living atmosphere and reduced spatial vitality.

4.3. Activation Values of Street Leftover Spaces. "The interestingness of overall street environment is an important measure of the appeal of a city to visitors." Given that street leftover spaces are scattered all over the city, activating the road network via spotted forms of renewal can provide an effective renovation strategy at the macroscopic level. It can improve street functions and enrich pedestrian spaces.

In the case of Macao, the activation design of street leftover spaces can be employed to reshape the street environment, turn leftover spaces into cohesive spaces that appeal to residents, and refresh their memories of good neighborly and friendly relations in subdistrict communities.

5. Quantitative Analysis of the Space Syntax

Space syntax is often employed to quantitatively analyze the pedestrian volumes of road sections and the direction of index fitting from the perspectives of urban planning or vitality blockages. This paper focuses on street leftover spaces with small volume and detailed morphology and investigates the relationship between spaces and pedestrian volume.

The following analyses were performed based on space syntax: (1) the integration and choice values of streets under different radii (at the interval of 100) were compared to study the accessibility and possibility of leftover spaces within the scope of the streets of Huawangtang District. (2) A total of 30 road sections were selected from the plots under investigation as observation points. Statistical evaluations were made of the pedestrian volumes in six different periods. Relying on linear regression analysis in SPSS, the pedestrian volumes of the junctions shot in different periods were fitted with the data parameters of the observation points in the space syntax model. Thus, the relationships between pedestrian volume and topological parameters were identified in different periods. (3) Site analysis was performed in combination with spatial accessibility to assess the activation potentials of different street leftover spaces, thus, offering a reference for sitting in subsequent design (as shown in Figure 5).

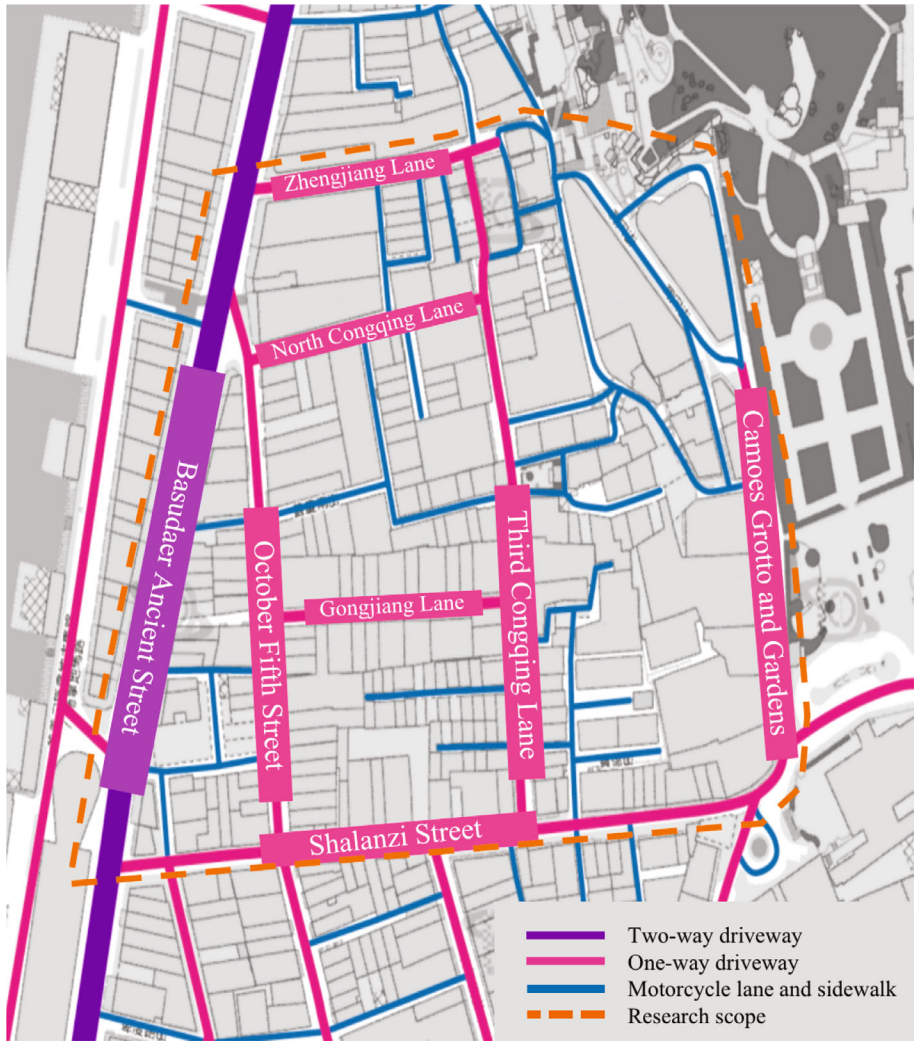

Figure 3: Research scope.

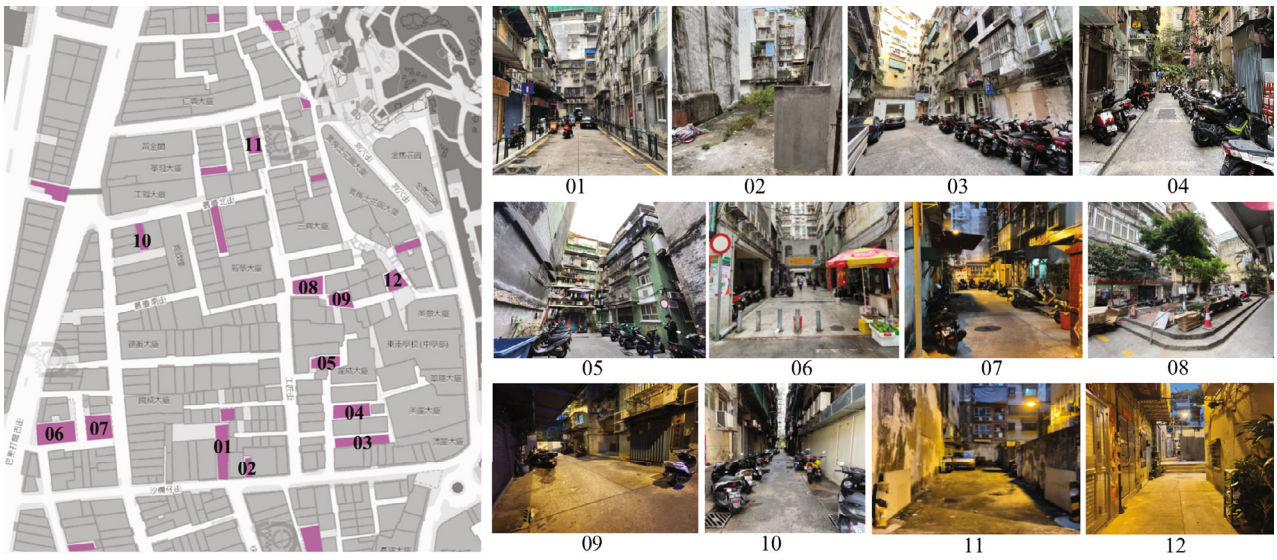

Figure 4: Distribution and status of street leftover spaces.

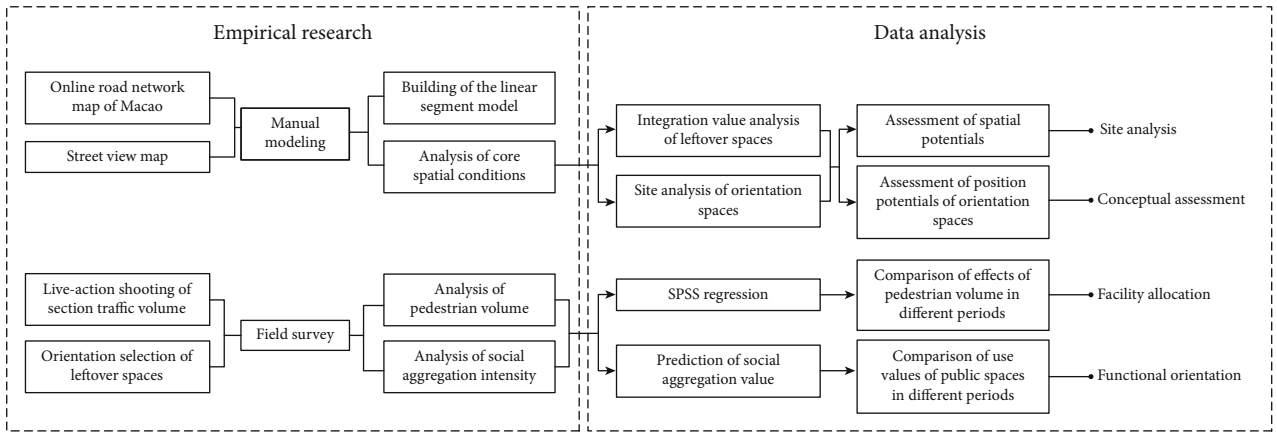

Figure 5: Research technology roadmap of space syntax.

Figure 6: R100-400 integration value of the axis model.

5.1. Space Syntax Segment Model

5.1.1. Integration Value Analysis. The accessibility radius was set as the integral multiples of 100 m within the range of 100-1,000 m according to the segment model. Focus was placed on the traffic volume of pedestrians and the accessibility distribution characteristics of pedestrian spaces.

In the integration value analysis diagram, a warmer color index represents a greater integration value, and consequently, higher accessibility. In the integration value analysis diagram under a radius of 300 m (Figure 6), the area north of Shalanzi Street has a large integration value, suggesting that this area has a high demand for outdoor activities within the radius of 300 m. In the diagram for a radius of 100 m (Figure 6), Third Congqing Lane and Shalitou Inclined Lane also have large integration values; moreover, the integration values of narrow lanes are generally higher than those of the main roads. This suggests that street spaces within the radius of 100 m are more accessible, and that the narrow passages in these blocks are more active and more appealing to pedestrians. The spaces on these streets are highly accessible; therefore, the leftover spaces within the scope of these streets have a high utilization rate and are suitable to serve as popular dynamic spaces. In contrast, for the activation design of street leftover spaces with small integration values, static spaces for quiet and leisurely activities can be developed, catered for specific age groups.

In the integration value model with a radius of above 500 m (Figures 7 and 8), the arterial Shalitou Seaside Street has the greatest activity value, while the areas in these blocks have smaller integration values on the whole. This paper investigates the street spaces in blocks as research objects; therefore, the subsequent regression analysis and design stages concentrate on spaces with an integration value of below 500 m.

5.1.2. Choice Value Analysis. Considering the scale of the research scope, this study set the radius of the segment model as integral multiples of 100 m within the range of 100-1,000 m to analyze the choice values of spaces. Choice values express the passability of spaces, and a positive correlation exists between the integration and choice values of the segment model.

As shown by analyzing the choice value model, the streets in this area have small choice values on the whole. Under a radius below 300 m (Figure 9), choice values are large around Third Congqing Lane and Shalitou Inclined Lane. Under a radius of 400 m (Figure 9), choice values are large on the whole on the south side of Third Congqing Lane and in the middle segment of Zhengjiang Lane. Under a

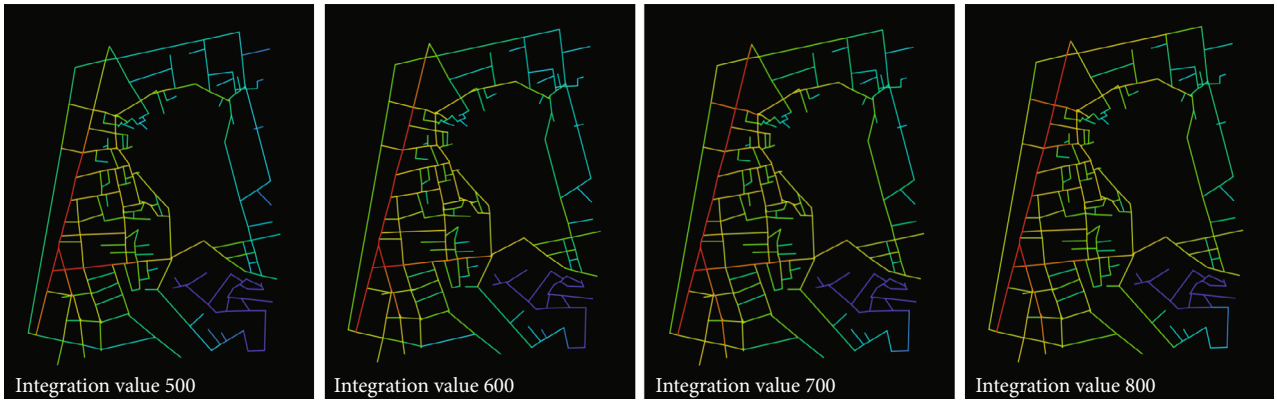

Figure 7: R500-800 integration value of the axis model.

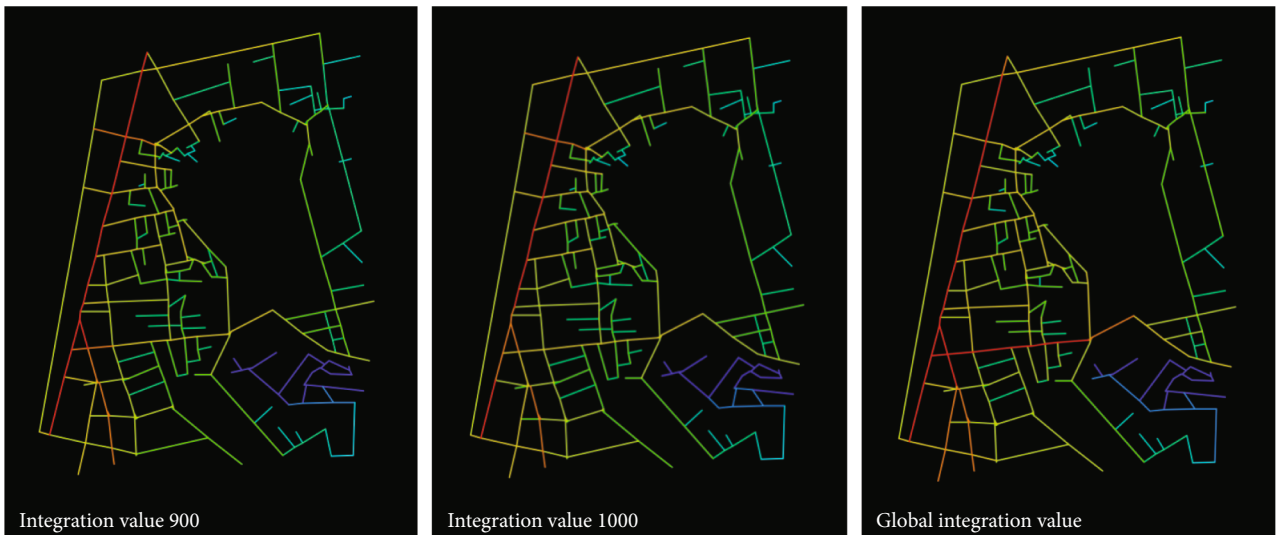

Figure 8: R900-1000 integration value and global integration value of the axis model.

radius of 500 m (Figure 10), choice values are uniformly distributed between roads around selected blocks, and each of the above four streets has high vitality. Under a radius above 600 m (Figures 10 and 11), choice values are large for the main roads around these blocks, but small for narrow lanes in these blocks. With regard to these results, subsequent research should select the model with a radius of below 500 m for analysis.

The use values and design approaches of street leftover spaces are related to their accessibility and pass ability; therefore, spatial sitting should refer to, and fully consider, the passing potentials of spaces under different radii. In this manner, the activation values of spaces can be maximized and matched with the actual pass ability to maximally satisfy the use demands of residents.

5.2. Pedestrian Survey. Select 30 road nodes (Figure 12), pedestrian volumes were calculated, converted into a pedestrian volume per hour, prediction of the pedestrian volume per hour for a specific period, and summarize the data.

After a preliminary statistical analysis of the pedestrian data of street spaces in the Huawangtang District, it could be roughly concluded that in the evening, the pedestrian volume of the block is mainly concentrated in the internal driveway network and scattered on various narrow lanes. There are also obviously more pedestrians on third-class roads that are closed to motor traffic on weekends. With regard to outdoor activities, places with resident gatherings and activities are mostly open spaces beside buildings. On working days, groups passing or remaining in these places are largely elderly people and housewives, as well as children (after school) [7].

For the activation of street leftover spaces, design is adjusted according to the pedestrian volumes and pedestrian groups in different periods. To more visually reflect the pedestrian status of surrounding streets, the above pedestrian data were analyzed by four categories, i.e., weekend pedestrian volume, midweek pedestrian volume, peak pedestrian volume, and off-peak pedestrian volume.

5.3. SPSS Regression Analysis. Based on the space syntax model, block analysis can objectively identify the main spatial logics of the blocks in the Huawangtang District. To better validate the results of the analysis of passing values of

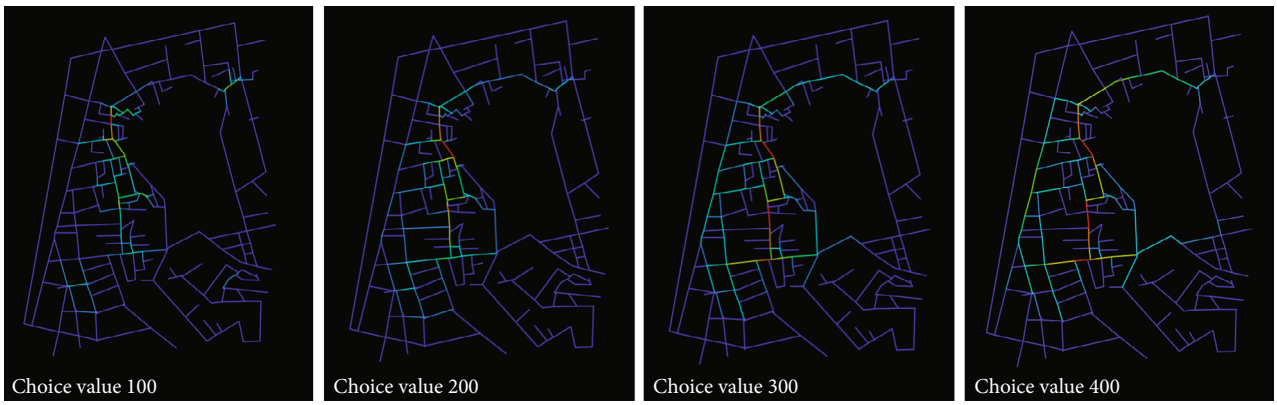

Figure 9: R100-400 choice value of the axis model.

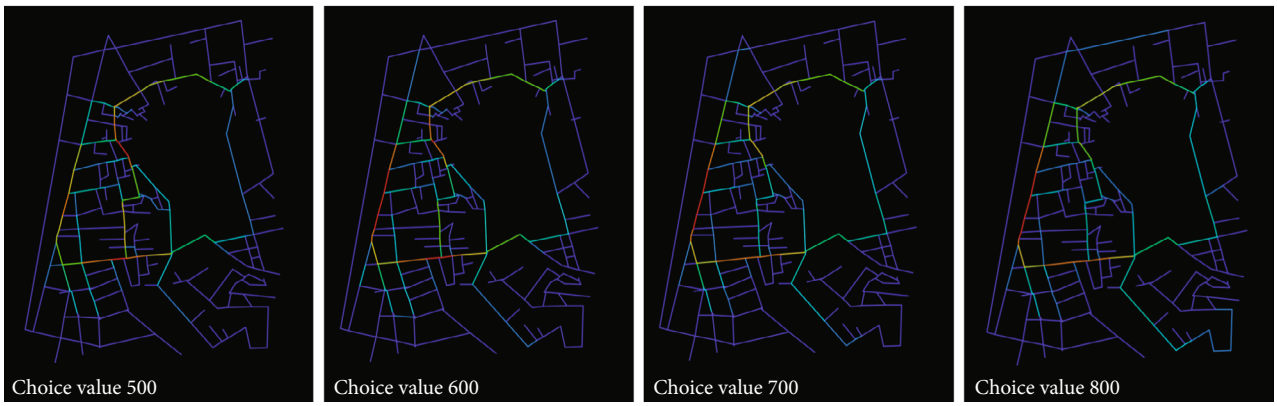

Figure 10: R500-800 choice value of the axis model.

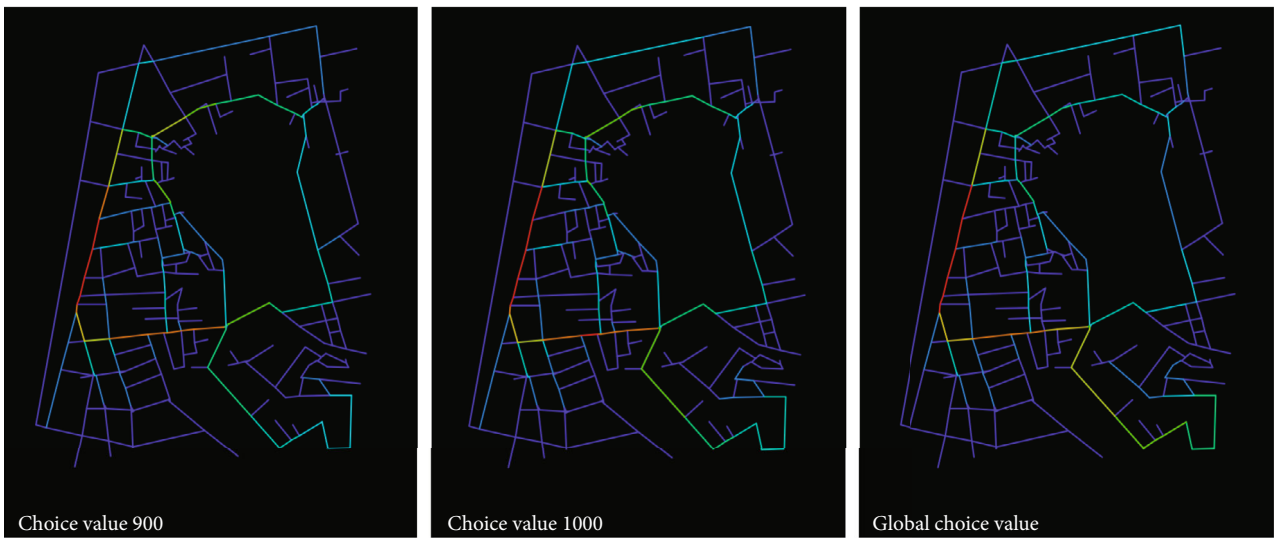

Figure 11: R900-1000 integration value and global integration value of the axis model.

spaces based on space syntax, SPSS analysis was employed to fit the data of the space syntax model with the pedestrian volumes of different periods. This was used to verify the correlation between space syntax analysis data and pedestrian volume. Furthermore, group behaviors were combined with roads that have different passing values to infer the behavioral patterns and influencing factors of different groups in different periods.

5.3.1. Correlation between Midweek Pedestrian Volume and the Syntax Model. A fitting analysis on midweek pedestrian volumes and choice values under different radii (Figure 13)

Figure 12: Pedestrian survey.

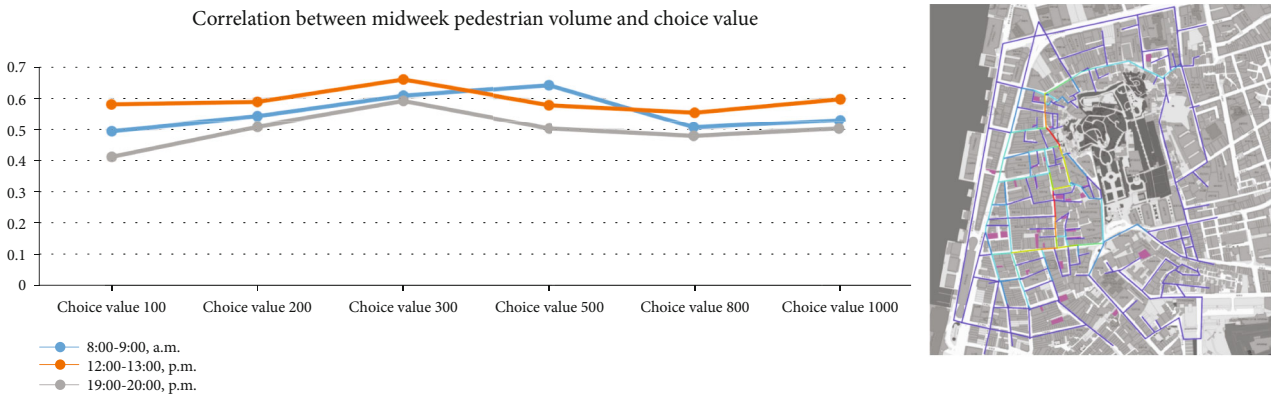

Figure 13: Correlation between the midweek pedestrian volume and choice value and 300 m-radius choice value.

shows that there is a high and balanced overall fitting degree between choice value and pedestrian volume on working days. Choice value and pedestrian volume are highly correlated within a choice value radius range of 200-500 m. This result also matches the 300 m-radius choice value of the syntax model [8].

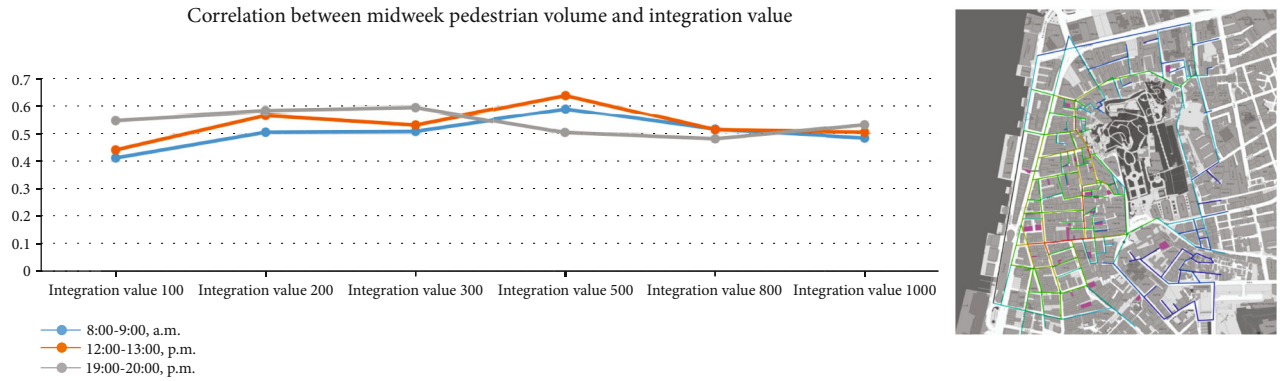

Figure 14: Correlation between midweek pedestrian volume and integration value and 200 m-radius integration value.

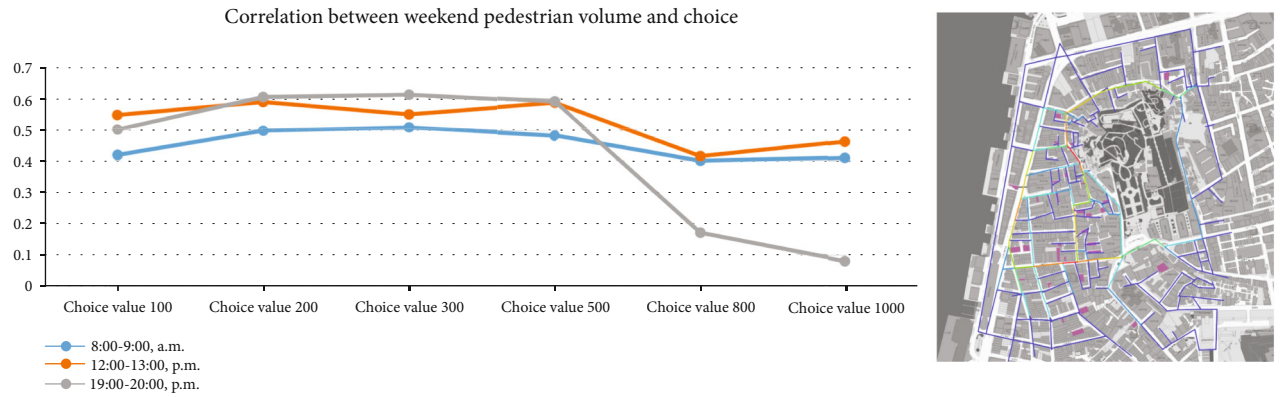

Figure 15: Correlation between weekend pedestrian volume and choice value and 400 m-radius choice value.

According to the fitting data, the integration and choice values of the pedestrian volume basically match within a radius of 300 m. The greatest fitting value was observed under a radius of 500 m, where R^2 reached 0.648 in the morning (Figures 13 and 14).

By analyzing the fitting data with a focus on actual situations, the following can be summarized: on working days, nearby residents going to work usually walk as far as the nearest bus stops; therefore, the peak active radius is 500 m. In the afternoon, housewives and elderly people go out for a walk or to buy vegetables, usually within a radius of 300 m. In the evening, there are less than pedestrians on the arterial roads, and the scope of activity is basically on streets inside this area. In combination with the scope of activity of different groups, it can be seen that the activity habits of residents are related to the accessibility of spaces [9]. Thus, in subsequent design approaches, functional layout can be achieved with regard to this scope.

5.3.2. Correlation between Weekend Pedestrian Volume and Syntax Model. In the fitting data between weekend pedestrian volume and choice values under different radii (Figure 15), the fitting data match best with a choice value model under a radius of 400 m, suggesting a high correlation between them.

According to the data (Figure 16), the integration value and the pedestrian volume match best for a radius of 500 m. The 300 m-radius integration value is largest in the afternoon. On weekends, many types of outdoor activities (such as walking, dining, shopping, and leisure) happen during peak periods and after 10 : 00. For this reason, residents have a wider walking radius range on weekends, and 300-800 m is the most active walking radius range. Analyzing the daily travel habits of nearby residents can identify the most suitable range of travel by walking in Macao. Clearly, the range of travel by walking is wide. In the subsequent setting of street leftover spaces, the scope of research can be adjusted on this basis.

5.3.3. Regression Analysis of Pedestrian Volume and Syntax Model in Different Periods. Midweek peak periods refer to the morning peak (8 : 00-9 : 00) and the evening peak (18 : 00-19 : 00), while other periods are all midweek off-peak periods. Weekend peak periods refer to the afternoon (10 : 00-12 : 00) and the evening (17 : 00-20 : 00) and last for a longer time, while all other periods are weekend off-peak periods. This division into four categories based on the pedestrian volume makes the time-based configuration of functional modules convent in the subsequent design.

The combination of choice and integration values (Figures 17 and 18) shows that weekend off-peak data and the syntax model are poorly correlated. A high fitting degree was found between 500 m-radius choice and integration values, suggesting that residents going out during peak

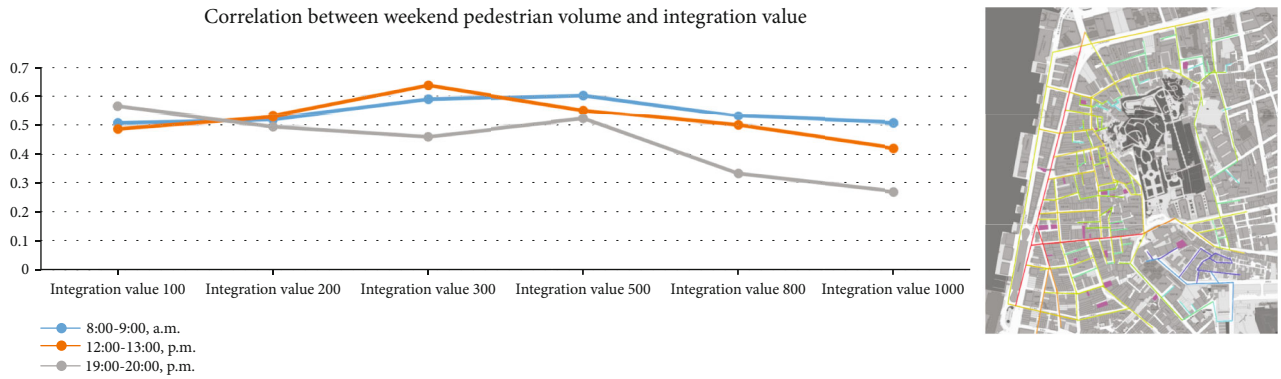

Figure 16: Correlation between weekend pedestrian volume and integration value and 500 m-radius integration value.

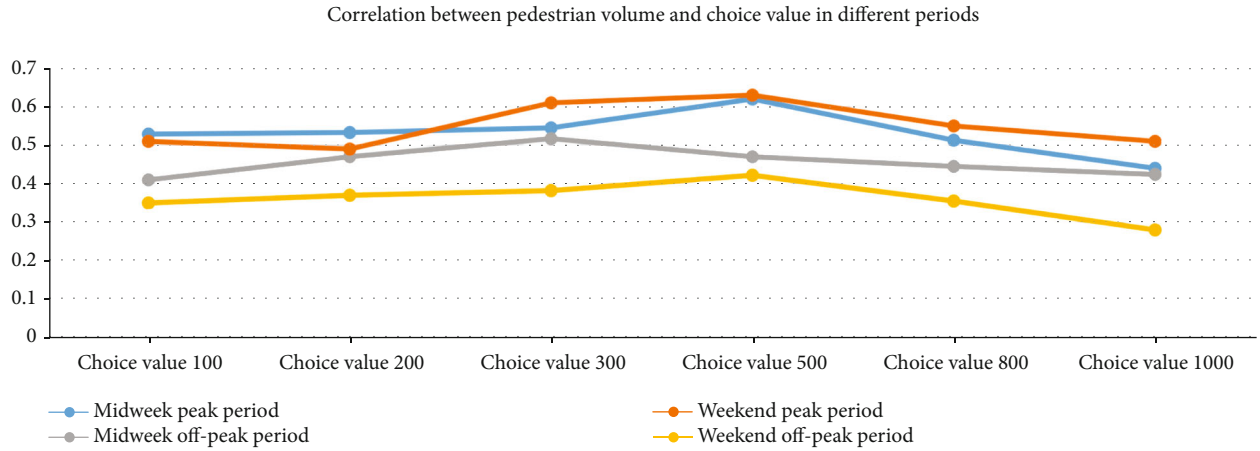

Figure 17: Correlation between pedestrian volume and choice value in different periods.

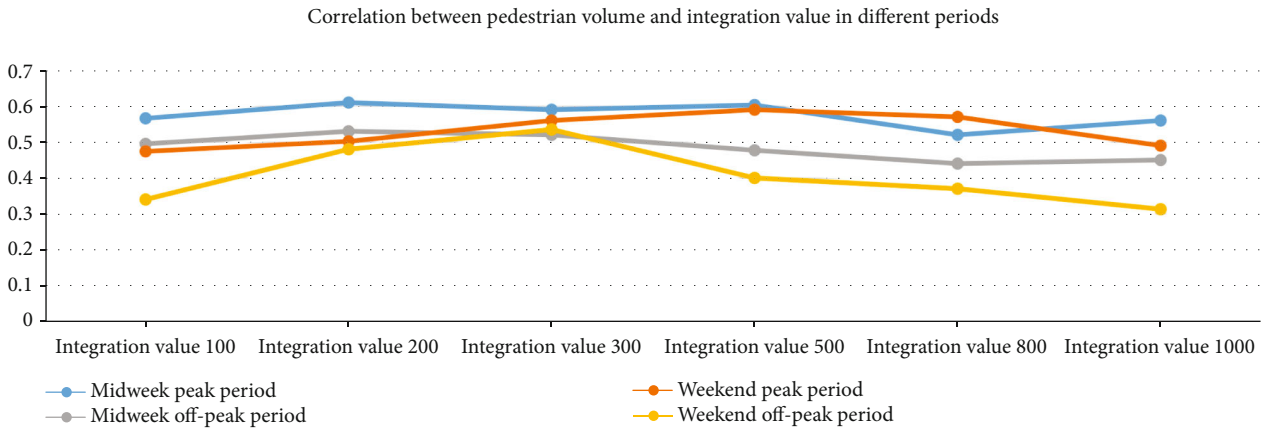

Figure 18: Correlation between pedestrian volume and integration value in different periods.

periods often go to commercial districts that are further away. This explains why the spaces in the investigated plots have a low activity values in peak periods. In off-peak periods, fitting values are higher under smaller radii. This is because, in off-peak periods, housewives and elderly people go out for a walk, for vegetables, or for babysitting, while most young people choose to stay at home.

Space syntax theories concur that human activities constitute an important factor influencing the geometric characteristics of spaces. By objectively studying spatial relationships, the relationships between spaces and human activities can be better understood. This paper not only analyses the passing potentials of spaces for different integrations and choice values but it also presents the results of linear regression analysis through fitting space syntax data and pedestrian data using SPSS. In this way, the correlation between pedestrian volume and spaces in places is visually exhibited, and more realistic research data for space syntax

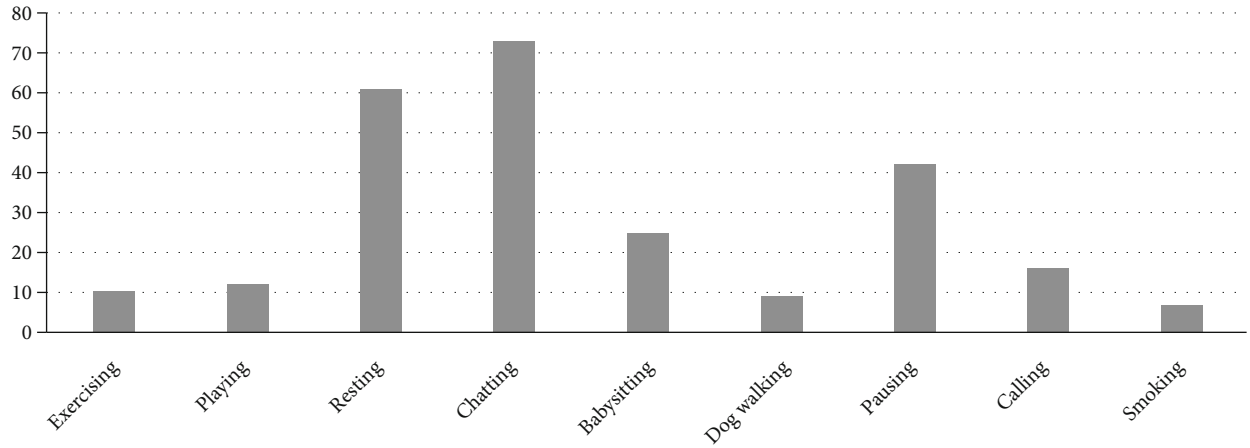

Figure 19: Analysis of resident activities.

is obtained. By combining space syntax data and pedestrian data, this paper offers guidance for sitting and functional orientation in the subsequent activation design of leftover spaces [10].

6. Activation Design of Leftover Spaces in the Huawangtang District

6.1. Modular Structure Mode. In the activation design of leftover spaces, spaces are commonly small and highly variable. To best adapt to various types of spaces and to maximize economic interests, this paper proposes to renovate leftover spaces based on a preset, assembled modular structure mode. That is, different functional modules are selected based on residents' age groups and are assembled on site according to the location factors of the selected site. Such an approach not only matches the demands of different groups but is also adaptable to different space patterns and makes construction and dismantling convenient.

The leftover space model is simulated by the wireless environments path model, and the utilization rate and pass rate of modular structures are monitored and analyzed in the later stage. By combining space syntax data and pedestrian data, this paper offers guidance for sitting and functional orientation in the subsequent activation design of leftover spaces. Only then can spatial design better satisfy both public interests and social demands and also achieve higher practicability for spaces.

An insertion-type modular structure mode offers the following advantages:

(1) *Flexible Spatial Layout*. Small-scale spotted forms can flexibly adapt to any space without compromising the normal passability or vision of roads. Moreover, such preset modules are also cheap and easy to construct

(2) *Rich Activities*. Different preset modules have different facilities and functions and can be freely combined according to on-site conditions. That is, a space can be equipped with diversified facilities and multiple functions, such as leisure, play, and fitness. Combinations of different facilities and functions like these can attract more residents for meeting, chatting, socialization, and entertainment and create more vital street spaces to serve different groups

(3) *Adaption to Changing Local Circumstances through Variable Spatial-Temporal Design*. As dynamic spaces, street leftover spaces can adapt to changing local circumstances via module filling and achieve higher variability both temporally and spatially. In addition, the attributes and functions of spaces can be dynamically changed according to time and season, either for long-term use or short-term adjustments

6.2. Survey of Street Pedestrians. Surveys have shown that the inhabitants of this area are mostly local residents of Macao of different age groups. Because of the shortage of land, elderly people living here have few spaces for leisure or entertainment activities, and children are sometimes seen playing in the open spaces besides buildings, but they would never stay long.

On the basis of several field surveys in this area, the authors have presented statistics of different activities that take place on the streets of this area (Figure 19). Most activities that take place here are necessary activities (such as passing), and free activities are only concentrated in certain spaces. There are basically no social activities here. Thus, recreation and fitness facilities can be added here in subsequent design.

6.3. Design Proposal Analysis. Plot selected in this design proposal is located at the center of a street, and this is the only street garden in this area. As the most active and cohesive plot here, it is adjacent to an arterial road and surrounded by many stores. However, the existing facilities of the garden are very simple (containing benches only, as shown in Figure 20).

To the west of this plot, there is a one-way driveway and all other roads are reserved for pedestrians and motorcycles. The buildings here are mostly seven-story residential

Figure 20: Status of the street garden.

Figure 21: Pedestrian analysis (300 m selectivity).

buildings with life service-oriented shops at the street-level, such as take-out restaurants, color TV stores, and hardware stores. This plot is surrounded by roads on all sides (Figure 21). As a small square in front of the gates of residential buildings, this plot has a large pedestrian volume and high vitality. According to the space syntax diagram with 300 m-radius choice value (Figure 21), this plot has high passability and accessibility within the 300 m-radius range.

This plot is located at a busy and bustling junction with large traffic flow; therefore, the design of this plot should combine dynamic and static elements by zoning and separate dynamic from static zones via a buffer zone. Considering the diversity of visitors to this plot, its functional layout should use diversified functional modules to meet the demands of different groups during different periods and enhance its appeal to different groups. In this way, elderly people can sit here for sunbathing or chatting on working days, and children can play here in the company of their mothers or grandparents. After school and work, students and commuters can also meet here in the evening.

The structural modules are $2\,m \times 2\,m \times 2\,m$ in size (Figure 22) and arranged with boards of different heights to provide sitting and climbing functions. Dividers are also mounted in the vicinity of seats for the elderly as a buffer zone between the children's playground on the eastern side. The sizes of seat modules are designed based on ergonomics, and their shapes can be adjusted to adapt to different spaces. Seats are enclosed to shorten the distance between people and make it more convenient for elderly people to sit here and chat with each other.

6.4. Principles of the Activation Design of Leftover Spaces. Several principles for the activation design of leftover spaces are introduced in this paper. The activation values of leftover spaces can be maximized to better simulate the vitality of streets and meet the use demands of its residents.

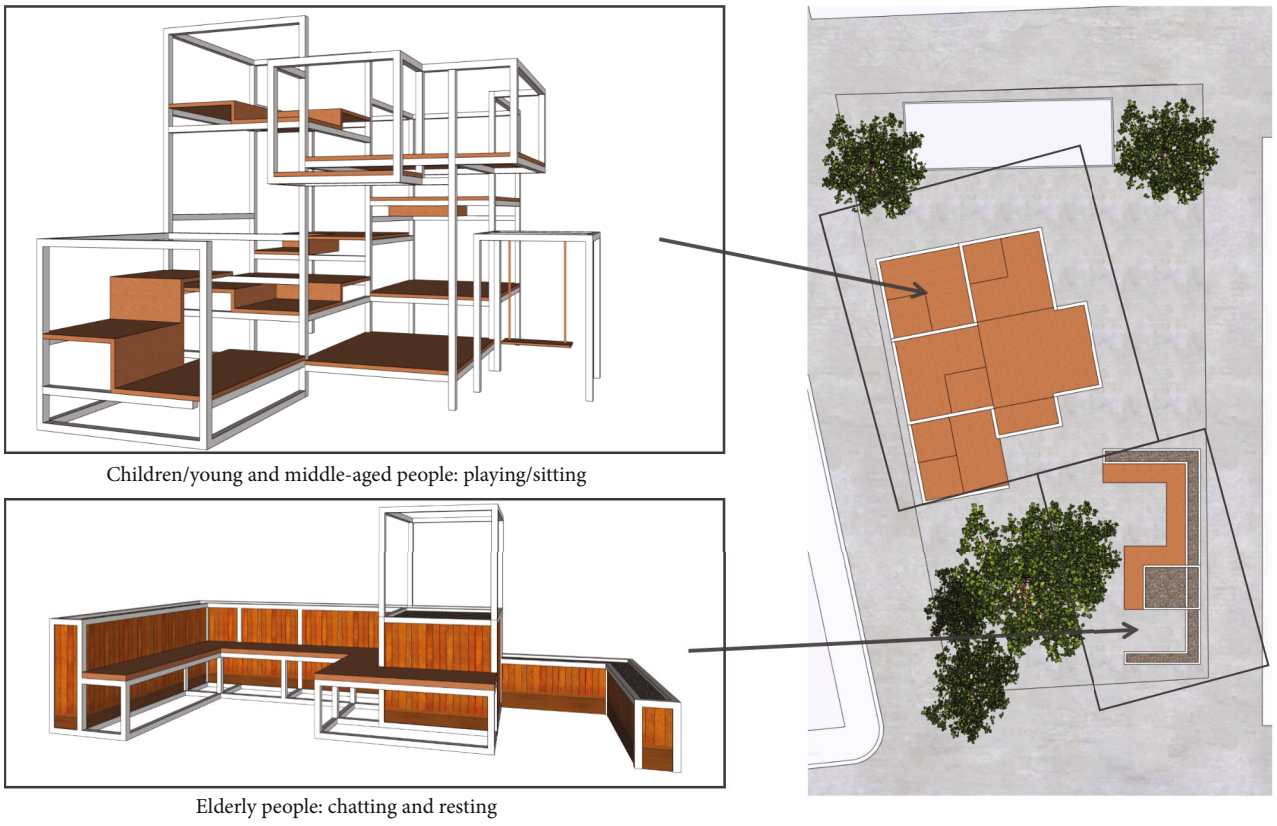

Figure 22: Proposal for an activation design of a street garden.

(1) *Overall Integrity*. Besides reshaping neglected spaces, it is also necessary to seamlessly blend new structures into the streets without compromising their original patterns and seek the development of local logics through moderate spatial interventions

(2) *Improvement of Residents' Living Experiences*. The pain points of nearby residents with regard to public spaces were analyzed to set different functional modules and develop accessible and safe spaces for different groups. This improves both the spatial quality of the spaces and residents' living experiences

(3) *Diversified and Rich Building Forms*. The combination of buildings should consider the population groups, road networks, and other factors of the block, to diversify module design, attract people of different age groups, and create spaces that are attractive to residents

(4) *Fitting of Structural Forms*. Small structural forms can be fitted by functional modules to adapt to different space patterns. Flexible adjustments can be made by plots to create a delightful sense of enclosure and scale

(5) *Human-Oriented Coordinated Participation of Multiple Parties*. When preparing a design proposal for street leftover spaces, people from all walks of life can be invited to take part in the design process, thus promoting the coordinated development of users, the surrounding environment, and structures. Public participation at preliminary design stages can create human-oriented spaces, and the involvement of residents in the implementation of design can enhance their senses of participation, identification, and belonging

7. Conclusions

This paper focuses on the activation design of street leftover spaces in the Huawangtang District of Macao. Because of the formation of old urban districts long time ago, the streets of this district are narrow and inactive and often scattered with fragmented negative spaces. For these spaces on the streets of old urban districts, self-development is almost impossible; however, they can be beautified by design techniques that enhance residents' senses of happiness and identification.

Space syntax was combined with SPSS analysis to analyze the passing values of streets in combination with the activity trails of pedestrians. Moreover, the characteristics and influencing factors of roads under different radii and in different periods were explored. The results identified a high correlation between pedestrian volume and accessibility for the space syntax model, offering an objective theoretical reference for the design and use of street leftover spaces. In

the design, model data of different scales can be selected to analyze the passing values, pedestrian volumes, and activity trails of investigated plots.

On the basis of the study of urban residual space, this paper first probed into the causes behind the changes of urban development and the formation of specific space patterns. An in-depth analysis of existing problems with street leftover spaces and the resident activities taking place there was presented. The activation values of these spaces were also explored. Field surveys were conducted on the streets of the Huawangtang District, and the street environment was analyzed based on survey data. On this basis, space syntax was combined with SPSS regression analysis to identify the relationship between passing value and pedestrian volume. Finally, leftover spaces are summarized to develop a design proposal for street leftover spaces in the Huawangtang District of Macao.

Due to the limitations of practical reasons, the sample data obtained in the field research is limited, the research is contingent, and some errors will inevitably occur in the data during the fitting analysis. Meanwhile, the analysis of crowd activity behavior based on data can be subjective and inferential to some extent; therefore, it is impossible to understand the situation of residents of all ages comprehensively and thoroughly in Kao Parish. In terms of the universality of the research conclusion, the research scope of this case is limited to the research on some plots of the Kao Parish in Macau. The houses in this area are old and the roads are narrow with unique characteristics. Considering the differences in construction, social background, and other factors in various cities and regions in urban construction and due to the limitations of the research scope, it should be noted that the conclusions of this paper have certain geographical limitations.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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